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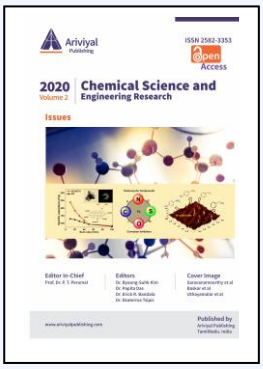

Recycling of "Spent Engine Oil'' using Activated Charcoal Derived from *Anacardium Occidentale*

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Abstract: Quality assurance parameters of spent engine oil obtained from the same automobile engine after 2, 4 and 6 months usage corresponding to a distance coverage of 2200, 3800 and 5570 mileage were analyzed along with the parameters of a brand new Society of Automobile Engineers (SAE) 10W – 40 engine oil (the same type as the spent oil) using Anton Paar SVM 3000 densitometer, Karl Fischer titrator, Pensky-Martens closed cup flash point tester and Normalab pour point cabinet. Results obtained showed that the parameters of the spent engine oils were not within acceptable limits as specified by the SAE and deviations increased with increase in time duration as well as distance covered by engine oil, this is contrary to the parameters of the brand new engine oil which were within specification. Activated charcoal obtained from the bark of *Anacardium Occidentale* tree was employed to recycle the spent engine oils used after 2, 4 and 6 months respectively and results showed that kinematic viscosities, density, flash point and fire point of the spent engine oil after 6 months of usage increased from: 110.2300 $mmsec^{-1}$, 0.8611 gcm^{-3}, 112.8000 ^0C and 216.0000 ^0C to 133.7200 $mmsec^{-1}$, 0.8955 gcm^{-3}, 225.0000 ^0C and 322.000 ^0C respectively, also the water content and pour point reduced from 0.8000 % and -8.0000 ^0C to 0.0800 % and -15.0000 ^0C respectively. Activated charcoal from the bark of *Anacardium Occidentale* tree is an anti-wear additive owing to its ability to increase the lubricity of the engine oil by increasing its kinematic viscosity and density, its ability to adsorb contaminants and volatile hydrocarbons in engine oil gives it the capacity to increase the flash and fire points of the engine oil. The ability of this activated charcoal to reduce the water content and pour point of the spent engine oil confirms its hydrophilicity and ability to maintain the flow properties of oil at elevated temperatures.

Keywords: contaminants; hydrophilic; volatility; absorption; additive and assurance parameters.

1. Introduction

Engine oils are viscous liquids of crude oil origin employed in lubricating moving parts of engines and machines, they are vital in protecting rubbing surfaces and promoting unhindered and smooth movement of machine parts. Engine oils are essentially formulated to reduce friction of metallic parts, protect against wear and tear as well as remove contaminants from engines.[1] They also act as cleansing, cooling and anticorrosion agents and as a medium to eliminate high accumulation of temperature on moving surfaces. Engine oils are made up of 90% base oil and 10% additives which are chemically broken down after usage resulting in the accumulation of metals, halogenated hydrocarbons, poly aromatic hydrocarbons (PAHs) and other polycyclic compounds in the oil from the engines wear and tear, these substances gradually reduce the quality of the engine oil resulting in adverse changes and deterioration of its properties.[2] An engine oil which has lost its properties after use can be referred to as spent engine oil. The engine oil during usage mixes with impurities, such as water, metal scrapping, dirt and other contaminants which degrades the additives as well as the base oil. Proper management of the spent engine oil is required during its disposal to avoid the pollution of the environment.[3] The improper disposal of spent engine oil is capable of polluting the environment to a large extent hence proper recycling of spent engine oil is critical to eliminate these environmental threats. In some countries, about 2 billion gallons of spent engine oil are generated annually and this has led to several studies channeled towards finding satisfactory ways of reducing pollution of the environment by spent engine oil.[4] Over the years, several methods were employed in addressing environmental pollution caused by used engine oil, for instance spent engine oil were disposed through incineration while others were used for dust prevention, however it is worthy to note that each of these methods of disposal pose a lot of threats to the environment. Environmental pollution by spent engine oil has proven to be more devastating than pollution arising from oil spillage in onshore and offshore locations put together.[3] Recycling of spent engine oil promises to bring an end to the menace and challenges faced during engine oil disposal. The recycling process involves the removal of contaminants as well as restoring the quality assurance parameters of the used engine oil thereby making it suitable for reuse. The recycled spent engine oil is

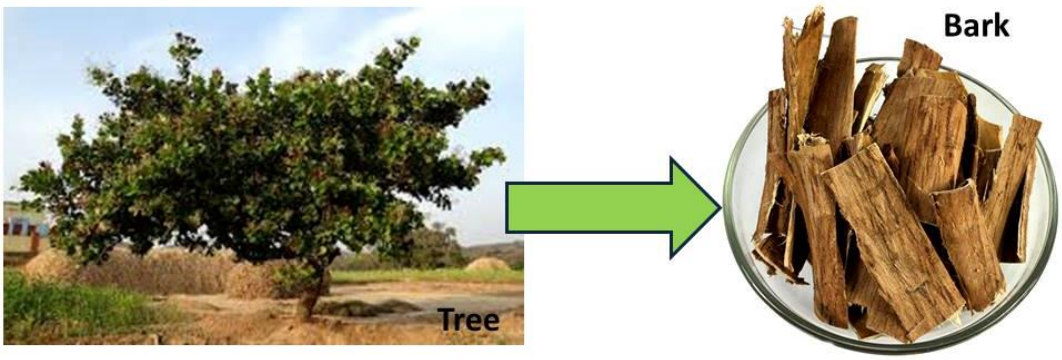

Fig. 1. Photograph of *Anacardium Occidentale* Tree and its bark.

expected therefore to possess parameters that fall within acceptable standards just like the brand new product.[5,6] The adsorption characteristics of activated charcoal makes it suitable for use in the recycling of spent engine oil. Activated charcoal is obtained from carbon rich materials such as wood, coal and other substances burnt at high temperatures of 600 – 900 ^{0}C to create a charcoal powder.[7] The aim of this study is to recycle spent engine oil using activated charcoal obtained from the bark of *Anacardium Occidentale* tree.

Anacardium Occidentale tree popularly known as cashew tree is an age long tree that produces the cashew seed and apple. The tree can grow as high as 14 m (46 ft) however the dwarf cashew can grow up to 6 m (20 ft). The shell of the cashew seed yields derivatives that can be used in many applications such as lubricants, water proofing, paints and arms production. A typical *Anacardium Occidentale* tree is shown in Fig. 1. This study focuses on the use of the bark from *Anacardium Occidentale* tree as a source of activated charcoal.[8]

2. Materials and Methods

The bark of *Anacardium Occidentale* tree was used as a source of activated charcoal, the tree was obtained in one of the Niger Delta areas of Nigeria. A brand new SAE 10W- 40 engine oil was obtained from the refinery section of Nigerian National Petroleum Cooperation (NNPC) to serve as a reference standard, The acronym 'SAE' stands for 'Society of Automobile Engineers' While 'W' stands for 'Winter' and '10' indicates that the oil must possess certain viscosity / flow at low temperatures while '40' indicates that the oil must possess certain viscosity / flow at high temperatures. The lower the number before 'W' (10) the better the oils performance in cold temperatures while the higher the number after 'W' (40) the better its performance at high temperature.[9] Three different spent engine oils were obtained from the same type of automobile after usage for 2, 4 and 6 months at a distance coverage of 2200, 3800 and 5570 miles respectively. Equipment used for analyses includes hot plate for heating, rotary evaporator for solvent recovery, weighing balance, water bath, Anton Paar SVM 3000 densitometer, Normalab pour point cabinet, Pensky – Martens flash point tester, Karl Fischer titrator, various graduated glass wares as well as solvents such as methanol, n-hexane, potassium hydroxide etc. Nicolet IS5 Fourier Transform Spectrometer was used to characterize the activated charcoal from *Anacardium Occidentale* tree.

Fig. 2. Photograph of activated carbon derived from the bark of Anacardium Occidentale Tree .

2.1. Preparation of Activated charcoal from Anacardium Occidentale

The bark of *Anacardium Occidentale* was peeled off the tree, dried in the sun for 72 hours, ground and sieved with a mesh of 500 µm size, 200 g of the powdered sample was made into a slurry with 80 cm^3 of distilled water, 60 ml of 0.35 M solution of H_2SO_4 was added and the slurry was left undisturbed for 48 hours. The slurry was then washed several times with distilled water to remove every attached acid. The neutral slurry was dried in an oven for 1 hour at 45 ^{0}C which completes the acid activation of the sample. The activated sample was carbonized at 600 ^{0}C to obtain activated charcoal as shown in Fig. 2.[10]

2.2. Sample Preparation

Samples of 1 L spent SAE 10W – 40 engine oil used after 2, 4 and 6 months respectively were allowed to settle at room temperature for 24 hours and then filtered to remove solid particles. 100 ml of each of the spent engine oil were mixed with composite solvent of 70% methanol and 30% n-hexane at a solvent to oil ratio of 5:1 and then 3 g of potassium hydroxide was added. Each of the mixtures was thoroughly stirred for about 30 minutes and heated at 60 ^{0}C and at atmospheric pressure to remove light hydrocarbons through solvent extraction. The mixture was thereafter allowed to settle in a separation flask for 24 hours and then heated at 120 ^{0}C to remove the solvent from the mixture.

2.3. *Sample Treatment using Activated Charcoal from Anacardium Occidentale*

Add 500 ml of the engine oil collected from the oil-solvent mixture with 20 g of activated charcoal from *Anacardium Occidentale*, heat at 150 ^{0}C for 1 hour, 30 minutes. Leave the heated mixture undisturbed for 2 hours at room temperature to allow for gravity settling and then filter with a filter paper to recover the treated engine oil.

Table 1. Quality Assurance Parameters of 2 months Spent / Recycled SAE 10W – 40 Engine Oil

Parameters	New Oil	Spent Oil	Recycled Oil	SAE Specification
Kine. Vis. @ 40 ^{o}C (mmsec^{-1})	146.5600	128.500	140.7200	130.0000 - 150.0000
Kine. Vis. @ 100 ^{o}C (mmsec^{-1})	14.4500	11.8700	14.0100	12.6000 - 16.3000
Water (%)	0.0000	0.4000	0.0500	Maximum 0.3000
Density (gcm^{-3})	0.8968	0.8920	0.8959	0.8955 - 0.8970
Flash Point (^{o}C)	230.0000	205.0000	229.0000	Minimum 225.0000
Fire Point (^{o}C)	350.0000	285.0000	344.4700	Minimum 300.0000
Pour Point (^{o}C)	-20.0000	-12.0000	-18.0000	Minimum -15.0000

Table 1 Shows a comparison of the quality assurance parameters of spent SAE 10W – 40 engine oil obtained from an automobile (after two (2) months of usage and a distant coverage of 2200 miles) with those of the new and recycled oil respectively

Table 2. Quality Assurance Parameters of 4 months Spent / Recycled SAE 10W – 40 Engine Oil

Parameters	New Oil	Spent Oil	Recycled Oil	SAE Specification
Kine. Vis. @ 40 ^{o}C (mmsec^{-1})	146.5600	120.0000	137.0100	130.0000 - 150.0000
Kine. Vis. @ 100 ^{o}C (mmsec^{-1})	14.4500	10.0600	13.5000	12.6000 - 16.3000
Water (%)	0.0000	0.6000	0.0600	Maximum 0.3000
Density (gcm^{-3})	0.8968	0.8800	0.8957	0.8955 - 0.8970
Flash Point (^{o}C)	230.0000	119.0000	228.0100	Minimum 225.0000
Fire Point (^{o}C)	350.0000	243.0000	330.7100	Minimum 300.0000
Pour Point (^{o}C)	-20.0000	-10.0000	-17.0000	Minimum -15.0000

Table 2 Shows a comparison of the quality assurance parameters of spent SAE 10W – 40 engine oil obtained from an automobile (after four (4) months of usage and a distant coverage of 3800 miles) with those of the new and recycled oil respectively

Quality assurance parameter test was carried out on the treated engine oil and compared with the brand new unused oil to ascertain the level of conformity.[11,12]

2.4. *Quality Assurance Test on Treated Engine oil*

Quality assurance test were carried out on the treated engine oil. Viscosity at 40 and 100 ^{0}C and density were determined with the use of an Anton Paar SVM 3000 densitometer, flash and fire points were determined with the use of a Pensky-Martens closed cup flash point tester and pour point was determined with the use of a Normalab pour point cabinet.[13]

3. Results and Discussions

Quality assurance parameters are parameters that indicate the suitability of a product for specific and designated purposes and the test carried out to determine these parameters are referred to as quality assurance test. Tables 1, 2 and 3 shows the quality assurance parameters determined for both spent and recycled engine oil. Viscosity is one of the most important quality assurance parameters of oil; it is a measure of the flow resistance between layers of the fluid. A high viscosity indicates a high resistance to flow while a low viscosity shows a low resistance to flow.[6] Viscosity varies with temperature and pressure having an inverse proportionality with temperature and a direct proportionality with pressure thereby increasing the load carrying capacity of the engine oil, these properties enables thin engine oil to be used in lubricating heavy engines.[14] The viscosity of a fluid can be defined in terms of two related parameters they are dynamic and kinematic viscosities. Dynamic viscosity is a measure of the internal resistance of the fluid; it is the fluids resistance to flow due to internal friction while kinematic viscosity is the fluids resistance to flow due to gravity. Mathematically, kinematic viscosity is the ratio of the dynamic viscosity and the density of the fluid and it is more commonly used in terms of application.[11] Kinematic viscosity is usually measured in terms of two reference temperatures, 40 ^{0}C and 100 ^{0}C. It is common to measure kinematic viscosity at 40 ^{0}C because it is the basis for International standard organization grading system whereas additional measurement at 100 ^{0}C reduces the rise of measurement interference.[2] Results obtained from Tables 1, 2 and 3 shows that the kinematic viscosities at 40 and 100 ^{0}C reduced with increased usage of the engine oil in terms of period of usage and mileage. Results also show that the kinematic viscosities of the engine oil after 2, 4 and 6 months usage were all below SAE specification. Reduction in the viscosity of engine oils can lead to higher wear rate, reduced engine life as well as increased maintenance cost.[6] Tables 1, 2 and 3 also shows an increase in the kinematic viscosities of the engine oils recycled with activated charcoal obtained from the bark of *Anacardium Occidentale* tree. It can also be deduced that the kinematic viscosities of the recycled engine oil in Tables 1, 2 and 3 were within SAE specification hence the activated charcoal from the bark of *Anacardium Occidentale* tree can be said to be an anti-wear additive.[11]

Results obtained from Tables 1, 2 and 3 shows that the water content of the engine oil increases with increase in usage in terms of time and distance covered, the spent engine oil after 2, 4 and 6 months usage were above SAE specification. The water content of the recycled engine oil was within SAE specification hence it is still suitable for the automobile engine. Water can have access to the lubricating oil through leakages from different parts such as the engine coolant, oil cooler, steam heating line etc. Water in engine oil can cause a lot of damages to engines for instance water oxidizes the base oil to form oxides which further react with more water to form corrosive acidic substances, water can also lead to fractures caused by hydrogen release which ultimately leads to pitting, etching and fretting in bearings.[3] Water promotes corrosive microorganisms, long accumulated water causes condensation in crankcase resulting in oxidation of the oil. The hydrophilic nature of the activated charcoal from the bark of *Anacardium Occidentale* tree reduces water in the spent engine oil to acceptable limits.[15]

Table 3. Quality Assurance Parameters of 6 months Spent / Recycled SAE 10W – 40 Engine Oil

Parameters	New Oil	Spent Oil	Recycled Oil	SAE Specification
Kine. Vis. @ 40 ^{o}C (mmsec^{-1})	146.5600	110.2300	133.7200	130.0000 - 150.0000
Kine. Vis. @ 100 ^{o}C (mmsec^{-1})	14.4500	9.8700	13.0500	12.6000 - 16.3000
Water (%)	0.0000	0.8000	0.0800	Maximum 0.3000
Density (gcm^{-3})	0.8968	0.8611	0.8955	0.8955 - 0.8970
Flash Point (^{0}C)	230.0000	112.8000	225.0000	Minimum 225.0000
Fire Point (^{0}C)	350.0000	216.0000	322.1700	Minimum 300.0000
Pour Point (^{0}C)	-20.0000	-8.0000	-15.0000	Minimum -15.0000

Table. 3 Shows a comparison of the quality assurance parameters of spent SAE 10W – 40 engine oil obtained from an automobile (after six (6) months of usage and a distant coverage of 5570 miles) with those of the new and recycled oil respectively.

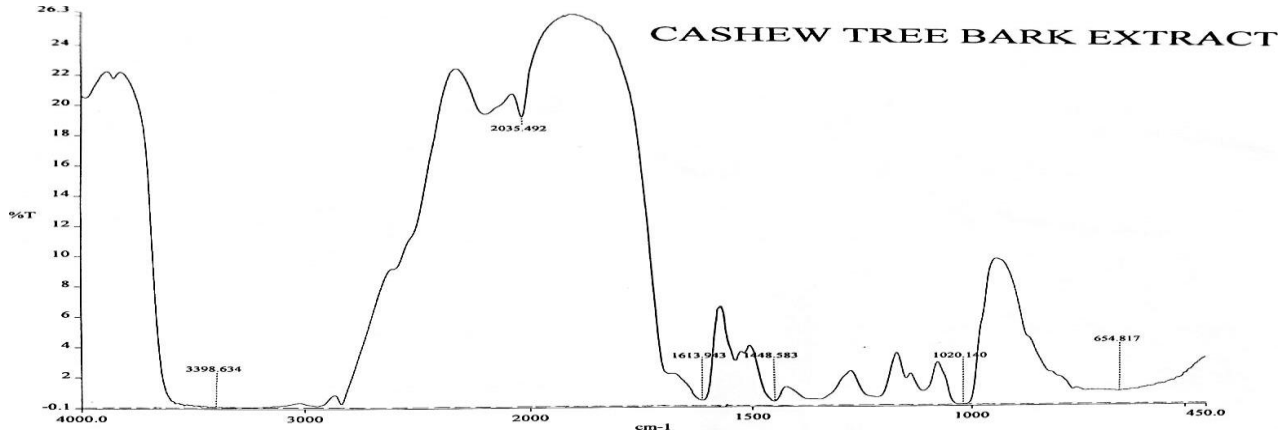

Fig. 3. Infrared Spectrum of *Anacardium occidentale* Extract.

The density of oil is the ratio of the mass of the oil to its volume. Results obtained from Tables 1, 2 and 3 shows that the density of the engine oil decreased with increase in usage from 2 to 6 months as well as distance covered from 2200 to 5570 miles. There are a lot of misconception on the difference between oil density and oil viscosity. Oil density refers to the molecular weight of the oil per unit volume while oil viscosity refers to the friction between the oil layers.[16] Both parameters decrease with increase in temperature however viscosity has a higher impact with respect to temperature compared to density hence viscosity has an exponential relationship with temperature while density has a linear relationship with temperature, this is also reflected in the impacts of the two parameters on an engine oil.[4] Engine oil density and viscosity are affected by the same factors and both parameters have the same impact on the engine ranging from higher wear rate and reduced engine life however the impact resulting from oil density is less compared to that of viscosity.[16] Results obtained shows that density of spent engine oil after 2, 4 and 6 months were below SAE specification whereas the density of the engine oil recycled with activated charcoal obtained from the bark of *Anacardium Occidentale* tree was within specification.

The flash point of an engine oil can be defined as the temperature at which the vapor above the oil ignites momentarily due to introduction of an ignition source, this is quite different from fire point which refers to the temperature at which the vapor above the oil ignites without an ignition source, both parameters are reflections of the fire resistant and volatility characteristics of the engine oil.[17] The flash and fire points also confirms the level of adulteration of the oil. Results obtained shows that the flash and fire points of the spent engine oil reduced with increase in time usage and mileage and are below SAE specification. Engine oils with low flash points (below specification) can cause a lot of hazards to engines such as crankcase explosion, they also have low lubricity due to high volatility which can lead to wear and tear of engines.[2] Results obtained showed that activated charcoal obtained from the bark of *Anacardium Occidentale* tree increased the flash point of the spent engine oil upgrading them up to specification hence they have the ability to absorb volatile hydrocarbons and other contaminants responsible for the reduction of the flash and fire points of the engine oil.[17] Fig. 4 shows the photographic image of spent oil before and after activated carbon treatment.

The pour point of engine oil is the lowest temperature at which oil pours or flows when cooled without agitation under standard conditions in other words oil ceases to flow below the pour point.[18] Results obtained show an increase in the pour point of the spent engine oil due to increase in usage in terms of time and distance covered. Results also show that the pour points of the spent oil after 2, 4 and 6 months of usage were above specification. An increase in the pour point of the engine oil indicates that the temperature at which the oil ceases to flow is fast and easily achievable especially in tropical regions such as Nigeria and if the oil stops flowing due to

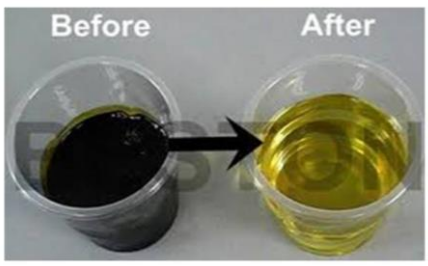

Fig. 4. The photographic image of spent oil before and after activated carbon treatment.

Table 4. Functional Groups Obtained from IR Spectrum of *Anacardium occidentale* Extract (activated charcoal)

Peak	Wavelength (cm^{-1})	Mode of Vibration	Functional Group
PI	3500 – 3200	O-H stretching	alcohol
P2	3500 - 3300	CO-N stretching	amide
P3	3000 – 2840	C-H stretching	alkane
P4	2260 – 2100	C-C stretching	alkyne
P5	2000 – 1665	C-C weak overtones	aromatic
P6	1600 – 1585	C-C stretch in ring	aromatic
P7	1500 – 1400	C-C stretch in ring	aromatic
P8	1300 – 1000	C-O stretching	ester
P9	690 - 515	C-Br^{-} stretching	halo compound

Table 4 shows the functional group obtained from the Infrared (IR) spectrum of *Anacardium occidentale* extract (activated charcoal) as shown in Fig. 3

high viscosity at certain temperature, it can prevent the engine from starting.[14] Results also show that the pour point of engine oils recycled with activated charcoal from the bark of *Anacardium Occidentale* tree were within specification. The wax forming ability of the oil at elevated temperatures could also increase the pour point of the oil hence activated charcoal from the bark of *Anacardium Occidentale* tree has proven to inhibit wax formation in the engine oil especially at higher temperatures hence it is a suitable additive for engine oils used in tropical regions.[2] Table 4 shows the characterization of the extract from the bark of *Anacardium Occidentale* tree using Fourier transform infrared (FT-IR) spectroscopy. Results obtained show the presence of a number of highly polarized functional groups such as alcohols, amides, ester and halo compounds. Molecular polarizability plays a predominant role in determining the adsorption capacity of an adsorbent (activated charcoal from *Anacardium Occidentale* tree). The higher the molecular polarizability of an adsorbent which is a function of the number of polar groups in the adsorbent the higher the adsorption capacity. Polarizability is dependent on the ability to form hydrogen bond, presences of electronegative atoms and high dipole moments which are all characteristics of the functional groups in activated charcoal from *Anacardium Occidentale* tree.

4. Conclusions

The environmental hazards and menace due to the indiscriminate disposal of spent engine oil is indeed a cause for immediate concern hence the need for scientifically tested and proven ways of recycling spent oil. Recycling of spent engine oil is also essential in reducing the cost implication arising from procurement of brand new engine oils owing to the increasing use of automobile as well as other engines maintained by engine oils. Activated charcoal obtained from the bark of *Anacardium occidentale* tree is a good additive for the recovery of the quality assurance parameters of spent engine oil. This activated charcoal as an anti-wear additive can restore the kinematic viscosity and density of spent engine oil to acceptable specification; it can also reduce the water content of the spent engine oil to acceptable limits due to its hydrophilic nature. Activated charcoal from the bark of *Anacardium occidentale* tree has the ability of inhibiting wax formation of used engine oils at elevated temperatures owing to its capacity to reduce the pour point of the spent engine oil thereby protecting engines from start-up issues. Activated charcoal from *Anacardium occidentale* tree also has the ability of restoring the fire and flash points of engine oil by adsorbing contaminants and volatile hydrocarbons responsible for its reduction thereby saving the engines from damages such as crankcase explosion as well as other hazards. The adsorption characteristics of activated charcoal from *Anacardium occidentale* tree is largely due to the presence of highly polarized functional groups such as alcohols, esters, amides and halo compounds.

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Conflicts of Interest

The authors declare no conflict of interest.

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