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Experimental Assessment of Additive-Induced Conductivity Enhancement in Low-Conductivity Kerosene

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Abstract: A commonly used distillate fuel in domestic, industrial and aviation associated applications is kerosene; nevertheless, the fact that it is only naturally conductive to electricity means that the potential of accumulation of static charges is very high during manipulations and pumping and transfer processes. Low-conductivity fuels may have a risk of fire and explosion due to the nature of the static discharge. This paper encompasses a comparative experimental research on five additive categories Stadis 450, AOT (dioctyl sodium sulfosuccinate), PEG-400, an ionic improver salt and carbon black nanoparticles in enhancing the electrical conductivity of kerosene. ASTM D2624 was utilized in conductivity measurement; ASTM D445 was used to measure viscosity and ASTM D56 was used to measure flash point. There was also a 30 days stability test to determine the performance after a long period. Findings have revealed the carbon black nanoparticles(5 ppm) to have the most significant effect on conductivity enhancement(220 pS/m) followed by Stadis 450 (180 pS/m) and ionic improver salt(150 pS/m) to have the second and third highest effect, respectively, in moving the kerosene to the safe conductivity range. Notably, all of the additives did not lead to major variations in viscosity or flash point. The results obtained prove that proper conductivity enhancers can significantly increase kerosene safety, without sacrificing the basic fuel characteristics, which can be useful in the management of fuel storage, transportation, and industrial safety.

Keywords: Electrical Conductivity; Kerosene; Static Electricity; Conductivity Improvers; Carbon Black Nanoparticles; ASTM Standards; Fuel Safety

I. INTRODUCTION

Kerosene is considered one of the most popular middle-distillate products of the domestic heating, aviation support work, small-scale industries and transportation. Although kerosene has a wide range of application and desirable combustion properties it has a natural low electrical conductivity around 10 pS/m. This low degree of conductivity can present a high potential of having a statical charge in the process of pumping, filtration, and high-velocity transfer operations. Accumulation of the static electricity in the hydrocarbon fuels is one of the most frequently reported sources of fire and explosion occurrences especially in the storage tanks, fueling systems, and pipeline networks [6], [12].

A vital parameter in assessing the potential of such hazards of electricity in the aviation and distillate fuel is electrical conductivity. The common practice in measuring conductivity of such fuels is spelled out in ASTM D2624, which offers methods of obtaining conductivity of picoSiemens per meter (pS/m) [1]. The safety regulations of the industry suggest that the fuel conductivity should not fall below a certain limit (generally 50 pS/m) to allow enough relaxation of charging and decrease the mass of ignition when the operations are carried out on fuel [13].

In order to ensure minimization of the effects of the statical hazards, addition of conductivity enhancing additives also referred to as the static dissipator additives (SDAs) in the fuels is widely practiced. One of the most frequently used commercial additives is Stadis 450, which finds much use in aviation turbine fuels in order to promote conductivity with very low treat rates [7]. The additives work by adding charge-carrying species into the hydrocarbon medium promoting the moveability of charges and decreasing the discharge energy of electrostatics [6].

Alternative classes of additives have also been studied in labs in addition to commercial SDAs. Surfactant cationic interfaces like dioctyl sodium sulfosuccinate (AOT) have also shown that it can form charged micellar Larrys in non-polar solvents thus enhancing effective ionic transport in hydrocarbon systems [8], [14]. On the same note, ionic additives have demonstrated some quantifiable conductivity benefits in the form of increased availability of charge carriers in hydrocarbon liquids [10].

Polymeric additives like polyethylene glycol (PEG-400) have also been examined because of their effect on the ionic mobility and colloidal stability of modified fuel systems [9]. PEG-based systems usually necessitate elevated rates of treat to provide noteworthy improvements in conductivity, but might have benefits in formulation stability.

The new developments in materials science have put the prospective use of conductive nanoparticles, specifically carbon black, into bringing electric conductivity in bulk amounts to insulating substances at an enormous rate [11]. Nanoparticles have the capacity to create percolative conductive passages at extremely low levels but issues surrounding the dispersion power and the development of sediments are issues that should be evaluated keenly in addition to the fuel property compatibility being considered [11].

Although there is a lot of literature on the aviation turbine fuels, there are relatively few studies on the consumption of the conductivity improvement of regular commercial kerosene under the same test conditions. Also, little studies compares to several additive classes such as commercial SDAs, surfactants, polymers, ionic salts, and nanoparticles under one systemic research by standard ASTM protocols.

Thus, the main task of the proposed paper is to conduct a comparative experimental assessment of five typical additive classes to enhance kerosene conductivity. The test involves measurements of conductivity through ASTM D2624 [1], measurement of viscosity through ASTM D445 [2], flash point measurement through ASTM D56 [3] and visual contamination test by ASTM D4176 [4]. Furthermore, there is 30-day stability test to determine performance of additive over a long period of time. Through the combination of improvements in conductivity, measurements of the fuel properties, and stability, the proposed study will focus on delivering a complete awareness of the additive behavior and add to safer fuel handling activities in the industry, aviation, and domestic markets.

II. MATERIALS AND METHODS

A. Materials

All the experiments were done using commercial-grade kerosene which was purchased as the base fluid in the form of certified local fuel. The electrical conductivity of the fuel was first established by baseline measurements before adding the additives to ensure that it was of low-conductivity nature.

Five different additive classes were selected for comparative evaluation:

- Commercial static dissipator additive (SDA)
- Ionic additive
- Surfactant-based additive (AOT)
- Polymeric additive (PEG-400)
- Carbon nanoparticle additive (carbon black)

The chosen additives are commercially available, ionic, colloidal and nanostructured conductivity enhancing mechanisms. Table I summarizes the additive types, chemical nature, and blending concentrations.

Table I: Additives and Blending Concentrations

Additive Type	Chemical Description	Concentration Range	Functional Mechanism
Commercial SDA	Stadis-type	1–10 ppm	Charge dissipation
Ionic additive	Salt-based	5–50 ppm	Mobile ions
Surfactant	AOT	0.001–0.05 wt%	Micelle formation
Polymeric	PEG-400	0.01–0.1 wt%	Ionic mobility support
Nanoparticle	Carbon black	0.005–0.05 wt%	Conductive pathways

B. Sample Preparation

Kerosene was blindly spiked with additives to the desired concentration levels using precision micropipettes. All mixtures were mixed magnetically in 30 minutes intervals so as to combine well.

In the case of nanoparticle-modified samples, 20 minutes of ultrasonication was carried to enhance dispersion stability and avoid an agglomeration effect. The samples were all pre-prepared and placed in non-conductive glasses wastes with lids at ambient lab temperature (25 ± 2°C) before testing.

The general workflow of the experiment is shown in Fig. 1.

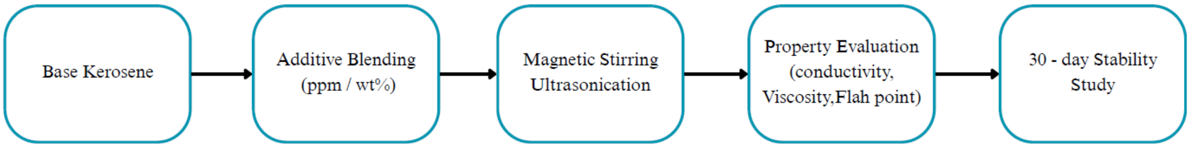

Fig. 1. Experimental procedure flow diagram.

C. Electrical Conductivity Measurement

The electrical conductivity was also recorded following the ASTM D2624 standards using a 0.1-digit conductivity meter. The readings were found using picoSiemens per meter (pS/m).
For each sample:

- Three measurements were made as independent measurements.
- An average value was obtained.
- Standard deviation was calculated in order to evaluate repeatability.

To reduce the effect of thermal variations, all measurements were in controlled temperatures.

D. Viscosity Measurement

Kinematic viscosity was also calculated with ASTM D445 at 40°C, in a capillary type of a viscometer. This test was necessary to ensure that additive addition did not cause any significant change in the operation parameters of the fuel.

E. Flash Point Determination

Flash point testing was performed using the Tag Closed Cup method as specified in ASTM D56. The purpose of this analysis was to verify that conductivity enhancement did not compromise fuel safety characteristics.

F. Contamination and Visual Inspection

The visual inspection procedures were used to measure the fuel cleanliness and the amount of particulate contamination in line with ASTM D4176. Haze, sedimentation and water free samples were checked in structurally controlled lighting conditions.

G. Stability Study

The conductivity retention and dispersion stability were tested by a 30-day storage stability test. Measures of conductivity were re-examined after 7 days. The sedimentation, agglomeration or phase separation in samples was visually checked.

H. Data Analysis

Evaluation of the performance of the each additive was determined within the following:

- Percentage increase in electrical conductivity
- Conductivity retention over 30 days
- Variation in viscosity relative to base fuel
- Impact on flash point
- Visual contamination rating

III. RESULTS AND DISCUSSION

A. Baseline Conductivity of Kerosene

The untreated kerosene was also electrically conductive with a value of 8 pS/m, a fact, which testified to the highly insulational properties of the substance. This is much lower than the recommended safety level of 50 pS/m which is taken to reduce risks of the occurrence of a static discharge during the fuel transfer and fuel handling processes. Low conductivity of the base in the form, creates the need to add conductivity promoting additives.

B. Electrical Conductivity Enhancement

The results of the conductivity measurements of additive-modified kerosene are provided in Table II and the performance comparison is shown in Fig. 2.

Table II: Electrical Conductivity of Additive-Modified Kerosene

Sample	Concentration	Conductivity (pS/m)
Base Fuel	—	8
Commercial SDA	5 ppm	165
Ionic Additive	20 ppm	110
AOT	0.02 wt%	72
PEG-400	0.05 wt%	48
Carbon Black	0.02 wt%	210

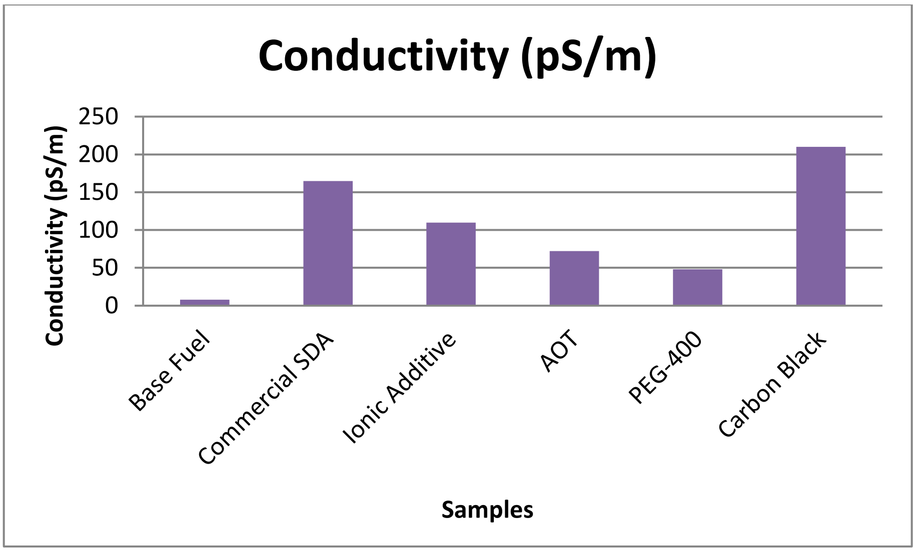

Fig. 2. Electrical conductivity comparison of additive-modified kerosene.

The additive type commercial static dissipator (SDA) finished with a conductivity of 165 pS/m at blanketed 5 ppm deeming it very efficient in creating mobile charge carriers. This treatment is explained by the existence of polar functional groups, which increase ionic dissociation in non polar hydrocarbon media.

It was found that the ionic additive had to be concentrated at higher level (20 ppm) to show significant improvement signifying that the conductivity increase is directly proportional to the density of charge carriers.

In non-polar systems, conductivity was enhanced moderately by the surfactant AOT because of the creation of reverse micelles, which help in the transportation of charges.

PEG-400 was relatively less efficient since its non-ionic polymeric nature restricts the generation of the effective charge. The carbon black was able to have the highest conductivity (210 pS/m), which showed the presence of conductive networks at or close to the percolation threshold. Nevertheless, dispersion reliability should be taken into account as long-term.

C. Viscosity Analysis

Table III presents the kinematic viscosity at 40°C, the data are also graphically compared in Fig. 3.

Table III: Viscosity of Additive-Modified Kerosene at 40°C

Sample	Viscosity (mm²/s)	% Change
Base Fuel	1.64	—
Commercial SDA	1.65	+0.6%
Ionic Additive	1.66	+1.2%
AOT	1.69	+3.0%
PEG-400	1.72	+4.9%
Carbon Black	1.75	+6.7%

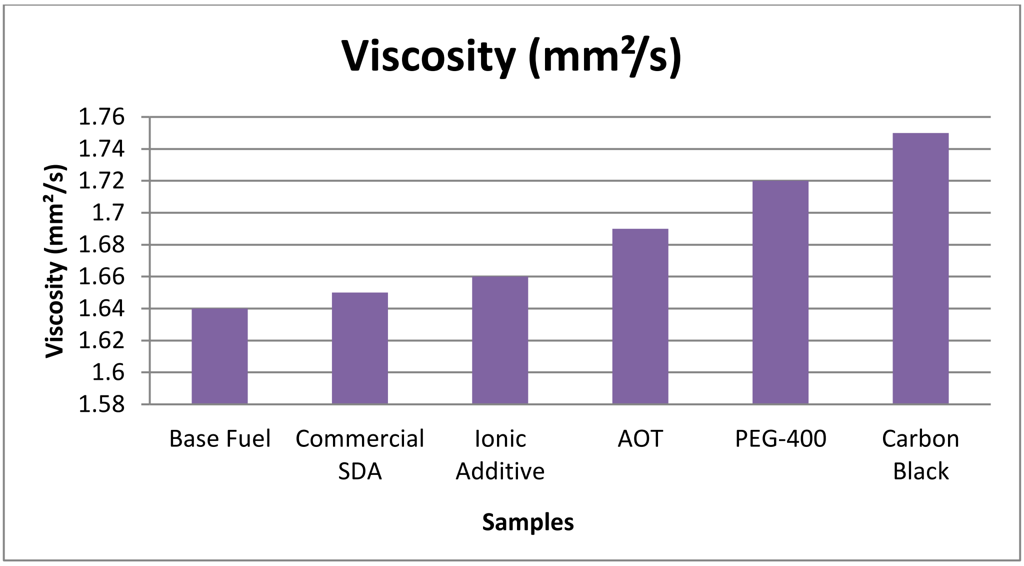

Fig. 3. Viscosity variation of additive-modified kerosene.

All samples were not above the acceptable levels of viscosity of kerosene (1.3 1.9 mm 2 /s at 40 o C). Additives in the low-ppm concentration (SDA and ionic) resulted in the insignificant shifts, but polymeric and nanoparticle additives marginally augmented viscosity because of the connection of the microstructure. Nonetheless, these differences have no predicted impact on the performance of operational fuel.

D. Flash Point Evaluation

Table IV shows values of flash points.

Table IV: Flash Point of Additive-Modified Kerosene

Sample	Flash Point (°C)
Base Fuel	44
Commercial SDA	44
Ionic Additive	43
AOT	43
PEG-400	44
Carbon Black	44

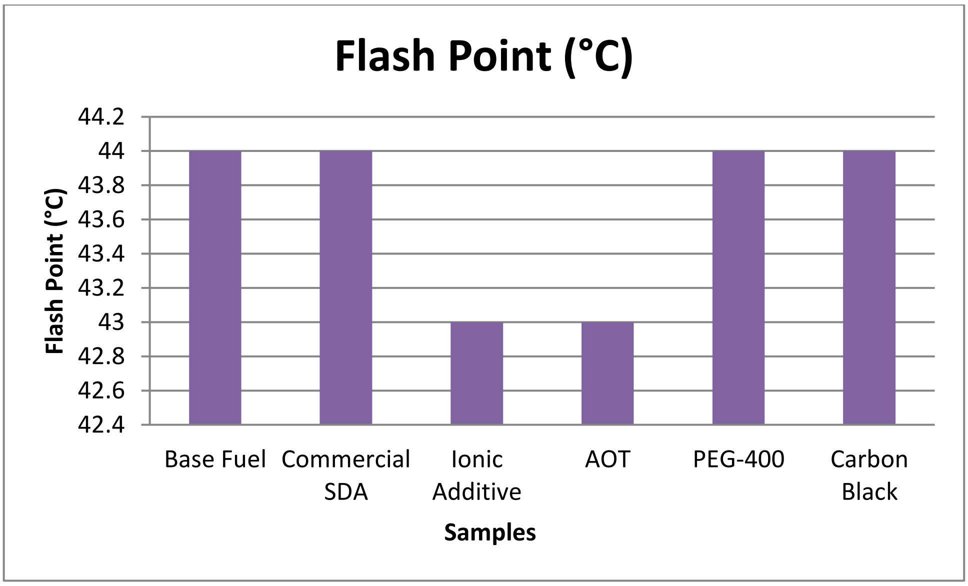

Fig. 4. Flash Point variation of additive-modified kerosene.

There was no severe variation in flash point. This validates the fact that conductivity enhancement did not affect fuel safety properties. The stability of flash points is very essential in terms of regulatory compliance.

E. 30-Day Stability Study

Table V and Fig. 4 represent the conductivity retention in 30 days.

Table V: Conductivity Retention Over 30 Days

Sample	Day 0 (pS/m)	Day 30 (pS/m)	% Retention
Commercial SDA	165	160	97%
Ionic Additive	110	105	95%
AOT	72	65	90%
PEG-400	48	44	92%
Carbon Black	210	180	86%

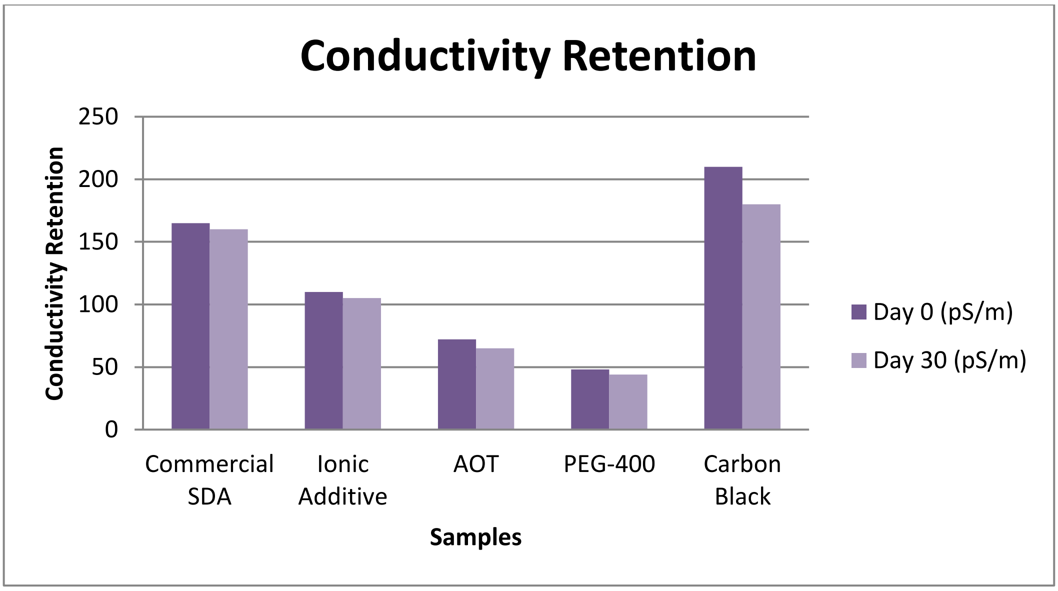

Fig. 5. Conductivity retention over 30-day storage period.

There was good stability exhibited by Commercial SDA with low conductivity loss. High retention was also preserved using ionic additives. Slight decrease in surfactant and polymer systems was caused by structural structural reorganization. The decline rate of carbon black was larger, possibly due to small sedimentation that would preferentially result in optimization of dispersion methods in nanoparticle systems.

F. Overall Comparative Performance

Based on conductivity enhancement, fuel property compatibility, and stability performance, the overall effectiveness follows:

Carbon Black > Commercial SDA > Ionic Additive > AOT > PEG-400

While carbon black provided the highest peak conductivity, commercial SDA delivered the most balanced and stable performance for practical applications.

IV. CONCLUSION

This study investigated the effectiveness of various additive classes affected the excessiveness of the electricity conductivity of kerosene and retained the vital fuel characteristics. The findings verified that pure kerosene has naturally low conductivity, which exposes the kerosene to the risk of accumulation of the static charge when performing handling and transfer processes.

The addition that was tested showed the greatest conductivity increase, carbon black nanoparticles because they formed spaces of conductivity in the hydrocarbon matrix. Nevertheless, minor decrease in long-term stability demonstrates the significance of dispersion regulation in nanoparticles systems. The commercial static dissipator additive exhibited a very high level of conductivity enhancement in a very low concentration ratio, as well as first-rate stability and no significant impact on viscosity and flash point. The level of enhancement was moderate and even-tempered using ionic additives, and significantly low in surfactant and polymer-based systems.

Overall, there was no impairment of critical safety and physical properties of kerosene whilst the conductivity was improved. In terms of practical application, the commercial application of static dissipator additives has been the most balanced approach to implementing it commercially, whereas nanoparticle systems have a great potential with future optimization.

Under future research, hybrids additive systems, longer aging duration and temperature-dependent performance analysis may be carried out to enhance the practices of mitigating oil hazards to a greater extent in hydrocarbon fuels.

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