The University of Akron
IdeaExchange@UAkron

Honors Research Projects

The Dr. Gary B. and Pamela S. Williams Honors College

Spring 2015

Electrowetting Applications for the Filtration of Diesel Fuel

Zachary Richmond
University of Akron Main Campus, zjr9@zips.uakron.edu

Please take a moment to share how this work helps you through this survey. Your feedback will be important as we plan further development of our repository.
Follow this and additional works at: http://ideaexchange.uakron.edu/honors_research_projects

Recommended Citation
Richmond, Zachary, "Electrowetting Applications for the Filtration of Diesel Fuel" (2015). *Honors Research Projects*. 11.
http://ideaexchange.uakron.edu/honors_research_projects/11

This Honors Research Project is brought to you for free and open access by The Dr. Gary B. and Pamela S. Williams Honors College at IdeaExchange@UAkron, the institutional repository of The University of Akron in Akron, Ohio, USA. It has been accepted for inclusion in Honors Research Projects by an authorized administrator of IdeaExchange@UAkron. For more information, please contact mjon@uakron.edu, uapress@uakron.edu.

Electrowetting Application for filtration of Diesel Fuel

Zachary Richmond

Advisors

Professor George Chase

Postdoctoral Research Associate Dr. Abdulwahab Aljuhani

Department of Chemical and Biomolecular Engineering

The University of Akron

May 2015

Abstract

New regulations in creating cleaner diesel fuel (ultra-low sulfur or biodiesel) create problems with conventional filtration of water from the fuel due to increased levels of surfactants in the fuels. The objective of the research done is to analyze using electrowetting phenomena to coalesce water droplets in a diesel emulsion. This was done by observing and recording the behavior of water droplets in a diesel emulsion when a potential is applied between conductive surfaces. A high speed camera under a microscope was used. Recordings were analyzed and the size of coalescing drops were found at 100 and 200 volt DC potentials. The result shows coalescence of droplets in the range of 18-65 micrometers at 100 volts DC and a range of 20-100 micrometers at 200 volts DC. An overall increase in drop diameter of 40.8% (+/- 12.65%) was found. An added filtration medium of glass fibers increased droplet coalescence; more droplets coalesced against the medium. By increasing droplet size both with and without a filtration medium, this research has laid the groundwork for using this phenomena to increase ease and efficiency of the diesel filtration process.

Executive Summary

Since the invention of the diesel engine, or any combustion engine, many steps are taken to ensure the safety and operability of the engine. Some of these regulations include federal regulations to ensure quality fuel or reduce emissions. Recently, the EPA has mandated that at least 80% of all diesel produced must be ultra-low sulfur diesel in 2006 and all highway diesel must be ULSD by 2010 (8). The new ULSD contains more surfactants than the older standard of fuel, as well as biodiesels (8). These new surfactants can lead to problems with conventional filtration systems used to remove water from diesel fuel (6). To combat the new difficulties of removing water from diesel fuel, new techniques are being studied.

One of these techniques includes using electrowetting phenomena to make the water easier to filter from the diesel fuel (1). Electrowetting is the use of an applied electric field or potential to change the wetting properties of a surface (3). The effects observed by electrowetting phenomena may prove to help filter water from an emulsion of diesel fuel. This effect occurs by creating a wetting surface by applying a voltage to a polarizable material and a grounded electrode. When this potential is applied, the molecules of the polarizable coating reorient in the direction of the electrical field, thus creating a capacitance between the electrodes. The result is a balancing of forces of a sessile droplet on the electrowettable surface, essentially changing the morphology of the water droplets. It has already been observed that large water droplets in diesel will coalesce into a larger droplet when a potential is applied (1).

The object of using electrowetting phenomena to filter diesel fuel is to observe water droplet coalescence in a diesel emulsion. This was achieved by applying a potential to conductive slides as seen in Figure 5. Using a high speed camera under a microscope, coalescence of water

droplets was overserved in a diesel emulsion at 100 and 200 volts DC. The droplet diameters were measured before and after coalescence. The coalescence of droplets occurred at a range of about 15-100 micrometers. A larger range of droplet coalescence was observed at the higher voltage, and the overall diameter of coalescing droplets increased by 40.8% with a standard deviation of +/- 12.65%.

The quantitative analysis was limited to the coalescence of water droplets without a filtration medium; however the addition of a medium was tested. The setup of coalescence can been seen in Figure 6. A qualitative analysis showed an increase in water droplet coalescence using a filtration medium; glass fibers were used but other filtration mediums should be assessed in the future. The glass fiber filtration medium was placed between conductive slides as a 200 volt DC potential was applied. Without a medium, the maximum coalescence included only 3 droplets, with the most occurring between only 2. With the filtration medium, coalescence of 5-6 droplets was observed multiple times. The increase in amount of droplets coalescing supports the hypothesis that the applied potential with the filtration medium will coalesce a larger amount of droplets than without the medium, which can then increase the ease of filtration. Coalescence of 5 water droplets can been seen in progression in Figure 13. A before and after picture can also been seen in Figure 14. Figure 14 shows larger droplets at the edge of the filtration medium after the applied potential, as well as fewer small groups of water droplets.

The results support the hypothesis that using a similar setup, water droplet size can be increased in a diesel emulsion, resulting in more efficient filtration of the water from diesel fuel. This may help reduce costs of filtration, or allow older conventional methods to be used for the filtration again. The next step for the research is a quantitative analysis of these methods using a filtration medium. Data proving that an applied potential in combination with a filtration medium removes water either more readily or more efficiently would allow this research to become new method of filtration of diesel fuel in industry.

Introduction

The diesel engine was first invented in the 1890s by Rudolph Diesel. The original design used slow speeds due to limitations of the compressed air fuel injection systems. High speed diesel engines were designed for commercial and passenger vehicles by the 1930s (4). Since this invention, water content in diesel fuel has always been a concern. As diesel fuel is exposed to moisture, whether it be from the air, or other external sources, it absorbs water to be in equilibrium with the atmosphere. A problem occurs when too much water enters the diesel fuel, beyond its saturation point, and creates water droplets out of emulsion in the diesel fuel. If the water droplets enter the components in the engine they can cause damage, wear, and corrosion (3).

New regulations for emissions push diesel manufactures to produce a cleaner and greener diesel fuel. These changes include lower sulfur fuels and biodiesel or biodiesel blends (9). New problems with water filtration present in these new fuels. Ultra low sulfur diesel (ULSD) fuels use a larger amount of surfactant, as well as biodiesel blends (9, 6). The surfactant in the diesel fuels makes conventional filtration of water from the diesel fuel less effective (6). To remove water from ULSD and biodiesel a new method of filtration is needed.

Different methods of filtration have been theorized. Using electrowetting phenomena to coalesce water droplets in the diesel emulsion may provide an easier way to filter the water from the fuel. This paper will discuss experimental methods and results of using electrowetting phenomena to coalesce water droplets in diesel emulsion to increase filtration (1).

Background

Electrowetting is the use of an applied electric field or potential to change the wetting properties of a surface (3). The effects observed by electrowetting phenomena may prove to help filter water from an emulsion of diesel fuel. This effect occurs by creating a wetting surface by applying a voltage to a polarizable material and a grounded electrode. When this potential is applied, the molecules of the polarizable coating reorient in the direction of the electrical field, thus creating a capacitance between the electrodes. The result is a balancing of forces of a sessile droplet on the electrowettable surface. The Young-Lipmann equation demonstrates this phenomena (1).

$$cos\theta(v) = cos\theta(0) + \frac{\varepsilon_0 \varepsilon_r v^2}{2d\gamma\varepsilon_{lg}}$$

ε_0 = dielectric constant in a vacuum

ε_r = dielectric constant of the coating material

v = applied voltage

d = thickness of the dielectric material

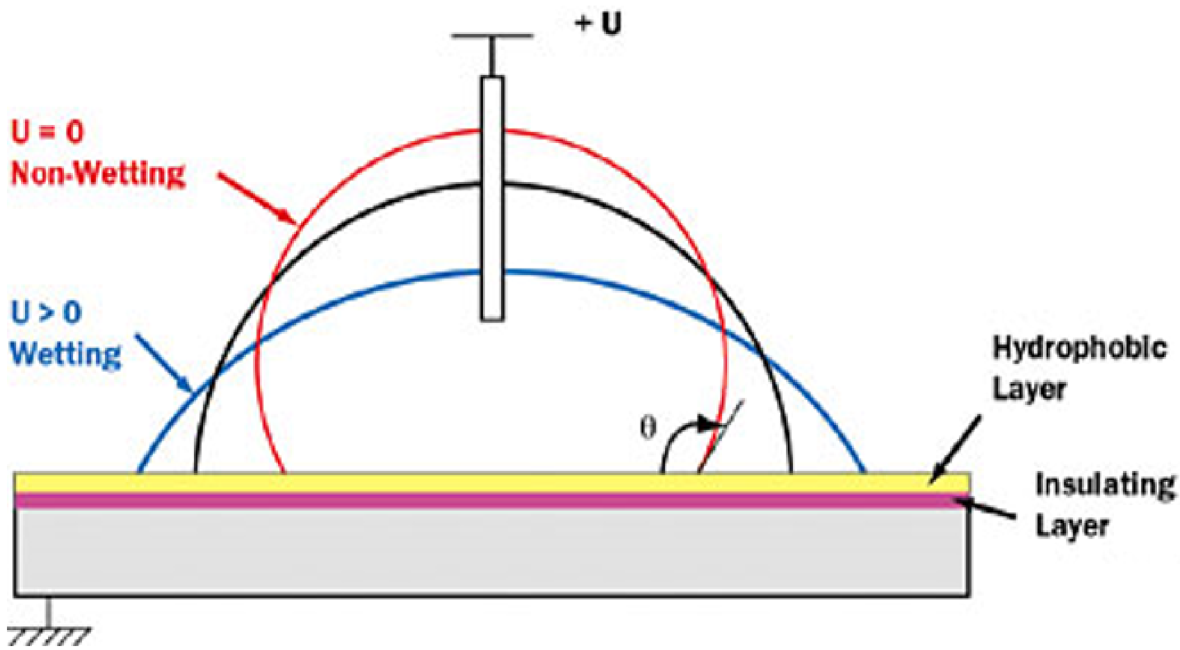
γ_{lg} = surface tension of the conducting drop

θ = contact angle, with and without voltage, denoted by the parenthesis (1).

This effect has been shown to coalesce water droplets to form larger sessile drops (1). The effect of creating larger droplets by electrowetting enables the filtration media to retain the droplet, rather than let it pass through the filter media in the emulsion.

Experimental Methods

A suitable surface and insulator medium was first found by observing electrowetting phenomena on multiple surfaces. A surface was coated with a conductive layer, insulating or protective layer, and then a hydrophobic layer. The layers are represented in Figure 1.



(From Baelmans, M. (2006, May 1))

Figure 1: Example of electrowetting phenomena and coating surfaces.

The insulating layer was prepared by spin coating a mixture of toluene and poly (styrene-co-methyl methacrylate) at 2 and 20 weight percent polymer to toluene onto a conductive slide at 1500 rpm for 90 seconds. The slide was dried overnight, then the hydrophobic layer was added by spin coating the slide with FluoroPel (PFC1601V from Cytonix, LLC) at the same condition as the protective layer.

The various insulating layers were evaluated using a Drop Shape Analyzer (DSA20E Krüss GmbH, Germany). A voltage was applied to a 5 µL deionized water droplet on the surface of the slide. The DC voltage was applied by A QuadTech programmable power supply (Model 42012-600-8) connected to an electrode on the conductive surface and an electrode connected to the water droplet. The change in contact angle of the sessile droplet was determined using the DSA setup, which can be seen in Figure 2 and 3.

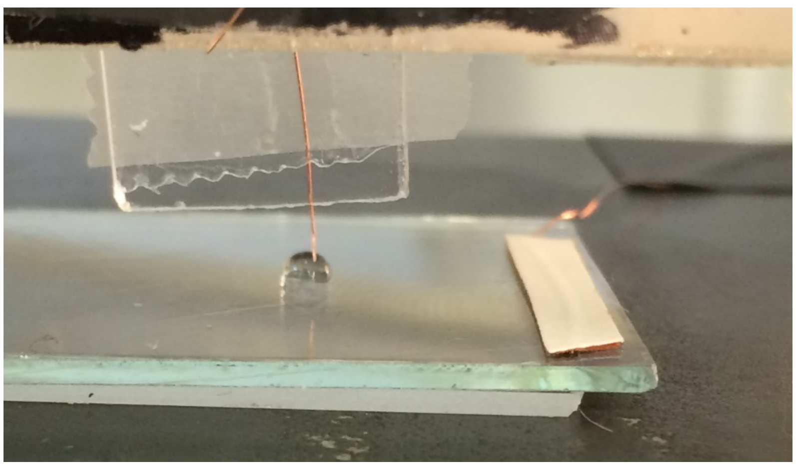


Figure 2: Setup of Electrowetting surface and electrodes.

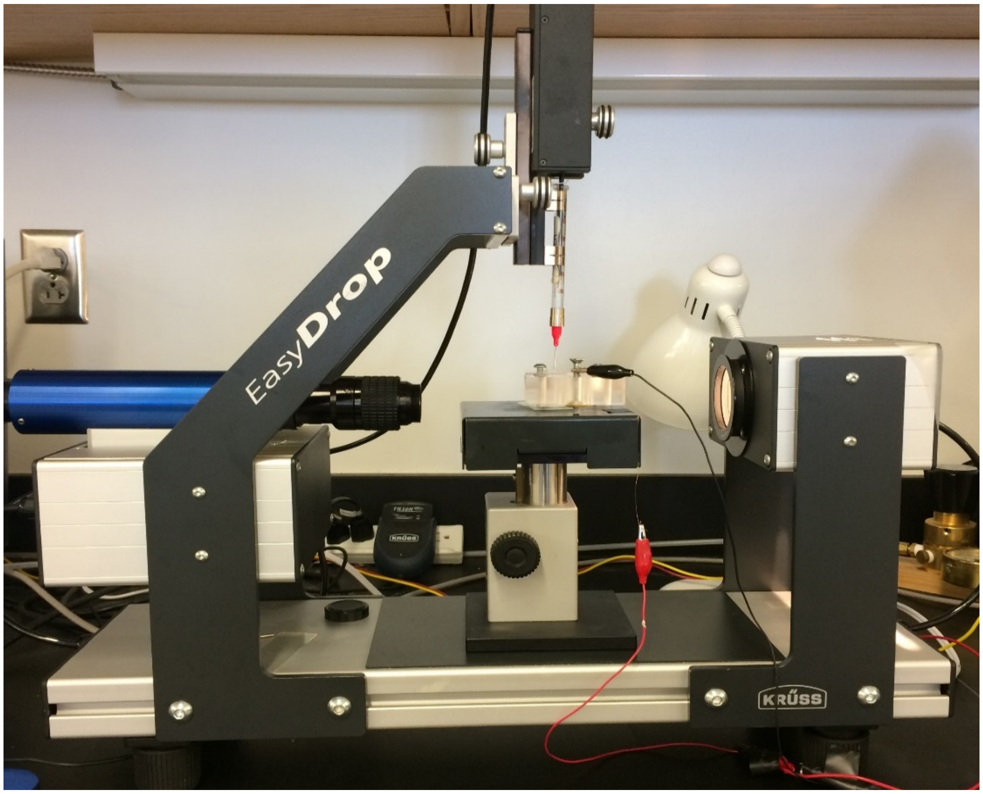


Figure 3: Setup of Kruss EasyDrop FM40 Drop Shape Analyzer

The measurement of contact angle reflects the effects of the electrowetting phenomena on the sessile droplets. The droplet setup and example of measurement of contact angle can been seen in Figure 4.

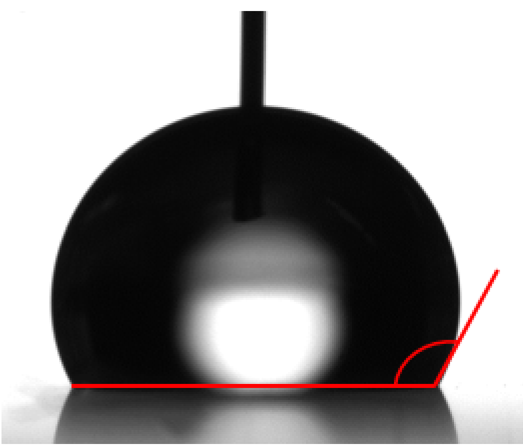


Figure 4: Measurement of contact angle

The application of electrowetting to filtration of diesel fuel was then applied to coalescing water droplets in a diesel emulsion. The coalescence of water droplets in diesel emulsion was observed under a microscope using a high speed camera. The setup used a conductive slide coated with a 20 weight percent protective coating and a hydrophobic coating layer, and an uncoated conductive slide. The setup is illustrated below in Figure 5.

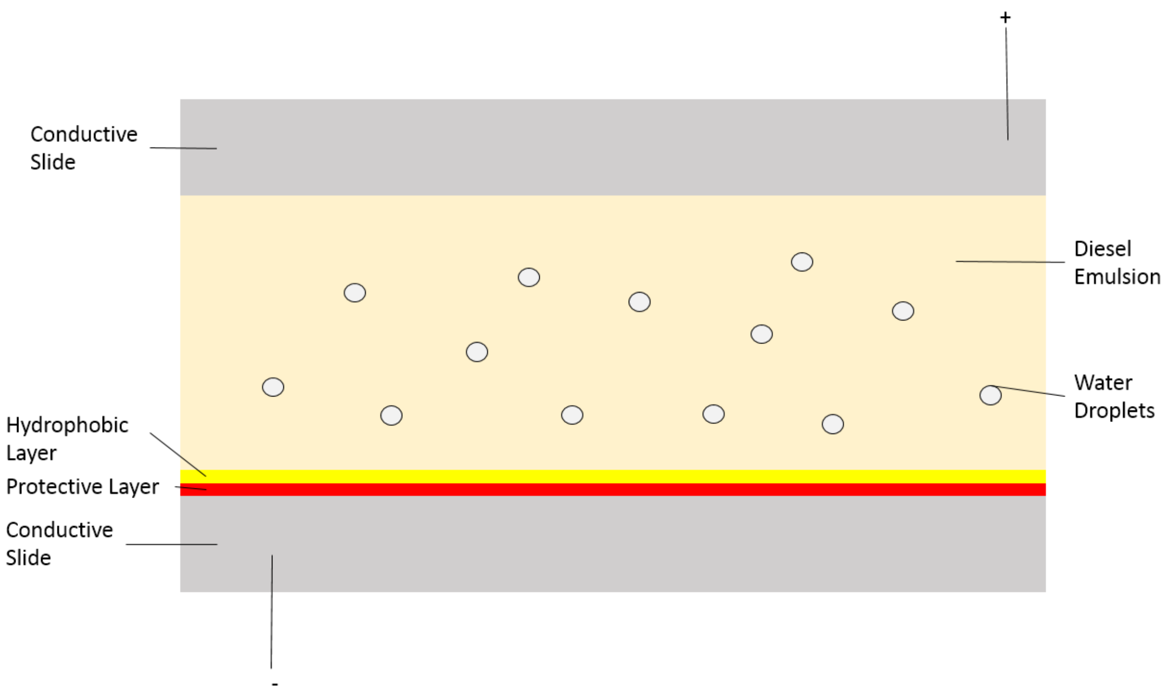


Figure 5: Setup to observe water droplet coalescence in diesel emulsion

Potentials of 100 and 200 volts DC were applied between the conductive slides and the behavior within the diesel emulsion was recorded under a microscope using a high speed camera at 500 frames per second. Coalescing water droplets then were measured using ImageJ software.

The experiment was repeated using a filtration medium of glass fibers to observe if the filtration medium had effects on the coalescence of water droplets in the diesel emulsion. The setup can be seen below in Figure 6.

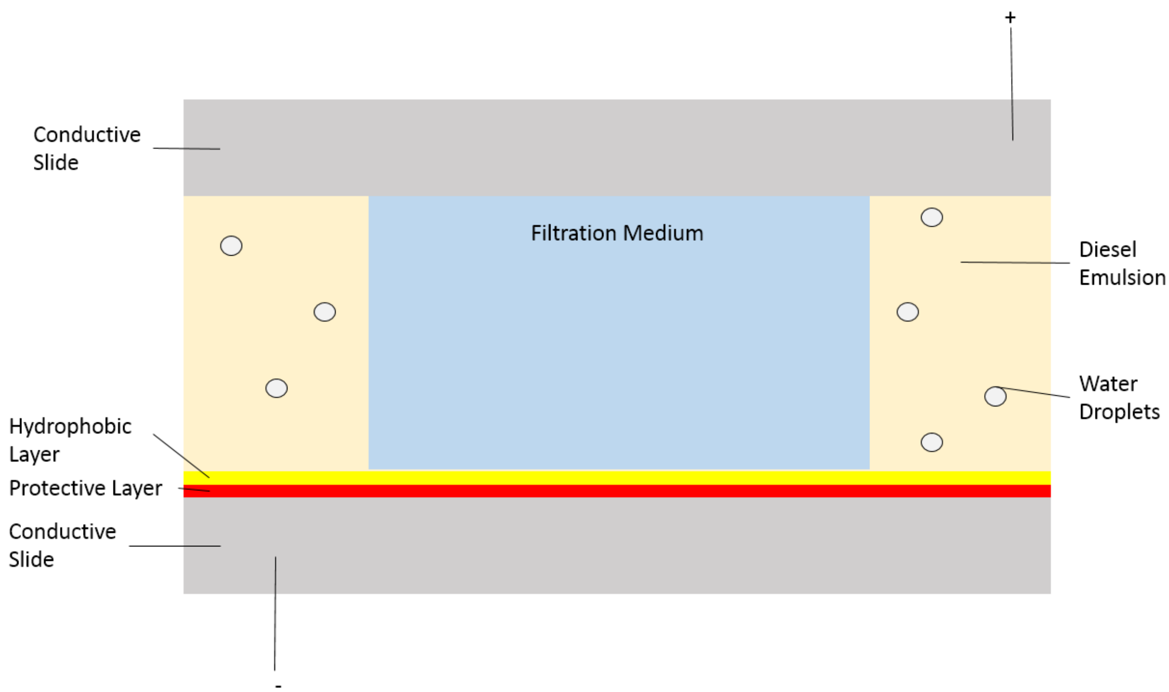


Figure 6: Setup to observe water droplet coalescence in diesel emulsion with medium

Data and Results

A suitable protective layer was determined by measuring contact angle of the droplet on a conductive slide as seen above in Figure 1. At 2 weight percent of polymer in the protective coating, the contact angle change was observed up to 30 volts. The change in contact angle at several voltages at the 2 weight percent protective layer can be seen below in Figure 7.

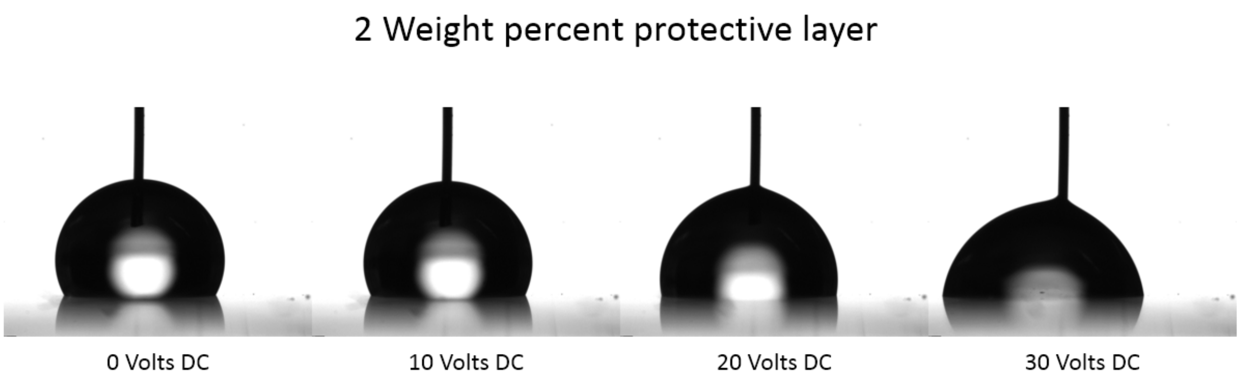


Figure 7: Change in contact angle as DC voltage is applied at 2 weight percent protective layer

The overall results of the runs at the 2 weight percent protective layer can be seen in Figure 8.

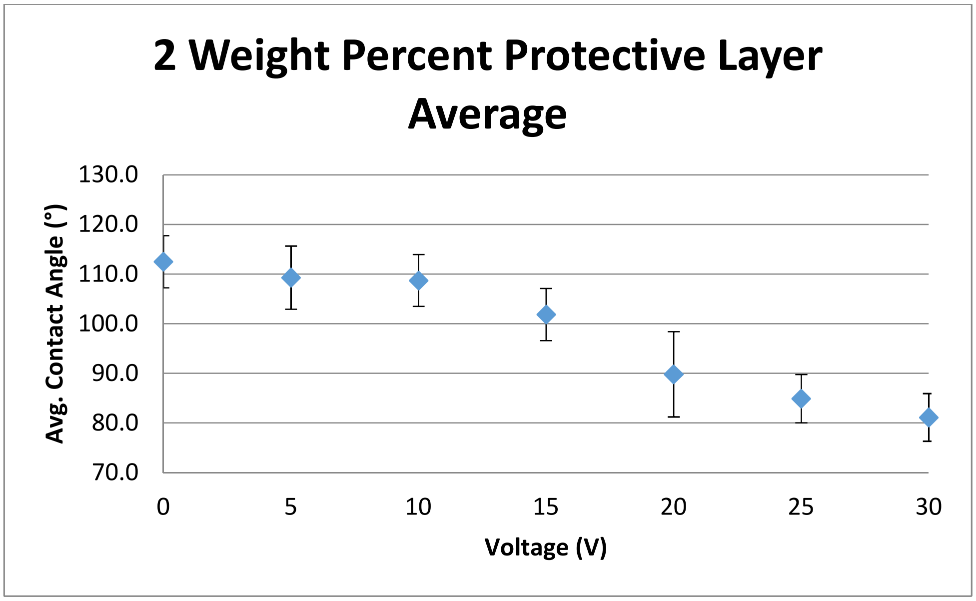


Figure 8: Overall results of contact angle against voltage at 2 weight percent polymer coating. Sample size n = 3.

The 20 weight percent of polymer in the protective coating showed a much larger voltage range than the previous coating. The change in contact angle at several voltages for the 20 weight percent protective layer can be seen below in Figure 9.

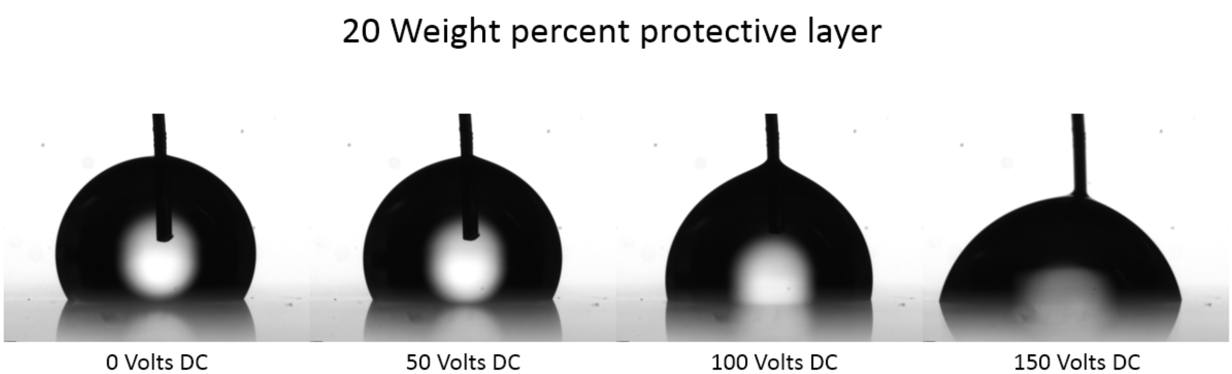


Figure 9: Change in contact angle as DC voltage is applied at 20 weight percent protective layer

The overall results of the runs at the 20 weight percent protective layer can be seen in Figure 10.

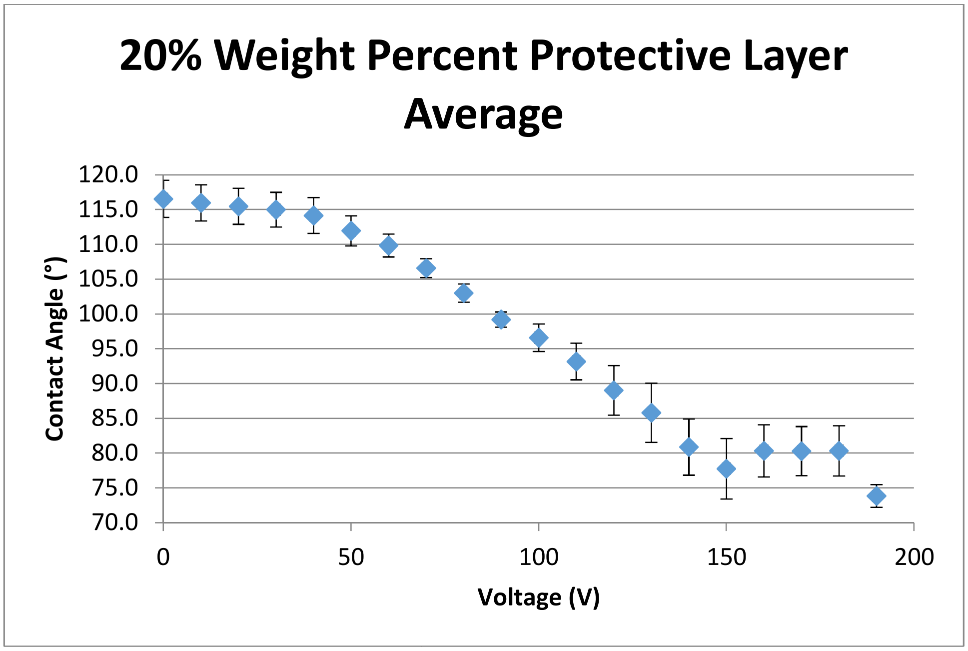


Figure 10: Overall results of contact angle against voltage at 20 weight percent polymer coating. Sample size n = 3.

Electrolysis of water was observed when 30 volts were applied to the water droplet using the 2 weight percent coating, as seen below in Figure 11.

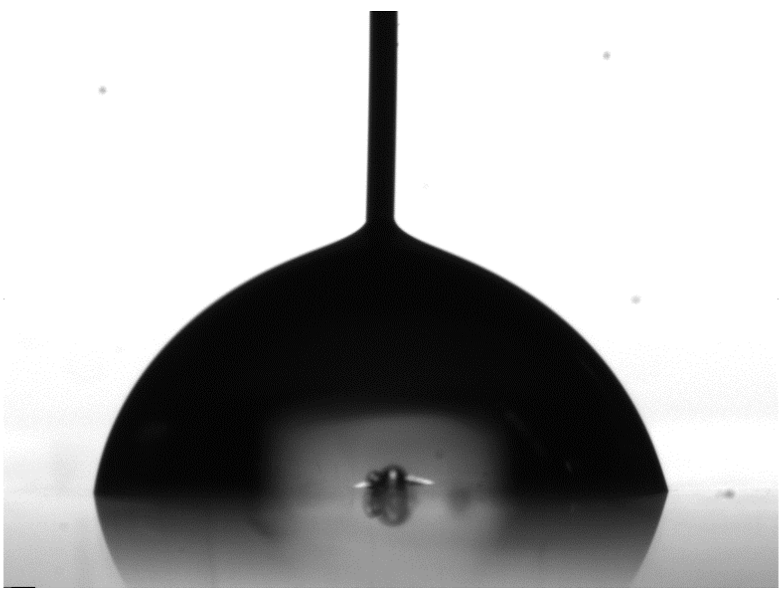


Figure 11: Electrolysis of water at 2 weight percent protective coating

The electrolysis of water shows that the 2 weight percent protective coating was not sufficient for further experiments. The 20 weight percent protective coating was better suited for continuing experiments. The voltage range allowed up to 200 volts without electrolysis.

The observation of coalescence of water droplets in diesel emulsion was done using the setup seen in Figure 6. Voltages of 100 and 200 volts were applied to the setup to observe coalescence of water droplets under a microscope with high speed camera. The size of the coalescing droplets were measured at each voltage. The size of droplet coalescence can be seen in Figure 12 and Table 1.

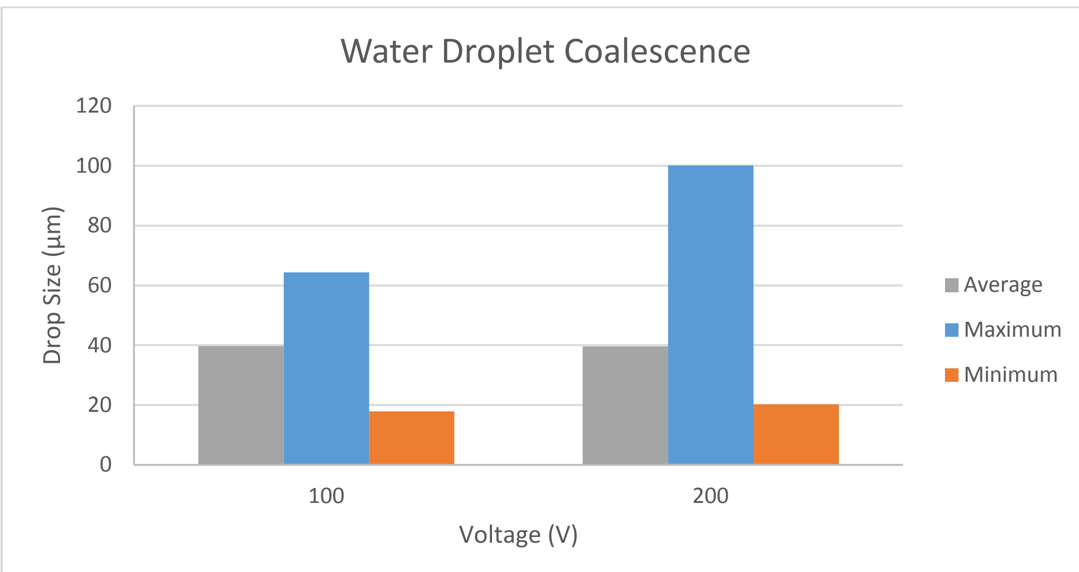


Figure 12: Range of droplet size coalescence by applied potential. Sample size n = 10 for each voltage.

Diameter of coalescing water droplets in Diesel			
100 V	Diameter (µm)	200 V	Diameter (µm)
Average	39.68	Average	39.62
Maximum	64.35	Maximum	100.14
Minimum	17.91	Minimum	20.22
St. Deviation	13.96	St. Deviation	17.01

Table 1: Data of coalescing water droplets by applied potential

An increase in droplet size was observed at both 100 and 200 volts. An overall increase of 40.8% of the diameter of coalescing droplets was seen. The results can be seen before in Table 2.

100 V			200 V		
Average Diameter (µm)	Before	After	Average Diameter (µm)	Before	After
	39.68	58.72		39.62	53.71

Table 2: Average drop size before and after potential is applied

The addition of a filtration medium qualitatively increased the amount of coalescence in the diesel emulsion. The larger range of coalescence occurred at the 200V potential, which was used when observing coalescence with the filtration medium. The progression of water droplets coalescing multiple times when a glass fiber filter medium can be seen below in Figure 13.

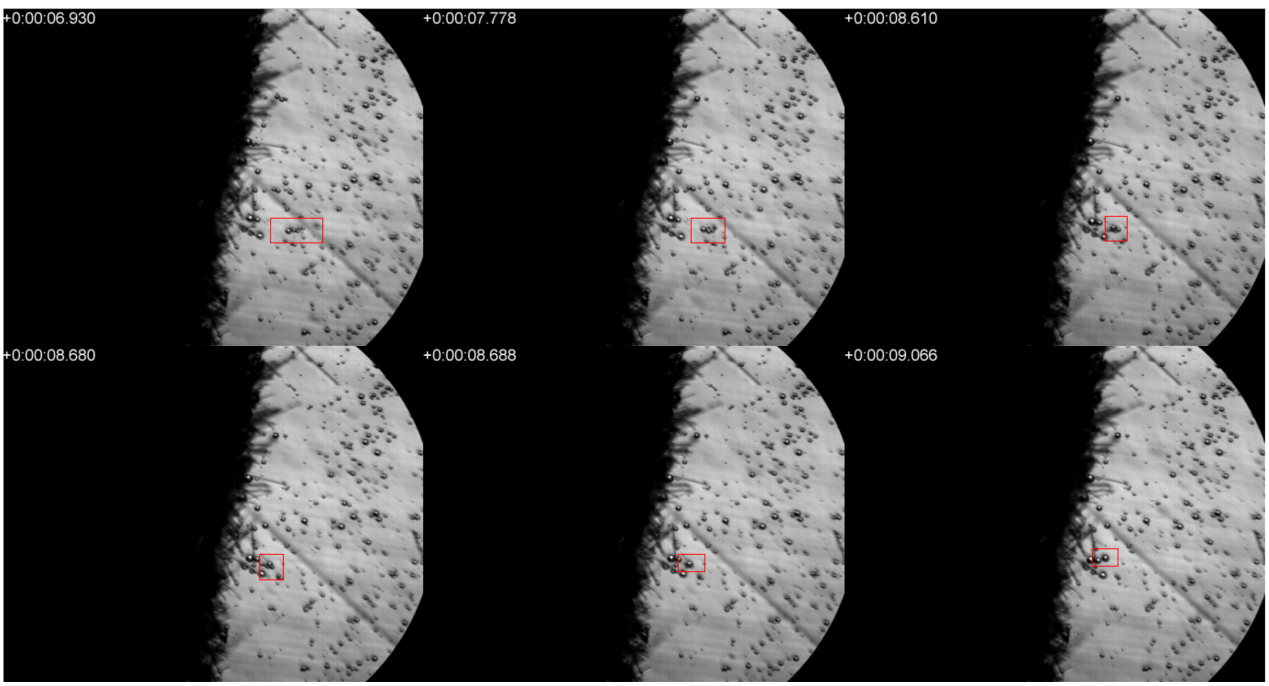


Figure 13: Coalescence on droplets using glass fibers as a filter medium

Applying a potential to the diesel emulsion without a filter medium showed coalescence of 2-3 droplets. When a filtration medium was added, a substantial amount more was observed. In Figure 13, five droplets coalesce into one much larger droplet. Figure 14 shows a before and after picture, where larger droplets can be seen after the voltage was applied, with fewer clusters of smaller droplets. The increase in amount of droplets coalescing supports the hypothesis that the applied potential with the filtration medium will coalesce a larger amount of droplets than without the medium, which can then increase the ease of filtration. Addition quantitative analysis is needed to prove this hypothesis.

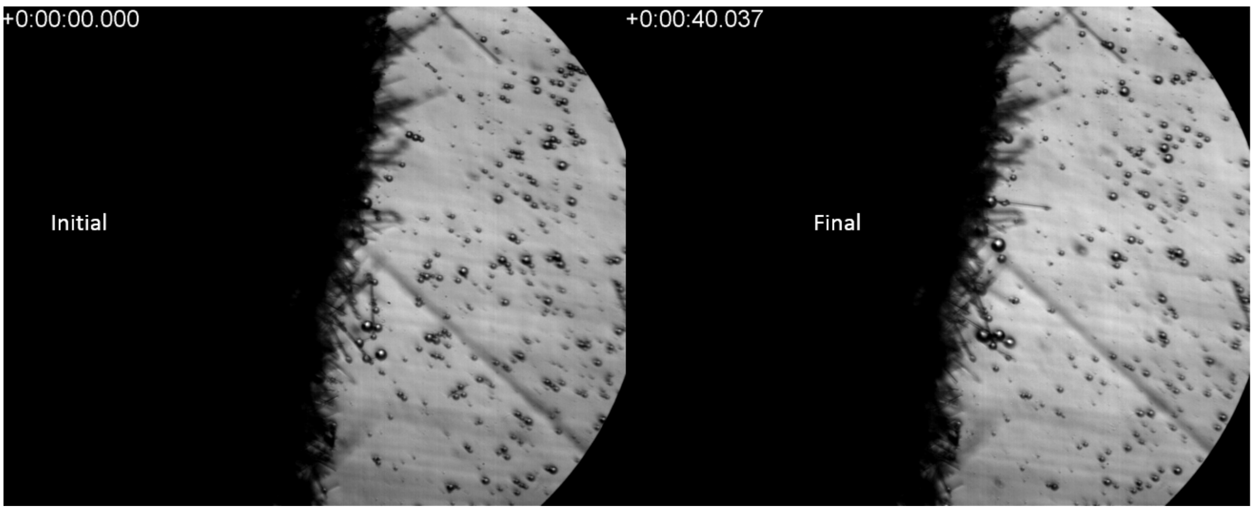


Figure 14: Initial and Final sizes of water droplets

Discussion/Analysis

The use of electrowetting phenomena can be used to coalesce water droplets in diesel fuel. The coalescence was observed between conductive slides, as seen in Figure 5. This coalescence can be observed without a filtration medium, and the range of water droplet coalescence increased with voltage, as a larger range was observed at 200 volts. The overall data showed a substantial increase in coalescing droplet size of 40.8% with a standard deviation of 12.65%. The use of glass fibers as a filtration medium increased the amount of water droplet coalescence occurring in the diesel emulsion. Other filtration mediums should be considered to determine the best environment for water droplet coalescence.

While the data provides proof that water droplets will coalesce in diesel fuel when a potential is applied, a quantitative analysis of filtration using a medium should be completed. An observation of how well a medium removed water from the emulsion should be compared to a baseline with and without a voltage potential. Other filtration mediums should also be evaluated and compared to each other to determine optimal filtration settings.

The results suggest that the use of electrowetting phenomena can increase the average size of water droplets in a diesel emulsion, and therefore increase the efficiency or ease of filtration. This is further supported by the increase in coalescing droplets when a filtration medium is added.

Appendices

Scale		
μm	pixels	ratio (μm/pixel)
1000	355	2.8

Table A.1: Scale used to determine droplet size

#	Voltage	Drop1 (pixels)	Drop2 (pixels)	Drop3 (pixels)	Drop1 (um)	Drop2 (um)	Drop 3(um)
2	100	12.21	6.11	18.44	34.40	17.22	51.94
3	100	5.27	7.34	8.53	14.85	20.68	24.04
4	100	8.25	4.53	8.39	23.23	12.77	23.62
6	100	11.72	4.69	12.98	33.02	13.22	36.55
8	100	5.69	5.59	8.19	16.03	15.75	23.08
9	100	9.09	3.40	12.57	25.62	9.57	35.41
11	100	7.21	7.50	8.87	20.32	21.13	24.99
12	100	7.85	10.36	11.16	22.11	29.18	31.45
1	200	5.76	6.77	8.27	16.21	19.06	23.28
3	200	19.00	8.43	20.19	53.52	23.76	56.88
4	200	5.79	3.84	7.34	16.30	10.81	20.68
5	200	5.40	6.38	7.88	15.21	17.97	22.19
6	200	6.64	8.06	9.50	18.70	22.69	26.77
6	200	5.32	7.43	8.00	14.99	20.92	22.55
7	200	5.56	11.61	12.08	15.67	32.69	34.04
8	200	12.23	7.65	12.84	34.46	21.54	36.18
9	200	7.59	5.74	9.48	21.38	16.15	26.69
10	200	8.19	6.33	8.67	23.08	17.84	24.43
12	200	6.46	5.22	7.85	18.19	14.71	22.11

Table A.2: Raw data taken from coalescing droplets

Drop 1 & 2 were the coalescing water droplets, Drop 3 denotes the size of the resulting droplet.

References

1) Aljuhani, A., & Chase, G. (2013). Coalescence of Submerged Water Droplets in Diesel by Electrowetting.

2) Baelmans, M. (2006, May 1). On-Chip Electrowetting Cooling - Electronics Cooling Magazine - Focused on Thermal Management, TIMs, Fans, Heat Sinks, CFD Software, LEDs/Lighting. Retrieved January 20, 2015, from http://www.electronics-cooling.com/2006/05/on-chip-electrowetting-cooling/

3) Diesel Fuel System Contamination Diagnosis and Service Procedure Job Aid. (2012).

4) Jaaskelainen, H. (n.d.). Early History of the Diesel Engine. Retrieved January 15, 2015, from https://www.dieselnet.com/tech/diesel_history.php

5) Mugele, F., & Baret, J. (2005). Electrowetting: From Basics to Applications. *Journal of Physics: Condensed Matter,* R705-R774.

6) Pangestu, D., & Stanfel, C. (2009, April 20). Media for Water Separation from Biodiesel-Ultra Low Sulfur Diesel Blends. Retrieved March 18, 2015, from http://papers.sae.org/2009-01-0871/

7) Shah, P., Wee, C., White, M., Sanford, S., & Meier, G. (2010). Experimental Determination and Thermodynamic Modeling of Water Content in Biodiesel-Diesel Blends.

8) Ultra Low Sulfur Diesel will be the primary highway diesel fuel produced - Clean Diesel Fuel Alliance. (2007, January 1). Retrieved March 19, 2015, from http://www.clean-diesel.org/highway.html

9) Wilfong, D., Dallas, A., Johnson, P., Viswanathan, K., Madsen, M., Tucker, B., & Hacker, J. (2010). Emerging Challenges of Fuel Filtration. *The International Journal for Filtration and Separation, 10*(2), 105-115.