Research Article

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Experimental investigation on treated transformer oil (TTO) and its diesel blends in the diesel engine

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Abstract: The increase in fuel prices, along with the lack of petroleum supplies, has led researchers to seek out alternative fuels. In recent years, the concept of transforming waste into a productive source of energy has gained attention. Several forms of agricultural products, chemical reactant, and treated blends have been studied by scientists all over the world over the past few decades. The work's goal is to determine the effectiveness with using treated transformer oil (TTO) as diesel engine fuel, thus minimizing the environmental issues created by its discharge into open space. This study also aims to capitalise used transformer oil as a renewable fuel source into compression ignition engine, since using waste oils decreases the cost of fuel. The characterization (aniline point, calorific value, density, diesel index, flash point, kinematic viscosity) of treated transformer oil (TTO) was determined and blended with diesel in the proportion of 10% (TTO10), 20% (TTO20), 25% (TTO25), 30% (TTO30), and 40% (TTO40) treated transformer oil. The outcomes are evaluated in comparison to the same diesel engine's operation. According to the findings of the study, blends of treated transformer oil and diesel fuel may be a best choice for diesel engines since they have the same calorific value as diesel fuel. The brake thermal efficiency of blends containing up to 20% TTO is greater compared to diesel fuel. It lowers as a proportion of treated transformer oil increases and increases as the load increases. Furthermore, when the fraction of TTO in blends grows, brake specific fuel economy (BSFC) declines with load.

Keywords: blending of fuels; diesel engine; engine performance; fuel properties; waste transformer oil.

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Introduction

Global warming has accelerated during a last three decades as a result of the dramatic rise in environmental produced due to fossil fuels (Woo 2019). The change in the environment triggered by global warming is the potential cause for events such as high temperatures, unexpected thunderstorms, cyclones, and flooding (Akasofu 2018; Karki 2007). The reduction of Greenhouse gases and changing climatic behaviour has emerged as a key impetus for renewable fuel research (Qasim, Ansari, and Hussain 2017; Simsek 2020). There is now a troubling challenge to the existence of fossil energy, with the situation of demand exceeding availability (Enweremadu and Mbarawa 2009; Tapanwong and Punsuvon 2019). Furthermore, the worries about environmental pollution as a result of intensive utilisation fossil fuels have prompted experts in the field to look for more environmental sustainable, possible, and renewable fuels (Agarwal 2007; Demirbas 2007; Qasim, Ansari, and Hussain 2017).

Overabundant fossil energy stocks and a sharp increase in fuel prices have culminated in an ongoing search for potential replacement fuels for internal combustion engines (Dong et al. 2019; Karagöz 2020; Yilmaz, Donaldson, and Johns 2005). The demand besides existing petroleum fuels is rising day by day as the number of automobiles increases (Simsek 2020). The need for suitable alternative fuels for compression ignition engines is very specific since they are commonly used in several applications (Ahamed et al. 2020).

Engines using compression ignition (CI) are widely utilised in transport, agriculture, and electricity production (Atmanli et al. 2015; Belkhode et al. 2021a). They outperform spark ignition (SI) engines in terms of dependability and durability (Naidu, Shelare, and Awatade 2020a, 2020b). Moreover, CI engines release several pollutants such as HC, CO, NOx, and soot, that are hazardous to human and environmental health (Atmanli and Yilmaz 2021; Belkhode 2018). Due to the general depletion of fuel supplies and tight pollution restrictions, industrialised nations and research community have been looking for renewable liquid fuel that is conveniently accessible, ecologically friendly, and financially feasible (Belkhode, Sakhale, and Bejalwar 2020; Dhande, Shelare, and Khope 2020). Various strategies have been explored in the past to reduce emissions in CI engines from an environmental standpoint. Alternative energy sources for CI engines, such as biofuel and ethanol, provide both environmental and economic benefits. Furthermore, the use of alternative energies as a direct/partial replacement for diesel fuels have sparked global concern in a pursuit of security of supply (Dhutekar et al. 2021; Shelare, Aglawe, and Belkhode 2021).

Transformer oil is used to keep electrical transformers cold. The higher the oil's compositional purity, the greater it's cooling and heat conduction potential (Belkhode et al. 2021b; Liu et al. 2013). This oil deteriorates and degrades with time, affecting the efficiency and lifespan of transformer (Tarateeraseth and Maneenopphon 2007). Though its real service life differs greatly based on the manufacturer, configuration, standard of construction, materials utilized, maintenance, and operational parameters, a transformer's estimated life is around 40 years (Mathew, Sakhale, and Shelare 2020). Waste transformer oil is Brown to Black in color with slightly low kinematic viscosity decrease in viscosity is due to temperature rise in transformer (Khanjani and Sobati 2021). The amount of WTO discarded of yearly is difficult to determine based on the figures provided, but when more transformers are added, old transformer oils must be discarded (Behera and Murugan 2013). As a result, regular inspection of properties of transformer oil is needed to prevent unsafe and oil degradation (Muhamad and Kamarden 2016). Preventive maintenance is undertaken based on the use of transformer oil. Transformer oil is not environmentally friendly. If serious leaks occur, it has the ability to infect our land and rivers (Waghmare et al. 2020). Presently, there is a growing interest in the study of alternative fuels, so it not only prevents the fossil fuel shortage, but also decreases the volume of contaminant gases released during the combustion of such fuels (Preethivasani, Senthilkumar, and Chandrasekar 2021). An alternative fuel is one that may be used instead of traditional fuels. It's often understood that such fuel does not consist exclusively of petrol or diesel, but also about certain additives (Waghmare et al. 2020).

Numerous studies upon this utilisation of pentanol-biodiesel blends shown that pentanol could be utilised to conquer the unfavourable adverse reactions of biodiesel (Atmanli 2016a; Yilmaz, Atmanli, and Vigil 2018). In other research, pentanol was shown to be a viable long term generations fuels and ingredient, since its inclusion enhanced the fuel qualities of diesel-biodiesel blends while lowering NOx emissions (Atmanli 2016b; Yilmaz and Atmanli 2017a; Yilmaz, Ileri, and Atmanli 2016). In a diesel engine, Yilmaz et al. evaluated 10 and 20% 1-pentanol blends through diesel fuel (Yilmaz, Atmanli, and Trujillo 2017). The test results showed that EGT and BSFC rose but BTE declined. Diesel blends containing 1-pentanol enhanced unburned HC and CO emissions whilst decreasing NO_X generation.

One of the potential upcoming techniques for decreasing CI engine emissions is partial elimination, which involves combining alcohols with diesel to optimise combustion. Many studies based on this method have been conducted in the recent decade (Atmanli et al. 2015; Atmanli and Yilmaz 2020; Yilmaz and Atmanli 2017b; Yilmaz, Atmanli, and Trujillo 2017; Yilmaz, Atmanli, and Vigil 2018). Lower alcohols (propanol, ethanol, and methanol) are alcohols with C1–C3 carbons that have been extensively researched as mixes with normal diesel fuel into the engines. An efficient application TTO, rather than being disposed of in the open land, can help to mitigate environmental problems. TTO could be utilized as an substitute fuel into diesel engines subsequent to appropriate treatment.

This research attempts to make better use of waste transformer oil by transforming it into a value-added product. In relation to the study's goal, sludge and suspended metallic components of transformer oil were removed using filtering, and hazardous PCBs were adsorbed on silica gel. The treated transformer oil is the result of the adsorption process (TTO). Following that, engine parameters such as brake specific energy consumption, brake thermal efficiency, exhaust gas temperature, and brake specific fuel consumption were investigated using treated transformer oil (TTO) blended with diesel (TTO10, TTO20, TTO25, TTO30, and TTO40) as fuel substitutes for diesel engines (TTO10, TTO20, TTO25, TTO30, and TTO40). Other parameters investigated were flash point, kinematic viscosity, density, calorific value, aniline point, and diesel index.

Methodology

Preparation of treated transformer oil

The waste transformer oil used for the process is used for one year in the transformer which is collected from Maharashtra State Electricity Board. The experimental setup consists of an adsorption Column of height 20 cm and diameter of 2 cm and an overhead reservoir for the supply of the sample from the height so as to use the gravity for maintaining the desired flow rate and a pipeline to connect the overhead reservoir to the adsorption column. The schematic experimental setup for the adsorption process is shown in Figure 1.

The product i.e. treated transformer oil is then blended through diesel because properties of treated transformer oil are nearly the same as that of diesel fuel. So the blends can be made such as in Table 1 by using a magnetic stirrer. Then check the properties of each blend like a flashpoint, aniline point, pour point, kinematic viscosity, density and also ASTM distillation (Yilmaz, Atmanli, and Trujillo 2017).

Experimental setup of engine

The diesel engine utilized in a study was a Kirloskar TV1, which is a single-cylinder, constant speed, water-cooled, four stroke, vertical, and direct injection with detailed engine specifications shown in Table 2.

Figure 2 illustrates a schematic diagram of an experimental engine setup.

The single-cylinder diesel engine was utilized for experimentation. The result obtained was fuelled with blends of treated transformer oil and diesel fuel varying proportion such as 10:90, 20:80, 25:75, 30:70, 40:60. The run was covered under a varying load of 5, 10, 15 kg.

Table 1: Composition of the test fuel.

S.N	Fuel blend (% vol)	Fuel name
1	100% diesel fuel + 0% TTO	TTO00
2	90% diesel fuel + 10% TTO	TTO10
3	80% diesel fuel + 20% TTO	TTO20
4	75% diesel fuel + 25% TTO	TTO25
5	70% diesel fuel + 30% TTO	TTO30
6	60% diesel fuel + 40% TTO	TTO40

Table 2: Specification of experimental engine set up.

Particulars	Specification
Experimental engine	Single cylinder diesel engine
Bore	87.5 mm
Stroke	110 mm
Cubic capacity	1.323 L
Normal compression ratio	17.5:1
Fuel tank capacity	11 L
Governor	Centrifugal mechanical type
Speed	1500 rpm
Cooling	Water cooling
Mode of starting	By hand cranking
B.M.E.P at full load and 1500 rpm	6.33 kg/cm^3

Result and discussion

Properties of waste transformer oil and treated transformer oil

Adsorption of coloured compounds from waste transformer oil is done by using silica gel of 60–120 mesh as an

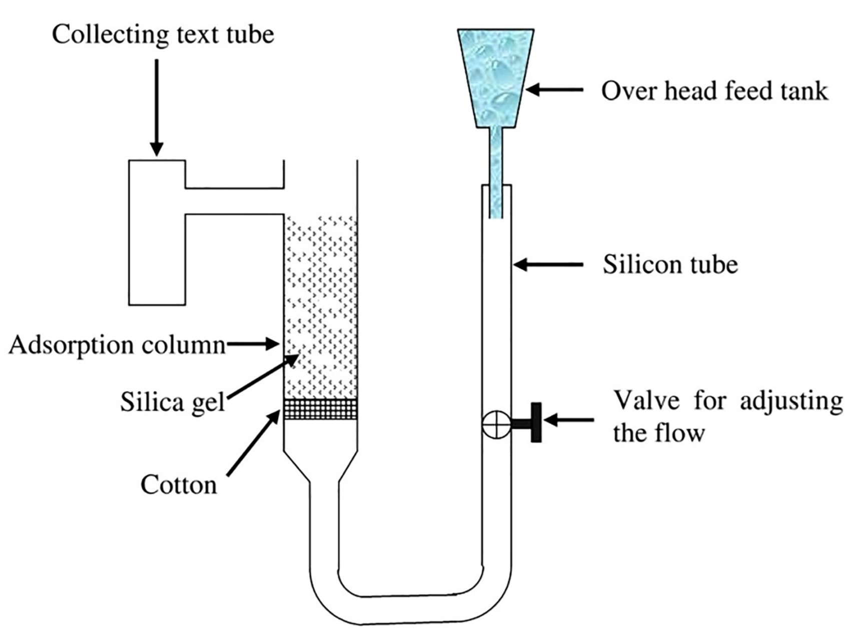

Figure 1: Experimental setup for adsorption process.

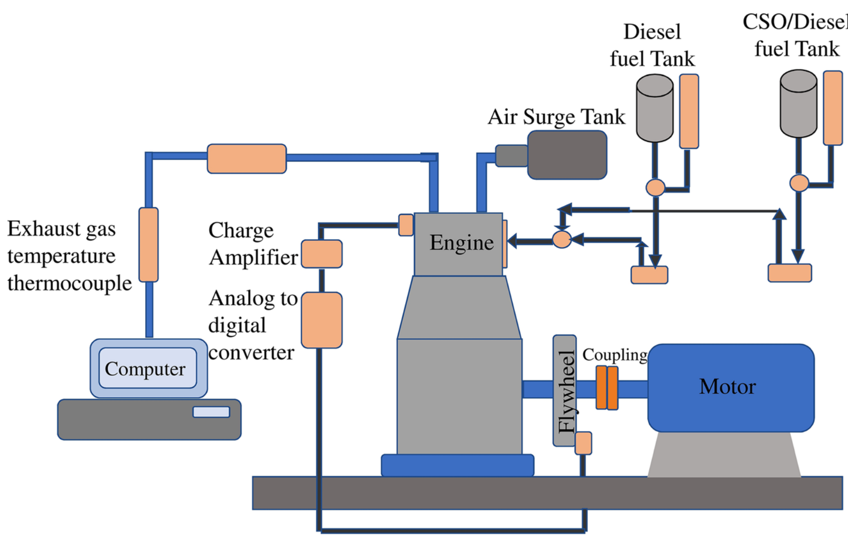

Figure 2: Diesel engine schematic diagram.

adsorbent because small size adsorbent is used to efficient depolarization and good yield give the product which are colourless and viscosity of TTO is decreased. Also the characteristics of waste and treated transformer oil (decolourized waste transformer oil after adsorption). The comparison of properties of treated transformer oil and Diesel fuel are given in Table 3.

The properties of TTO-diesel fuel blends are given in Table 4.

From Table 4 it is observed that properties like API gravity, density, diesel index and cetane number are nearly equal to that of purest diesel. Properties of various blends of treated transformer oil and diesel fuel show nearly equivalent properties up to 25% blends.

Analysis of TTO blends on diesel engine

Engine performance was evaluated on the basis of brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), brake specific energy consumption (BSEC) and exhaust gas temperature (Atmanli et al. 2015; Atmanli and Yilmaz 2020; Yilmaz and Atmanli 2017b). The result obtained for treated transformer oil and diesel fuels are compared with pure diesel fuel.

Table 3: Properties of TTO and diesel fuel.

SN	Properties	Waste transformer oil	Treated transformer oil	Diesel fuel
1	Density (gm/cm^3)	0.915	0.861	0.7996
2	Flash point (°C)	178	138	38
3	Kinematic viscosity (Cst)	8.16	6.78	3.35
4	Aniline point (°C)	90.10	85.50	66.70
5	API gravity	23.14	32.84	45.46
6	Diesel index	44.89	61.00	69.00

Brake thermal efficiency

Figure 3 depicts the brake thermal efficiency (BTE) with respect to load for treated transformer oil-diesel fuel blends and pure diesel.

Brake thermal efficiency increases with the increment of load and increment in the proportion of treated transformer oil in diesel fuel. The BTE is improved when fuelled with treated transformer oil. The maximum BTE is observed for 40% TTO blend at 15 kg load and minimum for 10% TTO at 5 kg load.

Brake specific fuel consumption

Figure 4 illustrates a deviation of brake specific energy usage with load for different TTO-DF blends.

Table 4: Properties of TTO-diesel fuel blends.

Properties	TTO10	TTO20	TTO25	TTO30	TTO40
Density (gm/cm^3)	0.814	0.822	0.828	0.834	0.846
Flash point (°C)	40	46	48	67	84
Kinematic viscosity (Cst)	3.6	3.75	3.82	4.8	5.6
Aniline point (°C)	68	72	76	78	82.7
API gravity	42.33	40.64	39.39	38.16	35.36
Diesel index	65.3	65.67	66.4	65.78	64

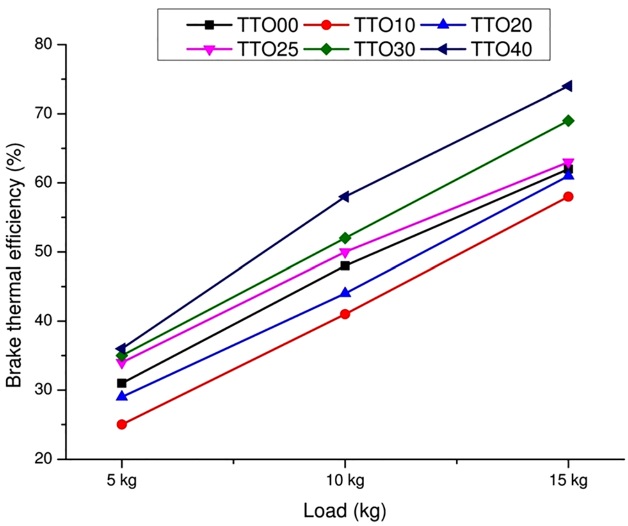

Figure 3: Influence on brake thermal efficiency due to variation in load for different blends.

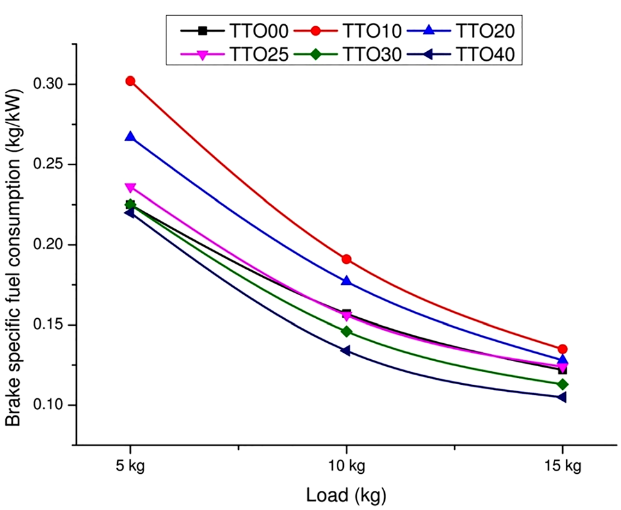

Figure 4: Influence on brake specific fuel consumption due to deviation in load for dissimilar blends.

From Figure 4 brake specific fuel consumption decreases with load and increment into the proportion of treated transformer oil and constant at 15 kg load which indicate the existence of BSFC value at 15 kg load. The BSFC varies from 0.30 kg/kW h at early load to 0.105 kg/kW h at highest load. The value of BSFC is maximum for 10% blend and minimum for 30 and 40% blends.

Brake specific energy consumption

Figure 5 illustrates the deviation of brake specific energy consumption with load for dissimilar TTO-DF blends.

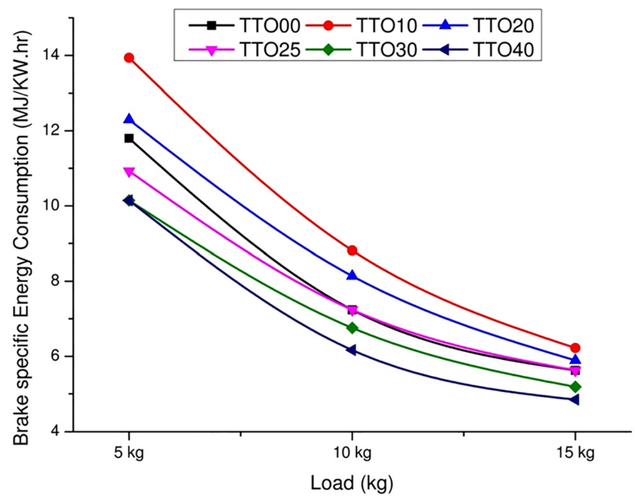

Figure 5: Influence on brake specific energy consumption due to variation in load for different blends.

The BSEC decreases with load and increases with a rise in the proportion of treated transformer oil. For pure diesel it is minimum and for 40% blend, it is maximum. The value of BSEC for maximum load of 10, 20, 30 and 40% is 5.3284, 5.5946, 6.2219, and 4.4810 MJ/kW h.

Exhaust gas temperature

Figure 6 depicts the variation of exhaust gas temperature as a function of load.

From Figure 6 it is clear that exhaust gas temperature increases with an increase in load as additional fuel is burnt with high load. Exhaust gas temperature of 10 and 20%

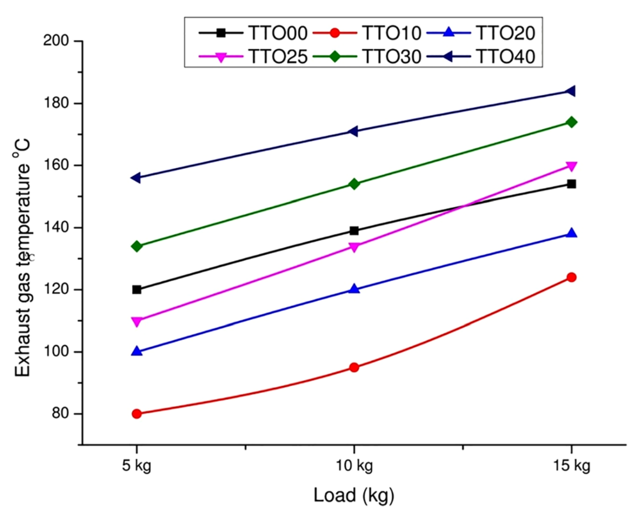

Figure 6: Influence on exhaust gas temperature due to variation in load for different blends.

blends is less as compared to pure diesel. At high load (15 kg) exhaust gas temperature for 40% blend is 184 °C which is higher than that of all blends due to higher release rate.

The product (treated transformer oil) obtained after adsorption of coloured components from waste transformer oil by using silica gel as adsorbent packed in a column was colourless and having physicochemical properties like viscosity, flash point, aniline point, density, diesel point is nearly equal to the diesel fuel. Blends of TTO and diesel fuel have the same kinematic viscosity, flash point, aniline point, diesel index, API gravity, and calorific value as pure diesel up to a 25% blend. These properties increase with increment into treated transformer oil proportion in diesel fuel.

Conclusions

On the basis of current research using a single-cylinder water-cooled diesel engine and treated transformer oil-diesel fuel mixes it can be concluded that the brake thermal efficiency of blends up to 20% TTO is higher than that of diesel fuel. It decreases with an increment of the proportion of treated transformer oil and increases with an increment of load. The exhaust gas temperature of 10 and 20% TTO blends is less than that of pure diesel but as the percentage of treated transformer oil increases the exhaust gas temperature also increases. The brake specific fuel efficiency (BSFC) decreases with load increases with the proportion of TTO in blends. BSFC is constant at a load of 15 kg which indicates the existence of BSFC value at 15 kg load. Finally, the blends of treated transformer oil and diesel fuel can be the best alternative or the diesel engine, as it possesses the same calorific value as diesel fuel.

Similar type of study can be conducted on the waste cooking oil in which different types of waste cooking oil with different techniques can be treated. Treated oil can be blend with the treated cooking oil in different ratio to observed the behavior in the diesel engine. This is promoting the search of alternative fuels.

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