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Fuel and engine characterization study of catalytically cracked waste transformer oil

S. Prasanna Raj Yadav [a,*], C.G. Saravanan [a], R. Vallinayagam [b], S. Vedharaj [c], William L. Roberts [b]

[a] Department of Mechanical Engineering, Annamalai University, Chidambaram, India
[b] Clean Combustion Research Centre, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
[c] International Research Centre, Department of Mechanical Engineering, Kalasalingam University, Krishnankoil, Tamil Nadu, India

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ABSTRACT

This research work targets on the effective utilization of WTO (waste transformer oil) in a diesel engine and thereby, reducing the environmental problems caused by its disposal into open land. The novelty of the work lies in adoption of catalytic cracking process to chemically treat WTO, wherein waste fly ash has been considered as a catalyst for the first time. Interestingly, both the oil and catalyst used are waste products, enabling reduction in total fuel cost and providing additional benefit of effective waste management. With the considerable token that use of activated fly ash as catalyst requires lower reaction temperature, catalytic cracking was performed only in the range of 350–400 °C. As a result of this fuel treatment process, the thermal and physical properties of CCWTO (catalytically cracked waste transformer oil), as determined by ASTM standard methods, were found to be agreeable for its use in a diesel engine. Further, FTIR analysis of CCWTO discerned the presence of essential hydrocarbons such as carbon and hydrogen. From the experimental investigation of CCWTO – diesel blends in a diesel engine, performance and combustion characteristics were shown to be improved, with a notable increase in BTE (brake thermal efficiency) and PHRR (peak heat release rate) for CCWTO 50 by 7.4% and 13.2%, respectively, than that of diesel at full load condition. In the same note, emissions such as smoke, HC (hydrocarbon) and CO (carbon monoxide) were noted to be reduced at the expense of increased NO_X (nitrogen oxides) emission.

1. Introduction

Over the past few decades, there has been an alarming threat over the availability of fossil fuels and the scenario of demand going larger than supply is apparent [1,2]. In particular, due to rapid depletion of crude oil, price of conventional petroleum based fuels has been reported to be increased and this inturn resulted in the search for alternate fuels [3,4]. These days, there has been an increasing interest in the research on alternate fuels, given that it not only evades petroleum fuel crisis but also minimizes pollutant gases being emitted in the event of combustion of these fuels. Evidently, researchers have identified a variety of biomass based liquid fuels such as alcohol, biodiesel, and other liquid fuels synthesized from the parts of plants as alternate fuel for engine application [5–10]. Characteristically, the physical and thermal properties of these reported fuels are different and hence to make use of them in a diesel engine, certain modifications either with the fuel or engine is required.

While biodiesel from certain vegetable oils such as Jatropha, Karanja, soybean, and rapeseed is acquiring the much needed attention [11–13], oils that are found to be waste have also been viewed as viable sources of alternate fuel. Notably, large amount of energy available in these waste products are being discharged, which otherwise can be harnessed in a better way. By doing so, not only the waste products can be effectively disposed but also the total fuel cost can be reduced, considering the fact that 80% of total fuel cost depends on feedstock cost [14,15]. In this regard, many researchers have focused on utilizing different waste sources such as waste lubrication oil, plastic oil, tire pyrolysis oil, waste cooking oil, waste cashew nut shell liquid, kapok oil, municipal waste and olive mill waste as feedstock for alternate fuel production and utilization in a diesel engine [16–22]. Further, it is also noteworthy to point out the effective utilization of UTO (used transformer oil) as source of fuel in a diesel engine by few researchers in the recent past [23,24].

Over a period of time, petroleum-based mineral oils have been used in liquid – filled electrical transformers, mainly for insulating purpose, besides the additional function of cooling the transformers [25]. Many transformers are located in populated areas and

* Corresponding author. Tel.: +91 4144221524, mobile: +91 9786190834.
E-mail address: sprasannarajyadav@gmail.com (S. Prasanna Raj Yadav).

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shopping centres, and long term use of transformer oil causes some changes in its physio-chemical characteristics [26,27], which makes it unfit for insulating purpose in an electric transformer. Therefore, after being used up, the disposal of UTO from electrical power stations and large number of transformers located throughout the country is becoming increasingly complex, since it could contaminate the soil and waterways if serious spills occur [28]. Therefore, government regulatory agents are already looking into this problem and are imposing penalties for spills.

Characteristically, the insulating oil used in electric transformers consists of complex blends of more than 3000 hydrocarbons and they are essentially highly branched aliphatics, naphthenic or paraffinic crudes [29]. Considering the fuel characteristics of UTO and in an attempt to dispose this waste product effectively, researchers have started seeing it as a viable alternate fuel for diesel engine application. In this connection, Behera et al. [24] reported the use of UTO in a compression ignition engine and evaluated the engine performance, combustion and emission characteristics. Initially, from the properties evaluated, viscosity of UTO was shown to be higher and in order to make it appropriate for its operation in a diesel engine, traditional strategy of blending it with diesel was adopted. Subsequently, the experimental testing of UTO – diesel blends had discerned an improvement in engine performance, whereas the ignition delay was noted to be shorter. While the optimum blend was found to be UTO40 (40% UTO and 60% diesel), 100% use of UTO was reported to evince deteriorated engine characteristics. Therefore, in an another study, Behera et al. [30] optimized the use of UTO in diesel engine by increasing the fuel injection pressure. As an outcome of their study, engine was perceived to show better performance with lower emission at a higher injection pressure of 230 bar, given increase in fuel injection pressure improves fuel atomization, air/fuel mixing and the subsequent combustion process. In a recent study, Nabi et al. [23], refined UTO by conventional trans-esterification process and reported that refining of transformer oil resulted in the improvement of fuel properties and engine characteristics. Reportedly, the refined transformer oil showed improved performance and emission than that of diesel to emerge as a viable source of alternate fuel.

From the above discussion, it is evident that rare attempts were made to effectively utilize WTO (waste transformer oil) in a diesel engine, despite it being a waste and economically viable source. Further, unlike vegetable oil based fuels, no attempts have been made to adopt advanced modes of chemical process to treat WTO effectively so as to improve its fuel properties. Therefore, for the first time, we have ventured into catalytic cracking of WTO in a measure to improve its fuel properties and make it more usable for diesel engine application. Distinctly, besides considering waste product as fuel for diesel engine, this study has also chosen waste fly ash as a catalyst for cracking process, rendering the additional benefit of reduced fuel cost. In this regard, a specially designed reactor was conceived and the waste catalyst was subjected to pre-treatment, before being used for cracking process. In this regard, WTO was preheated up to 200 °C in a preheater followed by cracking process in the main reactor at the temperature range of 350–400 °C. Once WTO was cracked, the physical and thermal properties, as well as its composition, were examined to ensure its operation in a diesel engine. Subsequently, CCWTO (catalytically cracked waste transformer oil) was blended with diesel in various proportions such as CCWTO 10 (10% CCWTO + 90% diesel), CCWTO 30 (30% CCWTO + 70% diesel) and CCWTO 50 (50% CCWTO + 50% diesel), and the blends were tested in a single cylinder diesel engine. The various engine test results in respect of engine performance, combustion and emissions were analyzed and reported for CCWTO – diesel blends.

2. Materials and methods

In the past, attempts on harnessing the required source of energy from WTO, have been brought to fore by Behera et al. [24] wherein, WTO was used as such in a diesel engine, despite its higher viscosity. Apparently, the higher viscosity of WTO would pose long term durability problems and hence, appropriate measures have to be taken to make it conducive for diesel engine application. Considering that WTO is not like contemporary vegetable oils, a different approach to break down the higher hydrocarbons known as cracking has been adopted in this study for the first time. Cracking, in general, is an endothermic reaction that occurs at a high temperature, between 400 °C and 1000 °C, depending on the nature of the feedstock and characteristics of the process (thermal or catalytic). In the present study, we have cracked WTO in the presence of a catalyst rather than thermal cracking, since the latter requires higher temperatures even up to 1000 °C that could tend to increase the refining and processing cost. Further, catalytic cracking renders an advantage of improvement in fuel properties and use of catalyst is reported to have decreased the cracking temperature.

2.1. Fly ash catalyst

Typically, zeolites, sulphonated ZrO_2, ZnO, Pd/Al_2O_3, SiO_2 and clay minerals are the most commonly used catalysts for cracking process. However, most of these catalysts have low efficiency or high cost and some of them induces polymerization of cracked products (reversed reactions). In this scenario, we decided to avail a low cost catalyst so as to reduce the total fuel cost and came up with an idea of utilizing waste fly ash as a catalyst for the intended cracking process. Notably, fly ash has not been considered as a catalyst before for cracking heavier hydrocarbons and hence it is remarkable to shed some interest in it. In this regard, fly ash, a waste and cheap product has been duly exploited as a green catalyst for the present study. By this measure, not only the selected feedstock is a waste product but also the catalyst, providing the intended benefit of reduced fuel cost. The activated fly ash, does have the constituents of $NaHSO_4$ SiO_2, $NaHSO_4$ Al_2O_3, and ZnO (Nano particles) in an inert atmosphere, which is almost equivalent to the constituents of zeolites. Further, the chemical compositional analysis of fly ash, as depicted in Fig. 1, clearly demonstrates the presence of higher percentage of Silica (64%), Alumina (15.5%) and iron oxide (6.5%), which are highly required for the cracking reaction to progress. Notably, percentage of each and every constituent of fly ash is computed based on the magnitude of respective peaks scaled in terms of eV in *y*-axis of Fig. 1. Actually, *y*-axis does represent counts, while *x*-axis signifies energy level of counts. Besides ascertaining the elemental composition of fly

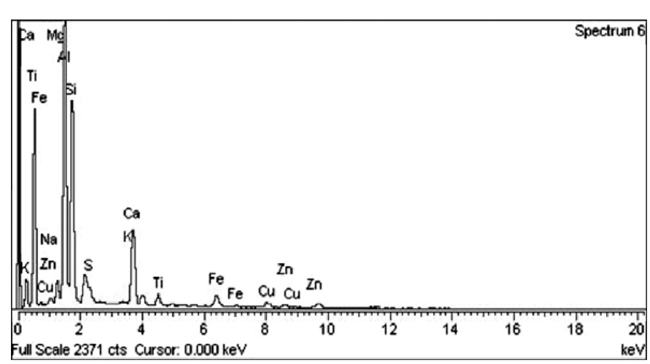

Fig. 1. Elemental composition of fly ash.