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The use and effects of ecofriendly surfactants in the meat rendering industry in the United States.

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THE USE AND EFFECTS OF ECOFRIENDLY SURFACTANTS IN THE MEAT RENDERING INDUSTRY IN THE UNITED STATES

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THE USE AND EFFECTS OF ECOFRIENDLY SURFACTANTS IN THE MEAT RENDERING INDUSTRY IN THE UNITED STATES

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This thesis would not be possible without the desire of HydroSolutions and Mr. David Davis to find an ecofriendly surfactant to replace their current one. I would like to thank Ms. Pamela White for granting me access to Ernst Hall; Dr. Gerold Willing for the use of his research lab; and Ms. Rodica McCoy allowing the equipment in the Conn Center for Renewable Energy to be used. A special thanks to Mr. James Lee, Ms. Maribeth Rucker, Ms. Rodica McCoy, and Mr. Alan Hanley for demonstrating how to use the Contact Angle Analyzer, Particle Size Analyzer, and Sonic Dismembrator. In addition, I am grateful for the research help and expertise of Mr. Charles Staff; and Mr. Alan Hanley for his help in conducting experiments and meeting with HydroSolutions. Most of all, I would like to thank Dr. Gerold Willing, my thesis advisor, for his support and help throughout the thesis process, providing both professional and academic advice, and offering me the opportunity to work on this project with him, Mr. Alan Hanley, and HydroSolutions.

ABSTRACT

Meat is a major component of the diet of an American. However, humans do not consume one-third to one-half of each animal raised for their needs. The leftover materials are subjected to processing in the meat rendering industry. The rendering industry turns the waste material into value added ingredients.

During the rendering process, air pollutants are released. These air pollutants are odor nuisances in residential areas around rendering plants. These pollutants can be controlled by the use of multistage packed towers.

The packed columns used by the rendering industry are distinctive because of the addition of animal fat in the air stream. The fat can agglomerate on the packing and clog the towers. To prevent this, operates introduce a surfactant into the liquid stream for the system. The surfactant serves two roles: suspend the fat in the packed tower so that it does not stick to the packing and clog the system and coat the packing to enhance mass transfer by allowing for the creation of an even water film over the packing.

HydroSolution is located in Louisville, KY and specializes in serving the rendering industries. The company makes a treatment that is added to the air scrubber, which removes air pollutants from the airstream. The air scrubber system consists of a venturi connected to two packed towers in series. The company is interested in increasing the efficiency of the packed towers and reducing the amount of fat accumulation in the system. In addition, they would like to switch to an ecofriendly surfactant. To achieve their goals, a “green” surfactant was found that has the ability to replace the current one and the concentration needed to coat adequately the packing been determined.

A contact angle analyzer was used to determine extent of water coating by the calculation of the contact angle between the water droplet and the packing. A result of this test showed the soak time for the polyethylene (PE) packing was critical for a hydrophilic layer to form whereas multiple alternating layers cab apparently form on polypropylene (PP). Better performance can be obtained using PE since the ultimate contact angle is lower than the PP packing which leads to a greater degree of wetting.

A sonic dismembrator was utilized to suspend animal fat of the correct size in a surfactant solution; and a particle size analyzer calculated the diameter of the particles in the solution. A force balance on the particle diameter entering the packed tower at 500-600 nm determined the size. Any particles larger than 600 nm would fall out of suspension while smaller ones would remain and be transferred through the system.

Once the equipment settings able to produce the proper size particles were found, the surfactant concentration needed to suspend fat was estimated. These results showed that more surfactant is needed to sufficiently coat the packing than to suspend fat.

To increase the efficiency of the packed towers and reduce the probability of clogging, it is recommended that HydroSolutions switch to 70 ppm Bio-Soft GSB-9. This concentration is able to coat packing as well as 60 ppm Triton X-100 and suspend 3% animal fat.

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NOMENCLATURE

C_D	=	Drag Coefficient
d_p	=	Diameter of the Particle
F_b	=	Force of Buoyance
F_d	=	Force of Drag
F_g	=	Force of Gravity
ΔG_{mixing}	=	Gibbs Free Energy of Mixing
ΔH_{mixing}	=	Enthalpy of Mixing
R	=	Gas Law Constant
ΔS_{mixing}	=	Entropy of Mixing
T	=	Temperature
U	=	Velocity of Particle
W	=	Number of Hydrogen Bonding Configurations
ρ_L	=	Density of the Liquid
ρ_V	=	Density of the Vapor

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I. INTRODUCTION

The largest segment of United States agriculture is the meat and poultry industry. This industry produced 90.9 billion pounds in 2009 and 92.1 billion pounds in 2010. In 2009, the meat and poultry industry processed:

- 8.7 billion chickens
- 33.3 million cattle
- 246 million turkeys
- 2.2 million sheep and lambs
- 113.6 million hogs (American Meat Institute, 2011).

From the above numbers, it can be seen that meat is a major component of the daily diet in the U.S. According to Meeker, on average, men consume 6.9 oz. of meat per day while women eat 4.4 oz. of meat per day (2006). Figure 1 shows the average percentage of red meat, fish, and poultry that the U.S. consumes.

However, humans do not consume one-third to one-half of each farm-raised animal (Meeker, 2006). The leftover raw materials are exposed to the rendering process to create useful by-products. The primary products are meat meal, poultry meal, hydrolyzed feather meal, blood meal, and fishmeal (Meeker, 2006).

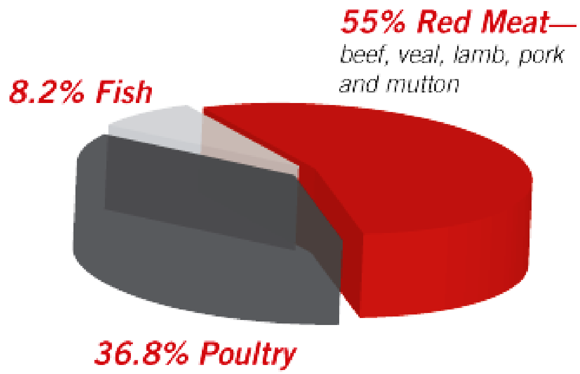

FIGURE 1 - Average Percentages of Meat Consumption in the U.S.

(American Meat Institute, 2011)

Annually, the rendering industry recycles about 59 billion pounds of perishable material. They turn the "waste" material into valuable ingredients for explosives, lubricants, pharmaceuticals, personal care products, and various soaps (National Renderers Association, 2006-2011).

In addition to the above products, the industry makes high-energy fats and high-quality protein ingredients that supplement the diet and enable efficient production of beef, veal, pork, poultry, fish, eggs, and milk for the feed industry (National Renderers Association, 2006-2011).

According to Meeker, rendering is "a process of both physical and chemical transformation using a variety of equipment and processes. All of the rendering processes involve the application of heat, the extraction of moisture, and the separation of fat" (2006). Figure 2, following, is the basic production process for rendering of meat products.

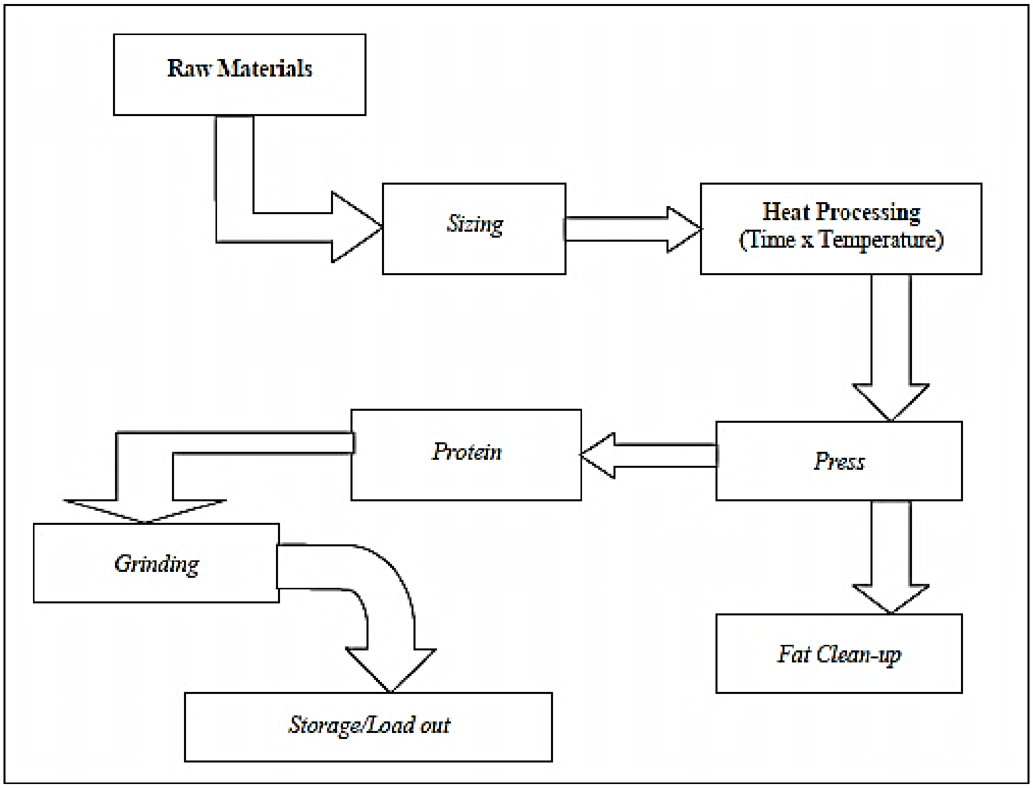

FIGURE 2 - The Basic Production Process of Rendering

(Hamilton, 2004)

The type of rendering process depends on which raw materials are being used. However, all systems start with the collection and transportation of raw materials to a facility. The raw materials are then crushed into smaller pellets and transferred to a cooking vessel. The cooking vessel separates the fat from the rest while removing moisture. This is an important step because cooking eliminates bacteria, viruses, protozoa, and parasites because of the high temperatures and the long exposures times (Meeker, 2006).

A screw press separates the animal fat from the rest of the cooked material. After separation, the protein, minerals, and some residual fat -- known as "cracklings" or "crax," -- are processed by additional moisture removal and grinding. The crax is then transferred to storage or shipment. The protein is either stored in feed bin structures or enclosed buildings while the fat is stored in tanks (Meeker, 2006).

Air pollutants are released from the cookers and the screw press of the rendering process (Neulicht, 1995). The major components that have been qualitatively identified as potential emissions include "particulates, ammonia, hydrogen sulfide, organic sulfides, disulfides, C-4 to C-7 aldehydes, trimethylamine, C-4 amines, quinoline, dimethyl pyrazine, other pyrazines, and C-3 to C-6 organic acids. In addition, lesser amounts of C-4 to C-7 alcohols, ketones, aliphatic hydrocarbons, and aromatic compounds are potentially emitted" (Neulicht, 1995). Generally, VOCs are odor nuisances in residential areas near rendering plants. The odor detection thresholds for many of these compounds are low, some as low as one part per billion (ppb). Of the compounds listed above, only quinoline is classified as a hazardous air pollutant by the EPA (Neulicht, 1995).

Besides VOC emissions, particulate matter is released from the grinding and separation of the cracklings from the screw press in the cooker and other rendering operations (Neulicht, 1995). The particulate matter and VOCs are controlled by the use of multistage packed towers (Neulicht, 1995).

Typically, packed towers or packed columns, shown in Figure 3, are vertical, cylindrical pressure vessels containing one or more sections of a packing material. Liquid flows downward over the packing by gravity as vapor flows upward through the wetted packing and coming into contact with the liquid. The packing sections are located between a lower gas-injection support plate and an upper grid or mesh hold-down plate. This arrangement prevents packing movement (Seader, 2006).

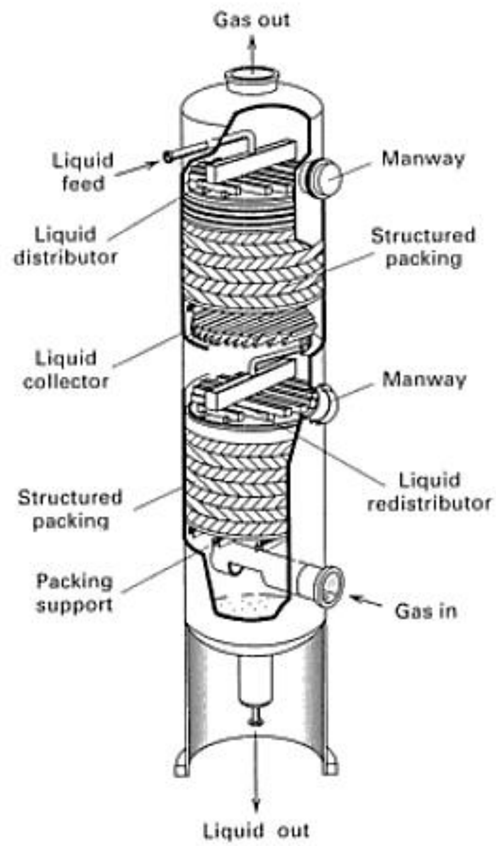

FIGURE 3 - Details of internal used in a packed column

(Seader, 2006)

Packed columns used in the rendering industry are unique in that the air stream flowing through contains animal fat. The fat can agglomerate on the packing and clog the system. To prevent this, surfactants are introduced into the liquid stream for the system (Advamed, 2012). The surfactant has two responsibilities. It is added to the system to suspend the fat in the packed tower so that it does not stick to the packing and clog the system. In addition, it coats the packing, which allows for the development of smooth water film, which enhances mass transfer through the system. These ability is due to the physical characteristics of surfactants.

Surfactants are amphiphilic molecules with polar head groups, which may be anionic, cationic, non-ionic and zwitterionic, and hydrophobic tails that may be hydrogenated or fluorinated, linear or branched (Lisi, 2009). To be amphiphilic is to contain both a water insoluble component and a water-soluble component. Figure 4 is a representation of a surfactant molecule.

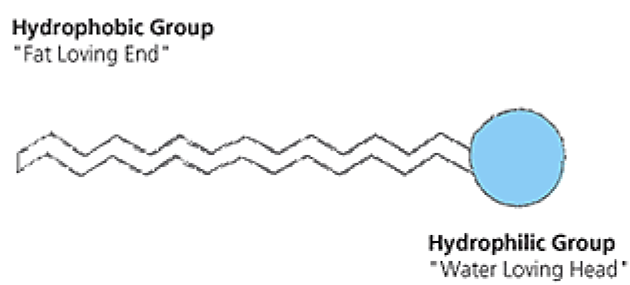

FIGURE 4 - Schematic of surfactant molecules

(P&G, 2005)

The insoluble hydrophobic group may extend out of the water phase into the fat phase, while the water-soluble head group remains in the water phase. This modifies the surface properties of water at the water/fat interface where the surfactant molecules are adsorbed (Lisi, 2009).

One of the major questions that the industry faces after they include the surfactant is how much is needed to transfer the mixture through the process. To answer this question, the maximum size of the particles that can be transferred through the system without falling out of suspension needs to be calculated by applying a force balance on a suspended liquid droplet. Once the size is calculated, an array of different surfactant concentrations can be used to determine how much is needed to stabilize the water/fat system for the rendering process. Rendering industries do not want to use more surfactant than is needed to avoid unnecessary costs.

A property of wetting agents is increasing their concentration above the critical micelle concentration does not result in more adsorption (Gragson, 1997). Figure 5 shows the effects of concentration on adsorption. At very low concentrations, the molecules lie along the interface. As the amount of surfactant increases, the molecules begin to align until a complete monolayer is formed at the critical micelle concentration (CMC). Above the CMC, a potential double layer of molecules is formed on hydrophilic surfaces, but not on hydrophobic surfaces. Additional increases in concentration leads to the formation of micelles (Gragson, 1997).

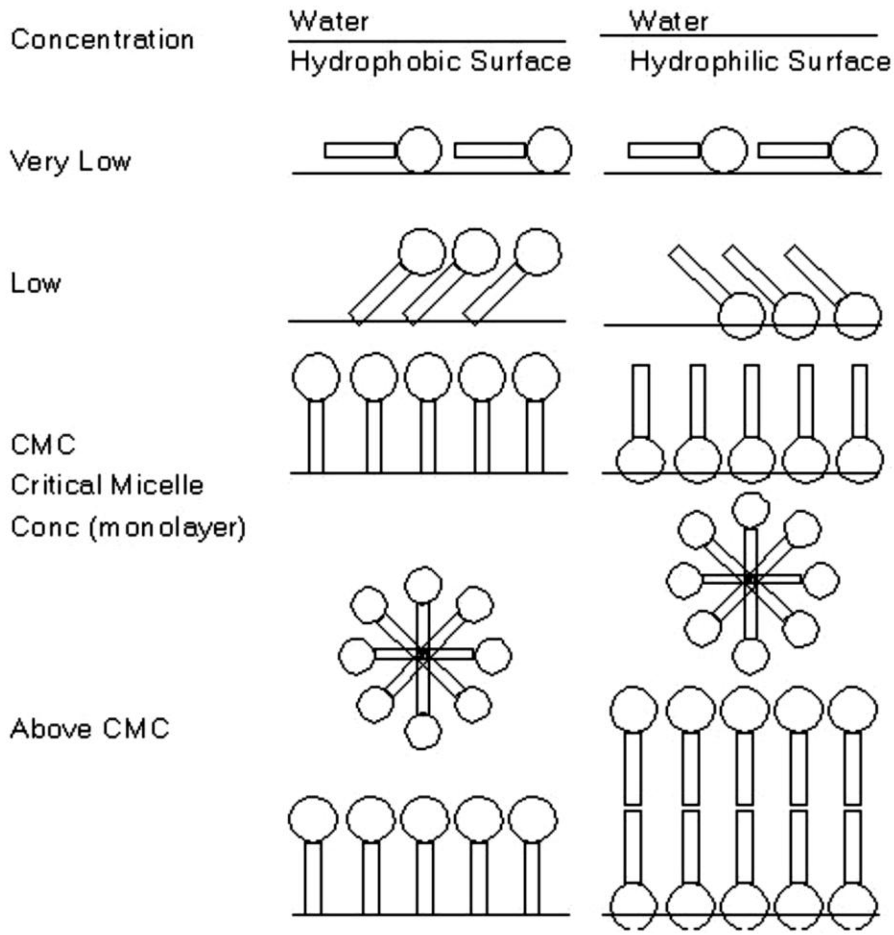

FIGURE 5 - Effects of Surfactant Concentration on Adsorption

(Gordon, 2010)

Surfactant molecules affect the surface tension of aqueous solution. Surface tension is the ability to resist an external force. As shown in Figure 6, surface tension becomes constant at the CMC. This means that using a higher concentration has little effect on the adsorption of molecules (Schramm, 2000).

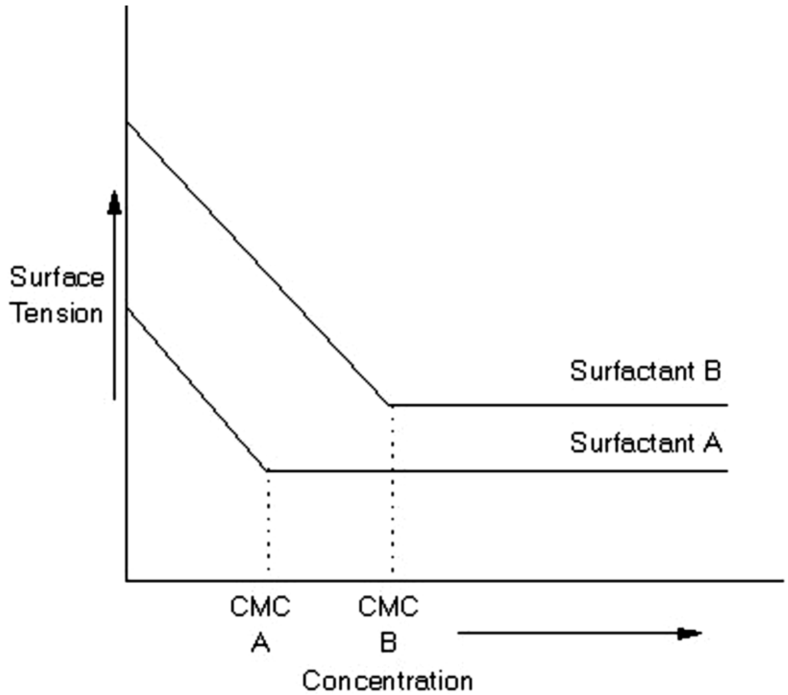

FIGURE 6 - Effect of Concentration and Surface Tension

(Gordon, 2010)

HydroSolutions located in Louisville, KY, has expertise in rendering odor control and water treatment. They specialize in serving rendering industries. The company makes a treatment to be added to the air scrubber that removes VOCs and odor-causing compounds from the airstream to meet downstream objectives (HydroSolutions). The air scrubber system used as a basis for the research is comprised of a venturi connected to two packed towers in series.

The company is interested in increasing the efficiency of the packed towers and reducing the amount of fat accumulation in the system. There is also a desire to use an alternative ecofriendly surfactant in the place of the current one. These goals were achieved by determining a “green” surfactant that has the ability to replace the current one and the concentration needed to coat adequately the packing. To determine this, several tests were required.

At the time of publication, no prior research on ecofriendly wetting agents in the meat rendering industry could be found to compare with the results of this research.

II. INSTRUMENTATION AND MATERIALS

Contact Angle Analyzer

The purpose of a contract angle analyzer is to calculate the contact angle between a water droplet and a packing sample coated with surfactant, which determines the degree of wetting which in turns is related to the amount of mass transfer within the packed tower. The instrument used was the Contact Angle System OCA 15 Plus built by Data Physics. The OCA 15 is equipped with a multiple dosing system, manual syringe units, and a liquid temperature control device. The special features of the OCA 15 is a 50 images per second CCD video camera with a resolution of 752 x 582 pixels and the ability to handle up to four manual dosing units or alternatively one direct dosing unit with one manual or electronic syringe unit (Maier, 2007). The analyzer, shown in Figure 7, was set up according to the operating manual.

FIGURE 7 - Contact Angle System OCA 15 Plus

Sonic Dismembrator and Particle Size Analyzer

A sonic dismembrator was used to suspend the animal fat in the surfactant/water solutions, while the particle size analyzer determined the diameter of the particles in the surfactant/fat/water suspension. As shown in Figure 8, the sonic dismembrator used was a Fisher Scientific Sonic Dismembrator Model 500 constructed in April 2005 and the particle size analyzer was the Brookhaven Instruments Corporation Particle Size Analyzer 90Plus manufactured in 2006.

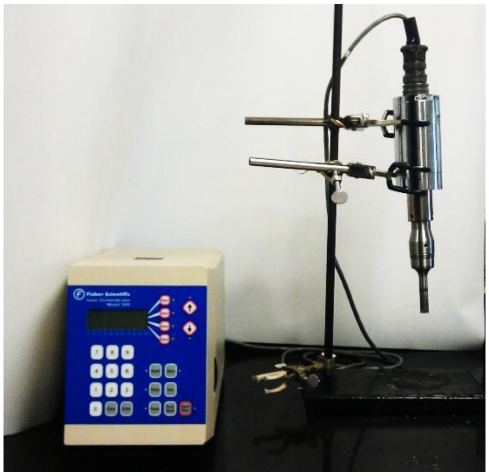

FIGURE 8 - Sonic Dismembrator Model 500

FIGURE 9 - Particle Size Analyzer 90Plus

The Model 500 Dismembrator consists of four core elements: the power supply, controls, converter, and horn. The Model 500 Dismembrator allows the user to specify the time duration and adjust the amplitude setting to obtain the desired results (Fisher Scientific, 2005). The sonic dismembrator was set up according to the specifications listed in the operating manual. No additional equipment or devices were used in tandem with the sonic dismembrator.

The particle size analyzer is operated by a computer control and equipped with a dust filter to allow for a high percentage of acceptable measurements to be made by the novice user. The software is menu driven with screens designed to guide and inform at each stage of the operation. After entering the initial parameters, the remaining calculations are automatic and required no other input from the user (Brookhaven Instruments Corporation, 1995).

Materials

The materials used in the thesis included eight surfactants: Bio-Soft GSB-9, Breakdown, DowFax 3B2, EcoSurf EH–3, Tergitol NP-30, Triton H-55, and Triton X-100. (A comparison of the surfactants can be seen in Appendix I.) Reverse osmosis water was used to formulate the surfactant solutions. The use of this water allows for an ideal system to be used for experimentation.

To verify the diameter calculations from force balance, a sample of process sump water was used. The process water contains residual fat particles, surfactant, and other chemicals that the HydroSolution Company adds to their air scrubber treatment.

The animal fats used to simulate the fat from the rendering process were beef, chicken, and pork. To ensure it contained no added preservatives and resembled the pure fat that would be present in the rendering industry, special attention was paid to product labels. As only pork is cured, this concern was not warranted for chicken or beef.

The contact angles were measured on polypropylene (PP) and polyethylene (PE) packing to test whether one substance would assist in coverage better than the other would. The PP is a plastic Flexring, cylinder shaped packing material (Figure 10); whereas, the PE is a plastic Hackett, spherical shaped packing material (Figure 11). The packing samples used in the contact angle calculations were pieces from the inside and outside areas of the packing. Because of the shape of the polyethylene spheres, outside sample pieces could not be used in the calculations. As such, only inside pieces were tested.

FIGURE 10 - Polypropylene Packing

FIGURE 11 - Polyethylene Packing

III. PROCEDURE

Three pieces of lab equipment were needed to fulfill the purpose of the thesis: contact angle analyzer, sonic dismembrator, and particle size analyzer. The contract angle analyzer was used to calculate the contact angle between a water droplet and a packing sample coated with surfactant -- the substrate. A sonic dismembrator was used to mix thoroughly the solution and animal fat, while the particle size analyzer determined the diameter of the particles in the surfactant/fat solution.

Contact Angle Analyzer

Packing samples were prepared by dropping four pieces into 70-ppm surfactant solution and removing at five-minute intervals. The contact angle was calculated by:

1. Checking the measuring device to ensure it was leveled
2. Opening the SCA20 – Software for OCA and PCA
3. Positioning the sample on the sample stage
4. Filling the necessary syringes with reverse osmosis water and inserting into the syringe unit
5. Positioning the sample and dosing needle
6. Adjusting the drop image appropriately
7. Pressing the base line detection button and adjusting to the base and top lines
8. Pressing the Profile extraction to get the contact angle

9. Repeating step 7 every 30 seconds for 3 minutes to develop a contact angle rate of dispersion profile
10. Repeating for all of the ecofriendly surfactant samples that were provided.

Sonic Dismembrator

A 100 mL 70 ppm Triton X-100 solution containing 3% animal fat was dismembrated using the macro tip by setting the amplitude to 40% and the timer to one hour to achieve the desired molecule size.

The dismembrated sample was checked after one hour to examine the amount of separation. Then it was left overnight to determine if the surfactant/fat solution was stable. This was done to investigate if additional separation occurs after the first hour. If minimal separation occurred with the appropriate particle size, the correct concentration has been reached.

This stationary sample was said to be stable after the first hour because normal operating conditions are 24 hours a day, 6 days a week for the rendering industry. The liquid stream entering the packed tower will be in constant movement, which should keep the fat suspended. If the stationary sample is stable for one hour, then the fat should remained suspended in the flowing liquid stream during operation.

This was repeated for all three animal fats.

Particle Size Analyzer

A small portion of the total dismembrated sample was diluted until it became transparent. Then a 5 mL surfactant/fat sample was inserted into the sample port of the particle size analyzer. Using the software, the dust filter was turned on, the appropriate parameters set, and the number of trials set to five. After the five trials were completed, the average diameter was calculated. Five trials were used to allow for accurate results and minimize error. The procedure for dismembrating and testing the particle diameter was repeated until the desired particle size was obtained and the surfactant/fat solution was stable for 24 hours.

IV. RESULTS AND DISCUSSION OF RESULTS

Contact Angle Results

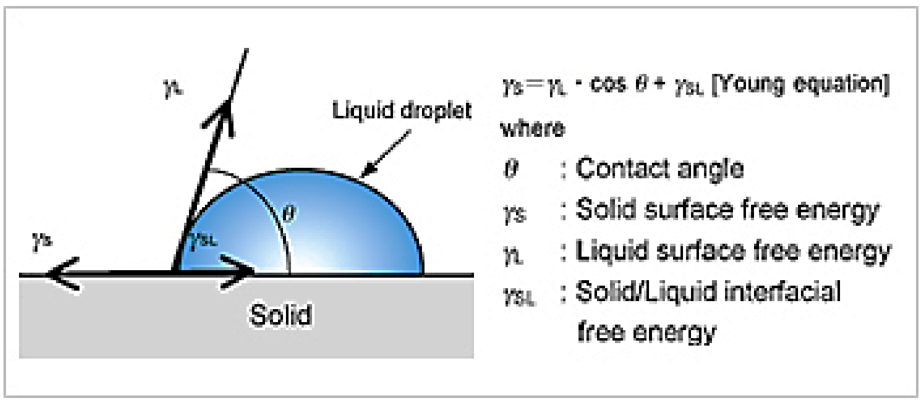

FIGURE 12 - Contact Angle Measurement

The contact angle is the angle at which a liquid/vapor interface meets a solid surface, as shown in Figure 12. A high contact angle means low wettability of the surface; whereas, a low contact angle means high wettability. In other words, a water contact angle measuring greater than 90º is characteristic of a hydrophobic surface and anything less is characteristic of a hydrophilic surface. It is desired to achieve contact angles less than 90º; the lower the angle the better.

1. <u>Triton X-100</u>

Due to the shape of the polyethylene spheres, the outside pieces could not be tested. The contact angle analyzer was unable to distinguish the baseline for the contact angle to be calculated.

Based on the measurements that were recorded, a large range of angles was seen for four soaking periods – 5-, 10-, 15-, and 20-minute – in the 70 ppm surfactant solution. The table below lists the minimum, maximum, and range of the angles seen for the different soak periods for the polyethylene in the Triton X-100. The first trial of each of the soak times is only for three 30-second readings.

As seen in the below table, the measured angles are largely distributed. It should stand out that, over the period that the data was taken, the water was able to spread quite a bit over the surface of the packing. Graphs of the data can be seen in Appendix I.

The purpose of adding surfactant to the system was to increase the spreading of water over the packing. By increasing the amount of wetting across the surface, a larger surface area is available for mass transfer. In terms of the application of rendering, the addition of the wetting agent to the system is allowing for more of the odor--causing compounds to be suspended.

According to the data collected and presented in Table I, Triton X-100 is assisting in the spreading of the water over the packing. However, the water is still forming small beads on the surface instead of creating a thin layer across the solid. The angles of beads are decreasing as the soak times are increased. This can be seen in Appendix II.

TABLE I

POLYETHYLENE IN TRITON X-100

Soak Times	Trial #	Max Angle Recorded	Min Angle Recorded
5 MIN	1	115.5	104.1
	2	71.5	53.4
	3	115.9	96.1
	4	99.8	77.9
	5	86.2	54.2
10 MIN	1	102.0	90.5
	2	59.4	30.4
	3	62.9	43.7
	4	100.0	76.5
	5	119.8	102.7
15 MIN	1	98.7	89.4
	2	73.3	53.0
	3	82.9	63.0
	4	69.1	46.4
	5	89.8	63.2
20 MIN	1		
	2	78.7	55.6
	3	64.9	41.8
	4	44.9	28.5
	5	109.3	71.5

Similar behavior of the drops of water on the packing was observed for all of the soak times that were tested. This would suggest that allowing the surfactant to coat the packing for a period before the product is added to the system would increase the amount of mass transfer.

Unlike the PE samples, both inside and outside pieces of the PP packing could be tested. The minimum angles recorded were compared for the sets of data because it is the minimum angles that will determine hydrophilicity of the sample surface.

When the PP table was compared with the PE table, it was observed that the PE experienced an overall decrease in the contact angle as the soak times increased, suggesting that the surfactant needs time to develop a full monolayer on the surface.

TABLE II

POLYPROPYLENE IN TRITON X-100

		Inside Pieces		Outside Pieces	
Soak Times	Trial #	Max Angle Recorded	Min Angle Recorded	Max Angle Recorded	Min Angle Recorded
5 MIN	1	104.1	89.6	71.8	57.6
	2	73.9	60.6	71.6	56.2
	3	67.7	58.4	90.1	76.7
	4	54.6	43.7	86.1	67.8
	5	70.8	63.3	81.3	61.6
10 MIN	1	105.4	94.9	96.4	79.3
	2	85.2	66.8	112.1	81.6
	3	82.6	62.1	80.2	62.8
	4	93.5	83.3	72.3	60.4
	5	66.6	58.8	78	61.4
15 MIN	1	96.5	83.8	81.4	65.4
	2	62.9	46.8	91.5	76.1
	3	63.2	54.5	72.6	52.4
	4	52.8	43.8	87.8	68.3
	5	77.9	67.8	78.9	68.8
20 MIN	1	98.0	85.9	72.8	68.1
	2	117.9	97.5	70.0	53.5
	3	68.7	55.7	68.0	52.7
	4	77.9	66.0	72.7	59.4
	5	66.1	58.4	88.2	76.8

The fluctuating values for the inside sample pieces of the PP suggest that multiple layers of surfactant were being formed on the surface alternating the direction of the hydrophilic heads. Below is a table of average minimum values for each soak times for the PE and the PP packing.

TABLE III

AVERAGE CONTACT ANGLES FOR PP AND PE

Soaked Times	POLYETHYLENE	POLYPROPYLENE	
		Inside Pieces	Outside Piece
5 MIN	66.1	60.8	64.7
10 MIN	83.5	70.7	67.8
15 MIN	59.7	56.4	67.5
20 MIN	48.7	69.2	58.4

The difference in the recorded contact angles of the inside and outside pieces of the PP packing can be due to the initial shape of the samples when the testing occurred. To ensure an accurate reading, a flat, balanced surface is needed to apply the drop of reverse osmosis water to the surface of the packing. The surface for the outside pieces of the PP was not as flat and balanced as the pieces that were used for inside sample pieces for either the PP or the PE. Thus far, it has been shown that the soak time for the PE is more important than it is for the PP and that better performance can be obtained on the PE since the ultimate contact angle is lower which leads to a greater degree of spreading.

2. <u>EcoSurf EH-3</u>

TABLE IV

POLYETHYLENE IN ECOSURF EH-3

Soak Times	Trial #	Max Angle Recorded	Min Angle Recorded
5 MIN	1	91.9	66.1
	2	63.7	26.9
	3	83.4	59.1
	4	99.2	83.6
	5	86.9	65.0
10 MIN	1	69.3	49.3
	2	78.2	50.6
	3	89.6	66.6
	4	94.4	70.9
	5	88.1	66.1
15 MIN	1	98.8	75.3
	2	82.9	57.3
	3	83.0	52.9
	4	97.4	78.4
	5	88.4	52.0
20 MIN	1	85.5	35.0
	2	94.7	55.2
	3	95.3	76.3
	4	90.2	69.9
	5	92.5	66.2

Above is a table listing the maximum and minimum contact angles recorded for each trial in each of the soak time slots. This table was used to determine the behavior of the surfactant and sample. The table suggests that the maximum angles are increasing for longer soak times.

This trend is more easily evidenced in the table and graph below. The table lists the averages of each of the groups. The average value was determined by first identifying which sets of data was one standard deviation above and below the average of all the data and excluding them. Then the remaining numbers were averaged.

TABLE V

AVERAGE CONTACT ANGLES FOR PE

Soak Times	Avg. Max. Angle	Avg. Min. Angle
5 MIN	87.4	63.4
10 MIN	82.3	60.7
15 MIN	88.4	52.0
20 MIN	98.2	63.8

This is a slightly different behavior than was seen with Triton X-100 in that increases in contact angle with soak time suggest that multiple layers of the surfactant are forming on the surface. The first hydrophilic layer decreases the contact angle (5-10 minute) and the formation of the second hydrophobic layer increases the contact angle (10-15 minute). The continuation of the increasing contact angle suggests that a potential wider spread hydrophobic layer was formed on the surface of the sample.

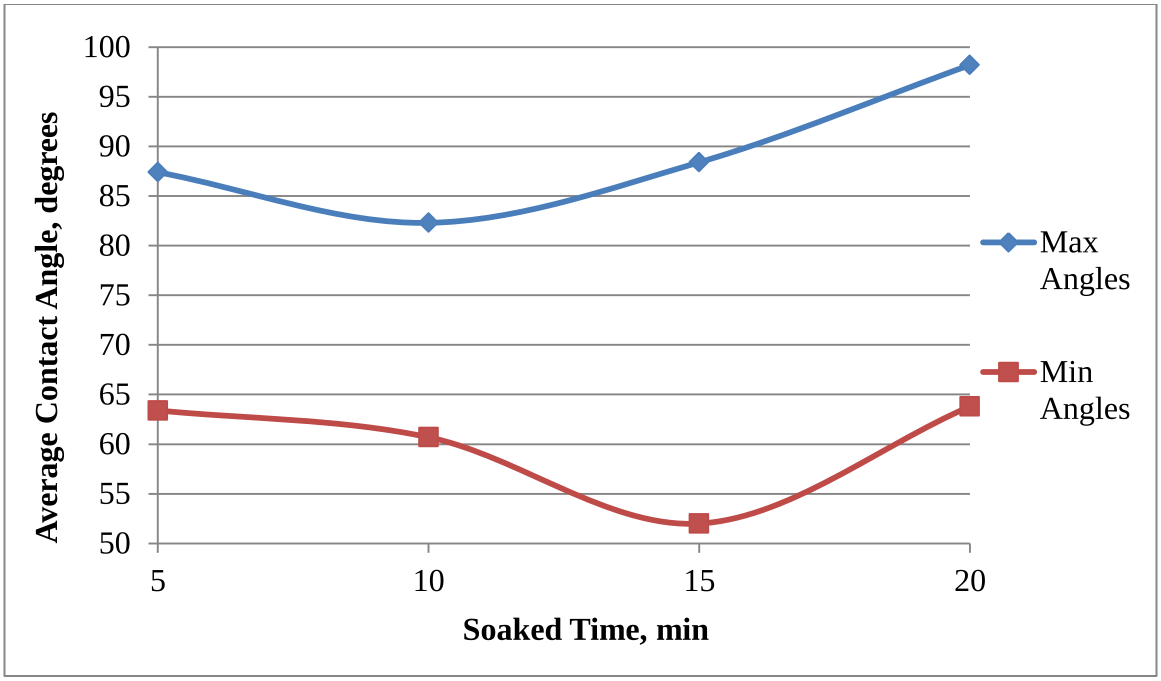

FIGURE 13 - Trend of Max and Min Contact Angles for PE in EcoSurf EH-3

Even though multiple layers are potentially being formed on the surface of the sample, the minimum contact angles recorded are decreasing with the 5-, 10-, and 15-minute soak times. The minimum angle for the 20-minute soak time increases with increased soak time. This suggests that between the start time and the 10-minute soak time, a hydrophilic layer is being formed on the surface of the sample. Then between the 10- and 15-minute soak times, a transition between the hydrophilic and hydrophobic layers. Next, a hydrophobic layer is being formed on the surface.

Even though the maximum angles recorded for the PP samples are higher than the maximum angles recorded for the PE in the EcoSurf solution, this is not of interest. The minimum angles are the ones that will determine hydrophilicity and therefore will be the angles of interest for this discussion.

The minimum angles of the PP samples are higher than the angles recorded for the PE samples. All minimum and maximum angles recorded for the PP soaked in EcoSurf solution are shown in the table below.

TABLE VI

POLYPROPYLENE IN ECOSURF EH-3

		Inside Pieces		Outside Pieces	
Soak Times	Trial #	Max Angle Recorded	Min Angle Recorded	Max Angle Recorded	Min Angle Recorded
5 MIN	1	96.1	77.1	65.1	42.4
	2	99.4	48.0	102.5	80.1
	3	79.5	53.6	99.8	77.3
	4	91.7	83.0	93.7	68.7
	5	97.6	85.3	99.2	75.1
10 MIN	1	92.6	66.1	61.2	44.8
	2	67.9	37.0	103.4	80.3
	3	97.6	85.7	95.1	74.9
	4	96.8	73.5	76.8	56.6
	5	91.0	80.7	82.8	64.3
15 MIN	1	101.7	84.7	81.7	62.3
	2	90.1	84.6	96.3	78.9
	3	93.5	85.1	96.1	71.9
	4	80.8	58.3	100.6	74.6
	5	94.3	77.2	105.2	89.1
20 MIN	1	99.4	86.4	104.9	81.6
	2	103.5	89.8	101.2	77.9
	3	93.4	83.4	92.3	70.0
	4	76.7	41.4	100.0	82.1
	5	70.2	58.8	79.9	59.4

The same process for the determination of the average minimum contact angles were used for the determination of the average minimum contact angles of the PP samples. The values are listed in the table below. The contact angles from the above table were graphed for comparison and discussion.

TABLE VII

AVERAGE CONTACT ANGLES FOR PP IN ECOSURF EH-3

	MAXIMUM		MINIMUM	
Soaked Times	Inside Pieces	Outside Piece	Inside Pieces	Outside Piece
5 MIN	96.2	98.8	73.4	75.3
10 MIN	94.5	84.9	76.5	65.3
15 MIN	92.6	97.7	82.3	75.1
20 MIN	89.8	98.2	70.4	76.7

According to the graph below, the decreasing trend of the maximum layers suggests that a single hydrophilic layer is being formed. However, the increasing then decreasing behavior of the minimum angles suggest otherwise. This trend proposes as the soaked time increases, the ability of the surfactant to wet the surface of the sample decreases. Between the 15- and 20-minute marks, this ability begins to increase.

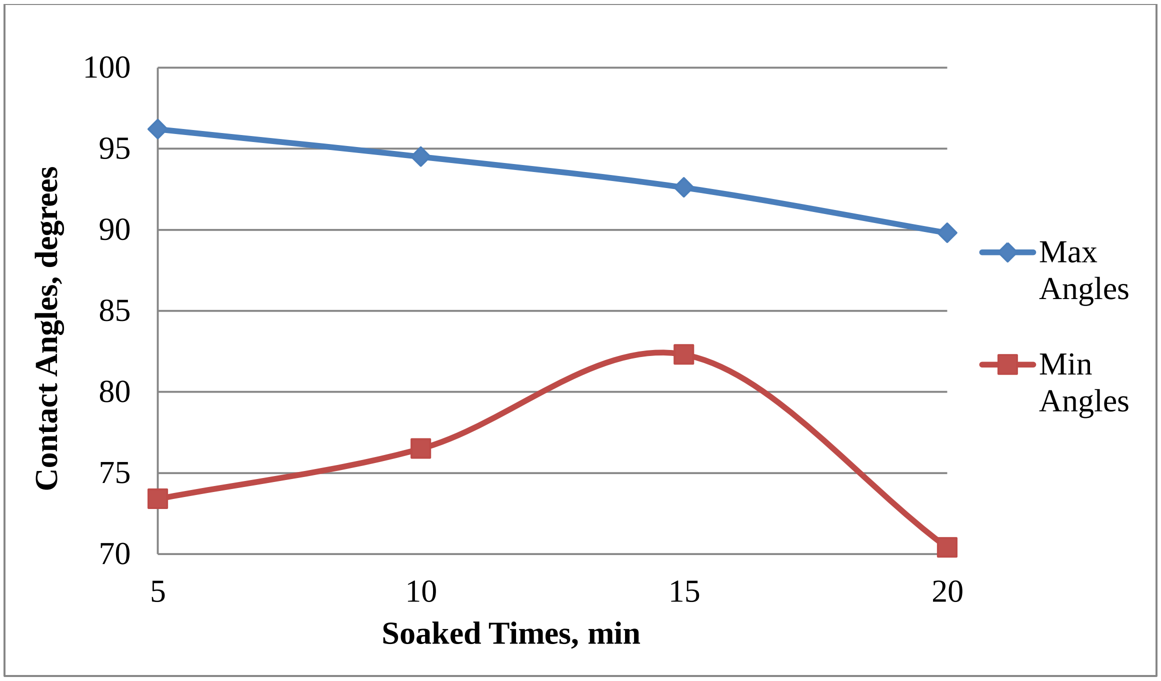

FIGURE 14 - Trend of Contact Angles for Inside Pieces of PP in EcoSurf EH-3

The graph below demonstrates a decreased, then increased, and finally a steady trend for both of the minimum and maximum contact angles. According to the graph, multiple layers are being formed of the surfactant on the surface of the sample. First, a partial hydrophilic layer is formed followed by a partial hydrophobic layer. The steady portion of the graph suggests that the hydrophilic and hydrophobic layers are nearly evenly distributed across the surface of the sample and causing neither an increase nor a decrease in the measured contact angle.

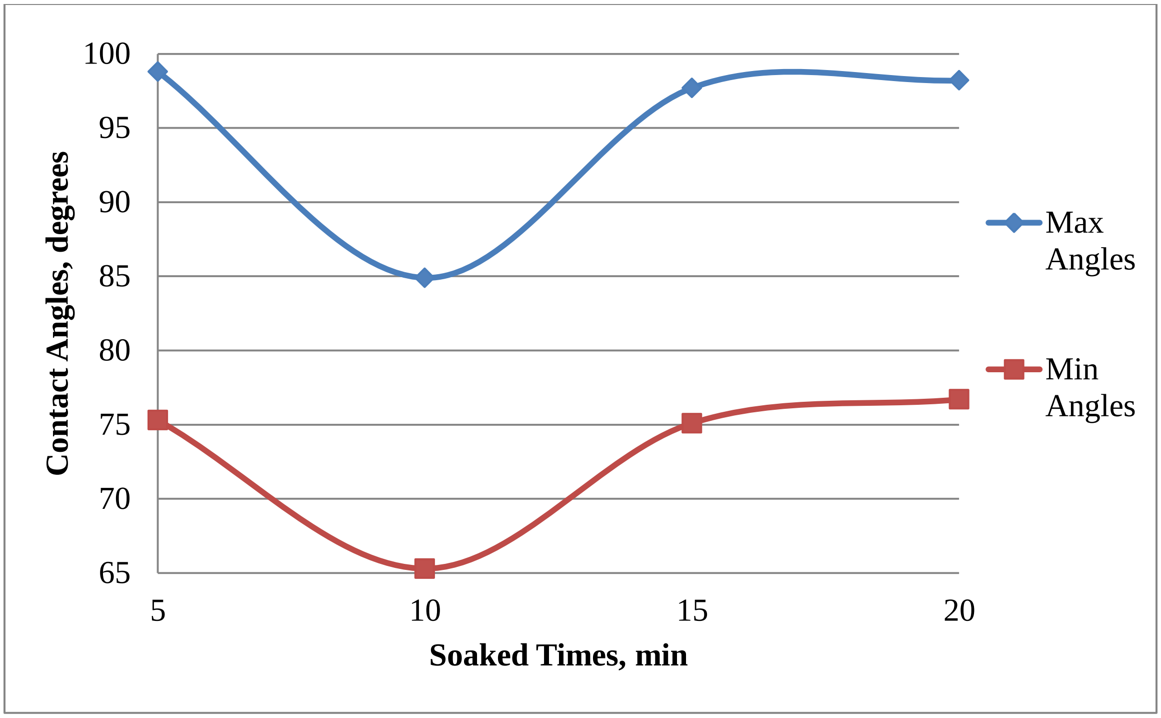

FIGURE 15 - Trend of Contact Angles for Outside Pieces of PP in EcoSurf EH-3

3. Bio-Soft GSB – 9, EcoSurf EH – 9, and Triton H-55

These three surfactants do not seem to show any more promise than the others that have been tested so far for the goals of this project. Each one appears to develop multiple layers over time. On top of this, no physical differences in the layering or droplets on the testing samples were noticed.

After analyzing the results, it was suggested that the equipment might need to be grounded. If static electricity is present on the surface of the packing then the surface charge will affect how the surfactant wets the packing. To minimize the effects of static electricity, a Static-Master refill unit was used. Wearing gloves, the refill was waved over each packing sample before being dropped into the solution. To test whether a surface charge was present a sample coverage test was conducted.

Coverage Test Results

After waving the refill over a piece of packing, it was soaked in a Triton X-100 solution for 20 minutes. When the sample was removed from the solution, a complete surfactant film was formed on the surface. The complete coverage of the sample suggested that static electricity was present on the packing samples. Therefore, all sample pieces were treated with the refill. Because of the formation of a complete film on the surface, the contact angle analyzer could not be used. When the drop of water was released, it immediately spread across the entire surface and the analyzer could not calculate the angle.

The coverage test was used again determine which surfactants were able to form a complete film on the surface of the packing. This was done by preparing a 70-ppm sample of each of the ecofriendly surfactants and dropping a packing sample into each of the solutions. The packing samples were removed after 20 minutes. After soaking the packing in the surfactant solution, the samples coverage were visually compared and ranked in order of best to worst. The results are listed in the table below.

TABLE VIII

RANK OF COVERAGE OF SURFACTANTS

Triton X-100
Bio-Soft GSB–9
Breakdown
DowFax 3B2
Tergitol NP30
EcoSurf EH–3
Triton H-55
EcoSurf EH-9

The wetting agents' ability to coat the packing experienced a definite drop between the first and second surfactants and the remaining ones. Triton X-100 was able to coat completely the packing sample, whereas Bio-Soft GBS-9 coated approximately 90%. Breakdown was only able to provide roughly 40% coverage at a concentration of 70-ppm. The remaining surfactants coated less than 30% of the sample.

Once an alternative ecofriendly surfactant was determined, the coverage test was repeated to estimate the concentration needed to achieve similar coverage to the Triton X-100. It was discovered that the concentration of Triton X-100 could be lowered to 60-ppm and still provide adequate packing coverage. It was best to use a 70-ppm concentration for Bio-Soft GSB-9 and a 90-ppm concentration of Breakdown to achieve comparable results to the Triton X-100. A concentration of 90-ppm to achieve coverage is not feasible in the meat rendering industry; therefore, the Breakdown was discarded from further intensive tests. Bio-Soft GSB-9 was used in the later test to determine if it could perform at the same level as Triton X-100. The other surfactants were not tested because to achieve adequate coverage, a prohibitively large concentration would be needed.

After the test was completed, a blind test was performed to determine if the amount of wetting of the top two surfactants were distinguishable. This test showed the amount of wetting between Triton X-100 and Bio-Soft GSB-90 was indistinguishable.

<u>Sonic Dismembrator and Particle Size Analyzer</u>

Recall that the addition of surfactant into the air scrubber system has two roles: to suspend fat in the system to prevent clogging and to coat the packing to enhance mass transfer. The system is comprised of a venturi connected to two packed towers. The venturi will remove most of the odor-causing compounds and particulates, but some will still make it to the packed towers (Meeker, 2006). To compensate for this, surfactant is added to suspend the fat in the air stream. To determine the amount of surfactant needed to suspend the fat, the maximum size fat particles leaving the venturi entering the packed towers needs to be calculated. The particles bigger than the calculated diameter will drop out of suspension due to gravity and the smaller ones will be covered to the packed tower.

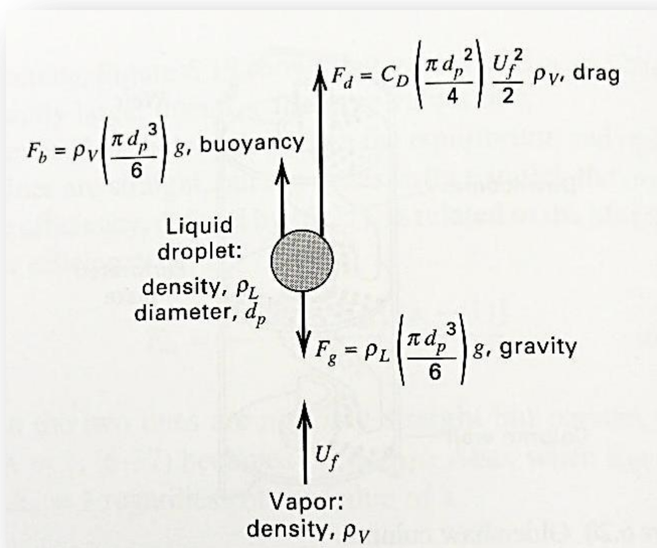

FIGURE 16 - Forces acting on a suspended liquid droplet

(Seader, 2006)

The forces imposed on the liquid particle are gravitational, drag, and buoyancy forces. This can be seen in Figure 16. The vector sum of these forces acting on the particle must be equal to zero for the particle of maximum size to be suspended in the system and thus be transferred through the process.

The gravitational forces act vertically downward on the liquid particle. Gravitational forces are present on all particles as long as gravity is present. Taken from J.D. Seader, the force of gravity can be calculated by:

$$F_g = \rho_L \left(\frac{\pi d_p^3}{6} \right) g \tag{1}$$

Where:

F_g = Force of gravity, N

ρ_L = density of the liquid, g/cm^3

d_p^3 = diameter of the liquid particle, cm

g = acceleration due to gravity, cm/sec^2

The drag forces act in the direction of the particle motion and are dependent on velocity. Drag forces result in a decrease fluid velocity and can be calculated using the following equation (Seader, 2006).

$$F_d = C_D \left(\frac{\pi d_p^2}{4}\right)\frac{U^2}{2}\rho_V \tag{2}$$

where:

F_d = force of drag, N

C_D = drag coefficient, dimensionless

d_p = diameter of particle, cm

U = velocity of particle, cm/sec

ρ_v = density of the vapor, g/cm^3

The third force acting on the liquid particle is a buoyant force. Buoyant forces are present due to displacement of the vapor by the particle. For particles less than 0.1 microns, buoyant forces are insignificant (Mueller Environmental Designs). Taken from Seader, buoyant forces are calculated by:

$$F_b = \rho_V \left(\frac{\pi d_p^3}{6}\right) g \tag{3}$$

where:

F_b = force of buoyance, N

ρ_v = density of the vapor, g/cm^3

d_p^3 = diameter of the particle, cm

g = acceleration due to gravity, cm/sec^2

By setting the vector sum of the forces to zero (Equations 4 and 5), the maximum particle diameter allowed by the system properties can be calculated. The maximum particle diameter calculated depends on the velocity of the particle and the density of the particle -- if the density is not similar to that of water.

$$\sum F = 0 = F_g - F_b - F_d \tag{4}$$

$$\rho_{Fat}\left(\frac{\pi d_p^3}{6}\right)g - \rho_{water}\left(\frac{\pi d_p^3}{6}\right)g - C_D\left(\frac{\pi d_p^2}{4}\right)\frac{U_f^2}{2}\rho_{water} = 0 \tag{5}$$

The particle diameter is calculated at the operating velocity instead of the flooding velocity because this allows for the maximum particle diameter that is able to remain suspended in the system to be determined. Those particles larger than this diameter fall out in the venturi and never make to the packed tower, whereas, particles of diameter smaller than the calculated one will remain in suspension and be carried through the process.

The fat particles are being transferred to the venturi by the air stream. However, for the force balance, the density of water was used in lieu of the density of air. This was because the fat is being suspended in the liquid stream and transported to the packed tower not the air stream.

The data needed to balance the force equation were manipulated from the tower designs given. These specifications are shown in Table IX. The equipment is operated between 110 ºF and 140 ºF. From this information, the velocity of the particle can be calculated. The duct size of the venturi is the same as the duct size in the packed tower.

TABLE IX

PACKED TOWER DESIGNS

(HydroSolutions)

Tower Design	**#1**	**units**
Volumetric Flow Rate	25,000	ft^3/min
Tower Diameter	8	ft
Tower Height	12	ft

After balancing the force equation, the lower (T = 110 ºF) and upper (T = 140 ºF) bounds for the particles of three common animal fats used in the rendering industry were determined and are listed in Table X. Full calculations can be seen in Appendix II.

TABLE X

LOWER AND UPPER PARTICLE DIAMETERS OF FAT

	Lower Bound	Upper Bound
Chicken Fat	500 nm	600 nm
Beef Fat	500 nm	600 nm
Pork Fat	500 nm	600 nm

A sample of sump water from a working rendering plant was used to verify the diameter calculations. Using approximately 5 mL of the sump water, the particle diameters were tested with the particle size analyzer. After five trials of the sample were completed, the diameters ranged from 467 to 624 nm. This is consistent with the force balance calculations performed to estimate the particle diameter.

These particle diameters are the maximum size of a particle that the rendering process operating at the design conditions can carry through the rendering process without the fat dropping out of suspension and obstructing the process. Any particle of diameter smaller than the calculated lower bound will be transferred through the rendering process with little effort by the process stream.

The lower and upper bounds for all of the fats are equal to one another because the densities of each are relatively similar to one another.

After the particle diameters are calculated, the concentration needed to suspend the fat particles was calculated by suspending them in different surfactant concentrations. After a period of time, the solutions were compared to one another to judge the amount of particle separation. The concentration with the acceptable amount of separation is the one that should be used in the rendering process.

Through trial and error, it was discovered that an amplitude setting of 40% and dismembrating for one hour allows the particles to be approximately 500 nm or less. In addition, the trial and error tests demonstrated that it takes more surfactant to coat the packing than it did to suspend fat. Because of this, the concentration needed to coat adequately the packing was used to verify if the surfactant/fat solution was stable.

The Triton X-100 surfactant/fat solution was stable for 24 hours using a 60 ppm solution containing 3% fat. The Bio-Soft GSB-9 surfactant/fat solution was stable for 24 hours by using a 70-ppm solution containing the same amount of fat. Figures comparing the amount of separation can be seen in Figure 17 and 18.

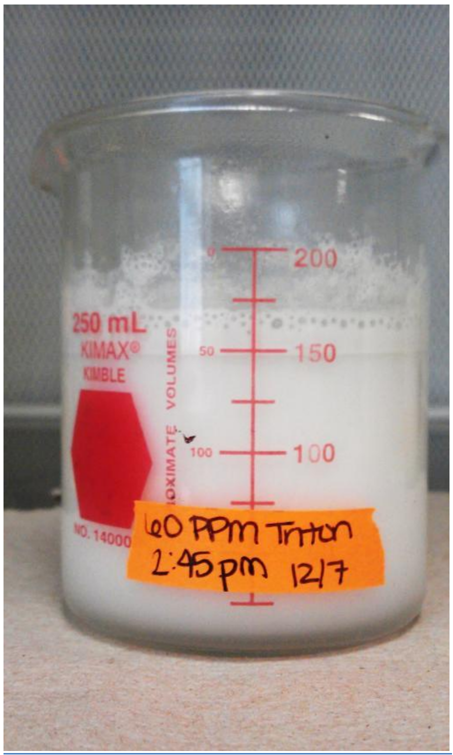

FIGURE 17 - Representation of the Amount of Acceptable Separation

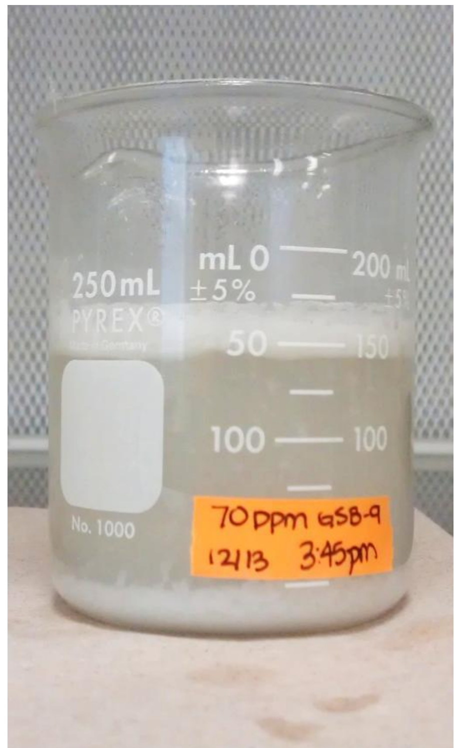

FIGURE 18 - Representation of the Amount of Unacceptable Separation

Three percent fat was used for the trials to allow for a visual inspection of re-clumping of particles. There is not 3% fat traveling through the normal rendering processes. It is assumed that less than one percent is present in the air stream of the rendering process. If 3% could be suspended in the system, then the actual amount in the stream will be able to be suspended.

V. CONCLUSION

HydroSolutions, a local company, specializes in serving rendering industries making a treatment that is added to the air scrubber that removes VOCs and odor-causing compounds from the airstream. The air scrubber system is comprised of a venturi connected to two packed towers in series. The company is interested in increasing the efficiency of the packed towers and reducing the amount of fat accumulation in the system by using an ecofriendly surfactant. This was achieved by finding a “green” surfactant that has the ability to replace the current one and the concentration needed to coat adequately the packing. To determine this, several tests were required.

A contact angle analyzer was used to determine the contact angle between the water droplet and the packing. A contact angle less than 90º was desired for wetting of the packing. It was found that the soak time for the PE packing is more important than it is for the PP and that better performance can be obtained with the PE since the ultimate contact angle is lower which leads to a greater degree of wetting.

A sonic dismembrator suspended the animal fat in the surfactant solution; and a particle size analyzer calculated the diameter of the fat in the solution. A force balance determined the size of the particles leaving the venturi. The balance determined particles between 500-600 nm were entering the packed towers. Particles bigger than this range would fall out of suspension, while smaller ones would be transferred through the system.

Once the surfactant/fat solution contained the proper size particles, the concentration needed to suspend the fat was determined. The results showed a higher concentration was needed to coat sufficiently the packing than to suspend 3% fat.

Based on the results of the tests, it is recommended that HydroSolutions could switch to 70 ppm Bio-Soft GSB-9 and obtains similar results to 70 ppm Triton X-100. This concentration is able to coat packing as well as 60 ppm Triton X-100 and suspend 3% animal fat.

VI. RECOMMENDATIONS

During the research, it was concluded that it takes more surfactant to laminate the packing than to solubilize the fat. Therefore, the company may wish to add a large amount of solution at the beginning of the process and decrease to a lower amount later. However, the lower amount of solution and the time lapse before the decrease in solution would need to be determined before the company could initiate this action.

Bio-Soft GSB-9 showed to be an alternative to Triton X-100; however, the Breakdown looked to be very promising at higher concentration (about 90 ppm). Because this thesis was based on a technical standpoint and not a financial one, it is recommended to explore Breakdown more closely to determine if the higher concentration is economically feasible for the company. In addition, it should be investigated to determine if Bio-Soft GSB-9 or Breakdown would be able to meet the demand of the company.

To verify particle diameters coming off the venturi, samples should be tested from the exit stream. A particle size analyzer can measure the diameter.

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APPENDIX I.

Table of Surfactants

Surfactant	Physical and Chemical Properties					Ecological Information	
	State	Color	pH (1% in H2O)	Ionicity (in Water)	Solubility	Ecotoxicity	Products of Biodegradation
Triton X-100	Liquid	Colorless to light yellow	n/a	Non-ionic	Soluble in cold water, hot water. Insoluble in mineral spirits and kerosene	n/a	Possibly hazardous short-term degradation products not likely. Long term degradation products may arise.
Bio-Soft GSB-9	Liquid	Colorless to Yellow	5.8 - 7.2	Non-ionic blend	n/a	EC50 Water Flea: 8.5-8.5 mg/l 48 hrs LC50 Fathead minnow: 6-12 mg/l 96 hrs	Components are readily biodegradeable
Breakdown	Liquid	Brown	6.0	n/a	completely soluble in water	n/a	n/a
DowFax 3B2	Liquid	Yellow	8 - 10.5	Anionic	completely miscible with water	LC50 Rainbow trout: 5.02 mg/l 96 hrs LC50 Water Flea: 1.50 mg/l 48 hrs	mineral is inherently biogradeable (reaches > 20% biogradation in OCED tests)
Tergitol NP-30	Liquid	Yellow	8.2	Non-ionic	Completely soluble but some compositions may form gels	LC50 Fathead minnow: > 60 mg/l 96 hrs LC50 water flea: > 1000 mg/l 48 hrs IC50 Bacteria: 1000-2400 mg/l 16 h	cannot be considered as readily biodegradable
EcoSurf EH-3	Liquid	Colorless to Yellow	5.0 - 7.5	Non-ionic	water dispersible	EC50 Water Flea: 72.1 mg/l 48 hrs ErC50 Green Alga: 31.9-97.7 mg/l 72 hrs	Material is readily biodegradable
Triton H-55	Liquid	Brown	n/a	Anionic	water soluble at 20C	EC50 Water Flea: 500-1000 mg/l 48 hrs IC50 Bacteria: 4700 mg/l 16 hrs	Material is readily biodegradable
EcoSurf EH-9	Liquid	Colorless to Yellow	5.0 - 7.5	Non-ionic	completely soluble in water	EC50 Water Flea: 72.1 mg/l 48 hrs ErC50 Green Alga: 31.9-97.7 mg/l 72 hrs	Material is readily biodegradable

APPENDIX II.

Raw Contact Angle Data

Time Soaked in Solution 5 minutes Time in sec Angle in degrees

TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4		TRIAL 5	
Inside Piece		Inside Piece		Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	115.5	0	71.5	0	115.9	0	99.8	0	86.2
30	113.8	30	69.6	30	112.7	30	96.7	30	74
60	104.1	60	66.5	60	108.9	60	93.3	60	68.9
		90	62.3	90	106.4	90	91	90	65.3
		120	59.1	120	103.8	120	86.4	120	62.2
		150	56.3	150	100.6	150	82.3	150	58.5
		180	53.4	180	96.1	180	77.9	180	54.2

FIGURE 19 - PE Packing Soaked in Triton X-100 for 5 Minutes

Time Soaked in Solution 10 minutes

TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4		TRIAL 5	
Inside Piece		Inside Piece		Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	102	0	59.4	0	62.9	0	100.0	0	119.8
30	94	30	56.9	30	58.9	30	97.3	30	116.1
60	90.5	60	52.9	60	56.1	60	91.9	60	112.4
		90		90	53.1	90	90.8	90	110.0
		120	41.9	120	50.5	120	83.3	120	109.6
		150	35.7	150	46.2	150	80	150	103.6
		180	30.4	180	43.7	180	76.5	180	102.7

FIGURE 20 - PE Packing Soaked in Triton X-100 for 10 Minutes

Time Soaked in Solution 15 minutes

TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4		TRIAL 5	
Inside Piece		Inside Piece		Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	98.7	0	73.3	0	82.9	0	69.1	0	89.8
30	92.4	30	69.9	30	80.7	30	65.3	30	
60	89.4	60	67.5	60	77.4	60	62.7	60	84.5
		90	64	90	74.1	90	59.2	90	77.8
		120	60.8	120	71.3	120	53.8	120	72.4
		150	57.3	150	66.7	150	51.3	150	68.1
		180	53	180	63	180	46.4	180	63.2

FIGURE 21 - PE Packing Soaked in Triton X-100 for 15 Minutes

Time Soaked in Solution 20 minutes

TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4		TRIAL 5	
Inside Piece		Inside Piece		Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0		0	78.7	0	64.9	0	44.9	0	109.3
30		30	76.2	30	61.9	30	41.7	30	93.4
60		60	72.5	60	58.6	60	39.4	60	91.8
		90	68.3	90	55.4	90	35.1	90	89.7
		120	63.9	120	50.3	120	34.3	120	82.4
		150	59.7	150	47.6	150	28.5	150	79.9
		180	55.6	180	41.8	180		180	71.5

FIGURE 22 - PE Packing Soaked in Triton X-100 for 20 Minutes

Time Soaked in Solution 5 minutes Time in sec Angle in degrees

TRIAL 1				TRIAL 2				TRIAL 3				TRIAL 4				TRIAL 5			
Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	104.1	0	71.8	0	73.9	0	71.6	0	67.7	0	90.1	0	54.6	0	86.1	0	70.8	0	81.3
30	102.7	30	69.6	30	72.3	30	68.8	30	65.7	30	88.4	30	50.9	30	82.9	30	69.0	30	75.0
60	100.3	60	66.7	60	69.8	60	66.4	60	63.0	60	85.2	60	50.4	60	79.8	60	68.1	60	70.5
90	98.5	90	64.7	90	68.8	90	63.6	90	62.8	90	83.7	90	48.1	90	78.0	90	67.2	90	69.0
120	95.1	120	62.8	120	60.6	120	61.1	120	60.6	120	82.1	120	46.4	120	73.8	120	65.1	120	63.3
150	92.4	150	60.0	150		150	58.8	150	59.3	150	79.3	150	45.8	150	72.5	150	64.2	150	62.9
180	89.6	180	57.6	180		180	56.2	180	58.4	180	76.7	180	43.7	180	67.8	180	63.3	180	61.6

FIGURE 23 - PP Packing Soaked in Triton X-100 for 5 Minutes

Time Soaked in Solution 10 minutes

TRIAL 1				TRIAL 2				TRIAL 3				TRIAL 4				TRIAL 5			
Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	105.4	0	96.4	0	85.2	0	112.1	0	82.6	0	80.2	0	93.5	0	72.3	0	66.6	0	78
30	102.5	30	95.5	30	80.7	30	106.8	30		30	74.5	30	92.8	30	70.0	30	65.2	30	74.9
60	100.5	60	94.3	60	75.5	60	105.8	60	71.5	60	72.2	60	92.3	60	68.1	60	63.7	60	72.6
90	99.6	90	91.7	90	73.9	90		90	70.0	90	64.3	90	92.1	90	66.1	90	62.4	90	70.8
120	98.7	120	84.2	120	70.9	120	89.5	120	63.5	120	63.0	120	88.5	120	64.1	120	61.3	120	66.7
150	97.4	150	82.9	150	68.9	150	85.0	150	62.1	150	62.8	150	87.4	150	61.8	150	59.9	150	64
180	94.9	180	79.3	180	66.8	180	81.6	180		180		180	83.3	180	60.4	180	58.8	180	61.4

FIGURE 24 - PP Packing Soaked in Triton X-100 for 10 Minutes

Time Soaked in Solution 15 minutes

TRIAL 1				TRIAL 2				TRIAL 3				TRIAL 4				TRIAL 5			
Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	96.5	0		0	62.9	0	91.5	0	63.2	0	72.6	0	52.8	0	87.8	0	77.9	0	78.9
30	94.3	30	81.4	30	60.4	30	88.3	30	61.6	30	70.5	30	51.2	30	84.2	30	74.9	30	77.9
60	92.9	60	74.6	60	58.5	60	86.9	60	60.4	60	68.5	60	50.5	60	81.8	60	73.3	60	74.5
90	91.8	90	70.8	90	56.2	90	83.7	90	58.9	90	64.0	90	49.1	90	79.1	90	72.2	90	73.0
120	89.6	120	66.5	120	51.3	120	81.0	120	55.8	120	63.1	120	48.7	120	75.6	120	70.5	120	71.3
150	86.6	150		150	50.4	150	78.0	150	55.8	150	54.5	150	46.4	150	72.6	150	68.8	150	70.7
180	83.8	180	65.4	180	46.8	180	76.1	180	54.5	180	52.4	180	43.8	180	68.3	180	67.8	180	68.8

FIGURE 25 - PP Packing Soaked in Triton X-100 for 15 Minutes

Time Soaked in Solution 20 minutes

TRIAL 1				TRIAL 2				TRIAL 3				TRIAL 4				TRIAL 5			
Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	98.0	0	72.8	0	117.9	0	70.0	0	68.7	0	68.0	0	77.9	0	72.7	0	66.1	0	88.2
30	97.2	30	69.5	30	116.9	30	67.3	30	64.8	30	65.0	30	74.1	30	69.5	30	64.1	30	84.2
60	95.4	60	68.1	60	111.6	60	65.8	60	62.4	60	62.4	60	72.9	60	67.2	60	63.5	60	82.6
90	92.9	90		90	108.8	90	62.6	90	62.1	90	59.6	90	71.3	90	65.6	90	62.0	90	80.6
120	90.2	120		120	104.2	120	59.7	120	59.5	120	56.9	120	69.0	120	64.8	120	60.1	120	79.3
150	87.7	150		150	100.4	150	56.6	150	58.4	150	54.7	150	67.4	150	62.1	150	59.2	150	77.1
180	85.9	180		180	97.5	180	53.5	180	55.7	180	52.7	180	66.0	180	59.4	180	58.4	180	76.8

FIGURE 26 - PP Packing Soaked in Triton X-100 for 20 Minutes

Time Soaked in Solution 5 minutes Time in sec Angle in degrees

TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4		TRIAL 5	
Inside Piece		Inside Piece		Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	91.9	0	63.7	0	83.4	0	99.2	0	86.9
30	88.4	30	59.8	30	80.0	30	98.0	30	84.7
60	85.6	60	56.0	60	76.1	60	94.6	60	81.4
90	81.4	90	46.6	90	72.5	90	93.5	90	77.9
120	76.5	120	40.9	120	68.3	120	90.2	120	73.8
150	71.7	150	33.6	150	64.1	150	86.8	150	69.5
180	66.1	180	26.9	180	59.1	180	83.6	180	65.0

FIGURE 27 - PE Packing Soaked in EcoSurf EH-3 for 5 Minutes

Time Soaked in Solution 10 minutes

TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4		TRIAL 5	
Inside Piece		Inside Piece		Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	69.3	0	78.2	0	89.6	0	94.4	0	88.1
30	66.6	30	72.7	30	85.6	30	91.2	30	84.2
60	64.1	60	70.5	60	82.2	60	85.8	60	81.5
90	60.9	90	65.4	90	78.8	90	83.6	90	77.9
120	57.2	120	61.8	120	75.4	120	81.1	120	74.5
150	53.7	150	56.1	150	70.9	150	74.8	150	70.6
180	49.3	180	50.6	180	66.6	180	70.9	180	66.1

FIGURE 28 - PE Packing Soaked in EcoSurf EH-3 for 10 Minutes

Time Soaked in Solution 15 minutes

TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4		TRIAL 5	
Inside Piece		Inside Piece		Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	98.8	0	82.9	0	83.0	0		0	88.4
30	96.4	30	71.2	30	75	30	97.4	30	81.1
60	93.5	60	64.0	60	71.7	60	95.4	60	77.2
90	89.4	90		90	67.5	90	93.4	90	74.8
120	85.9	120		120	62.7	120	88.2	120	70.0
150	80.8	150	62.7	150	58.1	150	82.4	150	66.0
180	75.3	180	57.3	180	52.9	180	78.4	180	52.0

FIGURE 29 - PE Packing Soaked in EcoSurf EH-3 for 15 Minutes

Time Soaked in Solution 20 minutes

TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4		TRIAL 5	
Inside Piece		Inside Piece		Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	85.5	0	94.7	0	95.3	0	90.3	0	92.5
30	83.0	30	88.2	30	92.7	30	87.7	30	90.9
60	80.7	60	84.2	60	90.0	60	85.1	60	86.3
90	77.7	90	78.8	90	87.0	90	82.5	90	82.7
120	74.3	120	70.7	120	83.9	120	78.6	120	77.7
150	65.7	150	64.3	150	80.2	150	74.7	150	72.8
180	35.0	180	55.2	180	76.3	180	69.9	180	66.2

FIGURE 30 - PE Packing Soaked in EcoSurf EH-3 for 20 Minutes

Time Soaked in Solution 5 minutes Time in sec Angle in degrees

TRIAL 1				TRIAL 2				TRIAL 3				TRIAL 4				TRIAL 5			
Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	96.1	0	65.1	0	99.4	0	102.5	0	79.5	0	99.8	0	91.7	0	93.7	0	97.6	0	99.2
30	92.6	30	61.4	30	97.7	30	99.5	30	77.7	30	97.9	30	91.1	30	90.4	30	94.7	30	96.7
60	89.8	60	57.2	60	93.7	60	96.5	60	70.7	60	94.0	60	89.5	60	83.3	60	91.7	60	93.4
90	87.1	90	52.8	90	88.2	90	93.4	90	64.8	90	90.7	90	88.1	90	80.1	90	89.1	90	89.3
120	83.5	120	48.9	120	76.7	120	89.4	120	60.8	120	86.7	120	85.9	120	77.1	120	88.5	120	85.4
150	79.4	150	45.3	150	56.1	150	85.3	150	56.3	150	82.2	150	85.0	150	72.8	150	87.1	150	80.5
180	77.1	180	42.4	180	48.0	180	80.1	180	53.6	180	77.3	180	83	180	68.7	180	85.3	180	75.1

FIGURE 31 - PP Packing Soaked in EcoSurf EH-3 for 5 Minutes

Time Soaked in Solution 10 minutes

TRIAL 1				TRIAL 2				TRIAL 3				TRIAL 4				TRIAL 5			
Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	92.6	0	61.2	0	67.9	0	103.4	0	97.6	0	95.1	0	96.8	0	76.8	0	91.0	0	82.8
30	88.7	30	58.1	30	66.6	30	101.2	30	95.6	30	92.6	30	93.1	30	73.7	30	88.5	30	80.6
60	84.7	60	54.9	60	64.5	60	97.6	60	93.4	60	89.5	60	90.4	60	70.5	60	86.5	60	77.5
90	79.9	90	51.7	90	60.2	90	94.3	90	90.8	90	87.0	90	86.8	90	66.9	90	84.9	90	74.8
120	74.6	120	48.6	120	52.4	120	89.7	120	89.9	120	83.2	120	83.1	120	63.2	120	83.1	120	71.2
150	68.9	150	46.0	150	51.0	150	85.2	150	88.0	150	79.2	150	78.5	150	59.5	150	81.9	150	67.3
180	66.1	180	44.8	180	37.0	180	80.3	180	85.7	180	74.9	180	73.5	180	56.6	180	80.7	180	64.3

FIGURE 32 - PP Packing Soaked in EcoSurf EH-3 for 10 Minutes

Time Soaked in Solution 15 minutes

TRIAL 1				TRIAL 2				TRIAL 3				TRIAL 4				TRIAL 5			
Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	101.7	0	81.7	0	90.1	0	96.3	0	93.5	0	96.1	0	80.8	0	100.6	0	94.3	0	105.2
30	98.5	30	79.6	30	87.2	30	93.6	30	91.0	30	93.2	30	78.7	30	98.0	30	91.4	30	103.0
60	94.3	60	76.3	60	86.5	60	90.9	60	89.2	60	90.0	60	75.3	60	92.5	60	86.8	60	100.4
90	92.6	90	73.4	90	86.2	90	87.6	90	88.8	90	86.2	90	71.9	90	88.3	90	85.1	90	97.7
120	89.4	120	69.8	120	86.0	120	84.7	120	88.2	120	82.4	120	67.8	120	84.6	120	84.2	120	95.2
150	87.3	150	65.9	150	85.6	150	81.6	150	86.0	150	77.5	150	63.1	150	80.0	150	80.9	150	91.8
180	84.7	180	62.3	180	84.6	180	78.9	180	85.1	180	71.9	180	58.3	180	74.6	180	77.2	180	89.1

FIGURE 33 - PP Packing Soaked in EcoSurf EH-3 for 15 Minutes

Time Soaked in Solution 20 minutes

TRIAL 1				TRIAL 2				TRIAL 3				TRIAL 4				TRIAL 5			
Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece		Inside Piece		Outside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	99.4	0	104.9	0	103.5	0	101.2	0	93.4	0	92.3	0	76.7	0	100.0	0	70.2	0	79.9
30	96.8	30	101.8	30	100.8	30	98.0	30	89.9	30	89.8	30	70.1	30	98.0	30	66.8	30	77.7
60	94.4	60	99.2	60	99.1	60	94.7	60	88.0	60	86.7	60	65.4	60	95.7	60	64.6	60	74.4
90	92.1	90	95.8	90	96.8	90	91.6	90	87.4	90	83.1	90	60.7	90	92.6	90	63.6	90	71.0
120	90.3	120	92.5	120	92.7	120	87.1	120	85.3	120	79.0	120	55.7	120	89.6	120	62.1	120	66.9
150	88.9	150	87.7	150	91.5	150	82.8	150	83.9	150	74.4	150	49.7	150	86.5	150	59.5	150	62.9
180	86.4	180	81.6	180	89.8	180	77.9	180	83.4	180	70.0	180	41.4	180	82.1	180	58.8	180	59.4

FIGURE 34 - PP Packing Soaked in EcoSurf EH-3 for 20 Minutes

Time Soaked in Solution	5 minutes	Time in sec	Angle in degrees

TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4		TRIAL 5	
Inside Piece		Inside Piece		Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	92.9	0	96.1	0	92.1	0	94.3	0	89.5
30	92.0	30	95.2	30	90.8	30	92.7	30	88.1
60	90.6	60	94.2	60	89.4	60	91.2	60	86.1
90	89.4	90	92.8	90	87.9	90	89.4	90	83.8
120	87.2	120	91.6	120		120	87.3	120	81.2
150	85.9	150	89.8	150	79.6	150	86.0	150	79.8
180	84.2	180	88.2	180	77.1	180	84.0	180	78.6

FIGURE 35 - PP Packing Soaked in Bio-Soft GSB-9 for 5 Minutes

Time Soaked in Solution	10 minutes

TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4		TRIAL 5	
Inside Piece		Inside Piece		Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	92.8	0	97.9	0	84.9	0	96.5	0	92.5
30	91.9	30	95.8	30	84.3	30	95.8	30	91.0
60	89.3	60	94.0	60	83.9	60	94.5	60	89.2
90	88.5	90	91.7	90	81.3	90	92.8	90	80.6
120	83.2	120	88.8	120	79.0	120	91.5	120	78.9
150	80.5	150	86.7	150	78.5	150	90.4	150	76.4
180	80.1	180	83.6	180	73.6	180	88.4	180	74.4

FIGURE 36 - PP Packing Soaked in Bio-Soft GSB-9 for 10 Minutes

Time Soaked in Solution 15 minutes

TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4		TRIAL 5	
Inside Piece		Inside Piece		Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	86.5	0	100.6	0	84.2	0	92.6	0	87.0
30	83.6	30	98.6	30	81.7	30	91.3	30	85.2
60	81.0	60	96.1	60	80.5	60	90.2	60	83.5
90	79.2	90	94.0	90	78.7	90	80.6	90	82.5
120	76.5	120	91.0	120	75.9	120	87.4	120	81.1
150	73.8	150	88.2	150	74.4	150	85.8	150	80.7
180	71.2	180	85.0	180	72.4	180	84.2	180	87.0

FIGURE 37 - PP Packing Soaked in Bio-Soft GSB-9 for 15 Minutes

Time Soaked in Solution 20 minutes

TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4		TRIAL 5	
Inside Piece		Inside Piece		Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	90.4	0	79.8	0	88.7	0	81.7	0	84.6
30	89.1	30	78.9	30	87.2	30	80.5	30	83.4
60	87.7	60	77.8	60	85.2	60	79.1	60	82.1
90	86.2	90	74.9	90	84.2	90	77.2	90	81.6
120	84.6	120	72.3	120	82.4	120	75.0	120	78.3
150	84.1	150	70.9	150	80.4	150	73.0	150	
180	82.7	180	64.3	180	78.6	180	70.7	180	73.4

FIGURE 38 - PP Packing Soaked in Bio-Soft GSB-9 for 20 Minutes

Time Soaked in Solution 5 minutes

TRIAL 1		TRIAL 2		TRIAL 3	
Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle
0	97.0	0	99.0	0	95.6
30	95.6	30	98.4	30	93.6
60	94.0	60	97.0	60	93.3
90	92.1	90	96.1	90	92.2
120	90.4	120	94.9	120	91.1
150	88.3	150	93.2	150	89.7
180	86.5	180	92.0	180	88.3

FIGURE 39 - PP Packing Soaked in EcoSurf EH-9 for 5 Minutes

Time Soaked in Solution 10 minutes

TRIAL 1		TRIAL 2		TRIAL 3	
Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle
0	99.2	0	94.4	0	97.7
30	96.7	30	92.5	30	
60	96.2	60	91.1	60	96.1
90	95.1	90	89.2	90	95.2
120	94.8	120	87.3	120	92.4
150	93.3	150	84.7	150	91.3
180	92.0	180	82.5	180	90.3

FIGURE 40 - PP Packing Soaked in EcoSurf EH-9 for 10 Minutes

Time Soaked in Solution 15 minutes

TRIAL 1		TRIAL 2		TRIAL 3	
Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle
0	96.4	0	99.1	0	98.5
30	95.0	30	97.2	30	97.0
60	93.6	60	96.0	60	95.5
90	91.9	90	92.6	90	93.5
120	90.2	120	91.8	120	91.3
150	88.7	150	89.1	150	88.9
180	86.7	180	84.8	180	86.8

FIGURE 41 - PP Packing Soaked in EcoSurf EH-9 for 15 Minutes

Time Soaked in Solution 20 minutes

TRIAL 1		TRIAL 2		TRIAL 3	
Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle
0	94.0	0	95.0	0	93.6
30	92.2	30	93.0	30	91.8
60	90.7	60	90.9	60	90.5
90	88.8	90	88.2	90	88.0
120	86.5	120	84.1	120	86.0
150	84.8	150	81.4	150	83.1
180	83.0	180	79.4	180	81.9

FIGURE 42 - PP Packing Soaked in EcoSurf EH-9 for 20 Minutes

Time Soaked in Solution 5 minutes

TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4	
Inside Piece		Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	96.5	0	93.5	0	94.2	0	94.8
30	93.3	30	90.7	30	91.6	30	91.9
60	89.9	60	87.8	60	88.4	60	88.4
90	86.7	90	84.8	90	85.4	90	85.3
120	83.9	120	81.3	120	81.8	120	82.0
150	83.2	150	77.3	150	79.1	150	80.6
180	82.4	180	72.9	180	78.5	180	79.5

FIGURE 43 - PP Packing Soaked in Triton H-55 for 5 Minutes

Time Soaked in Solution 10 minutes

TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4	
Inside Piece		Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	104.6	0	97.1	0	102.6	0	97.6
30	100.6	30	94.6	30	100.6	30	95.0
60	98.1	60	91.9	60	98.2	60	92.1
90	97.2	90	88.3	90	95.5	90	89.1
120	92.1	120	84.9	120	93.1	120	87.1
150	90.3	150	81.3	150	89.9	150	86.0
180	86.5	180	77.0	180	86.7	180	85.1

FIGURE 44 - PP Packing Soaked in EcoSurf EH-9 for 10 Minutes

Time Soaked in Solution 15 minutes

TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4	
Inside Piece		Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	95.2	0	96.7	0	98.5	0	111.1
30	93.0	30	94.0	30	95.9	30	107.0
60	89.9	60	91.0	60	93.6	60	105.7
90	86.8	90	88.1	90	90.8	90	103.2
120	84.5	120	85.5	120	87.8	120	99.4
150	83.7	150	83.0	150	84.3	150	96.9
180	82.2	180	84.4	180	81.1	180	95.1

FIGURE 45 - PP Packing Soaked in EcoSurf EH-9 for 15 Minutes

Time Soaked in Solution 20 minutes

TRIAL 1		TRIAL 2		TRIAL 3		TRIAL 4	
Inside Piece		Inside Piece		Inside Piece		Inside Piece	
Time	Angle	Time	Angle	Time	Angle	Time	Angle
0	95.5	0	102.6	0	98.3	0	95.9
30	93.1	30	98.6	30	95.5	30	93.4
60	90.2	60	95.8	60	93.0	60	91.1
90	87.3	90	93.1	90	90.0	90	88.5
120	83.7	120	89.9	120	86.2	120	85.7
150	81.0	150	86.4	150	83.7	150	82.1
180	78.9	180	82.8	180	81.5	180	79.2

FIGURE 46- PP Packing Soaked in EcoSurf EH-9 for 20 Minutes

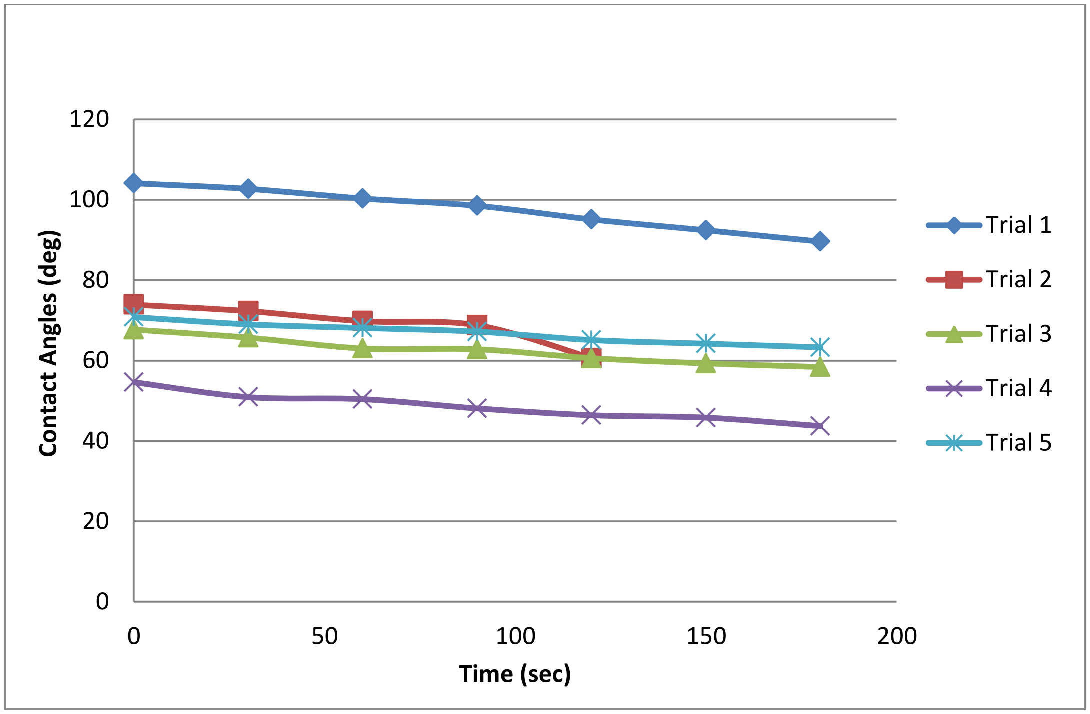


FIGURE 47- PP Trend of Inside Samples Soaked in Triton X-100 for 5 min

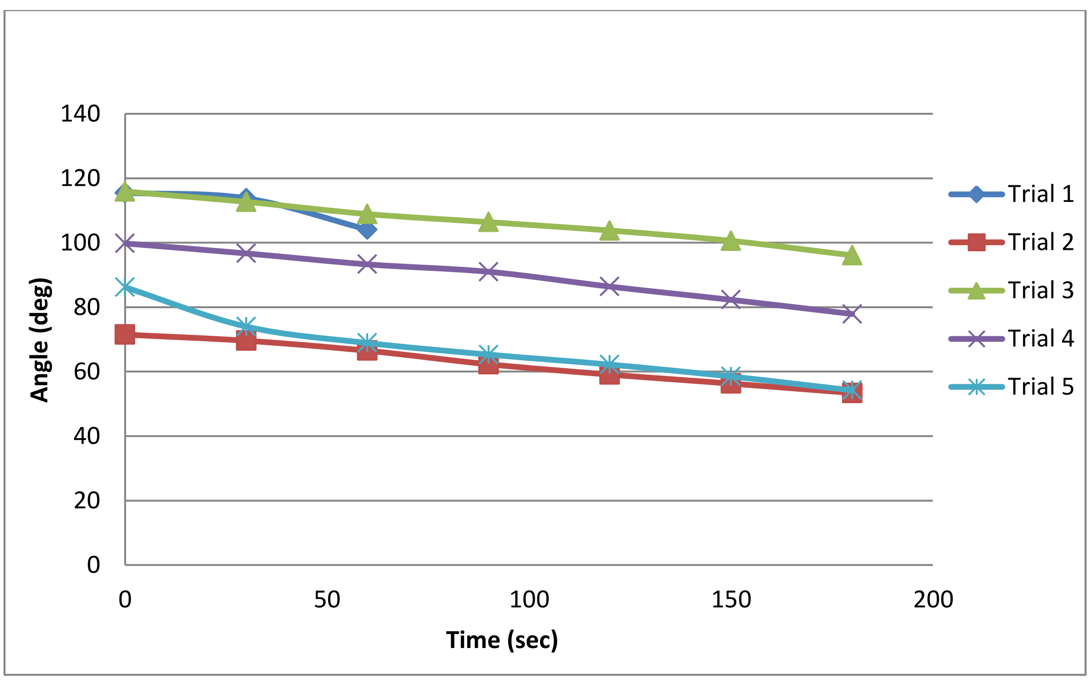


FIGURE 48 - PE Trend of Inside Samples Soaked in Triton X-100 for 5 Min

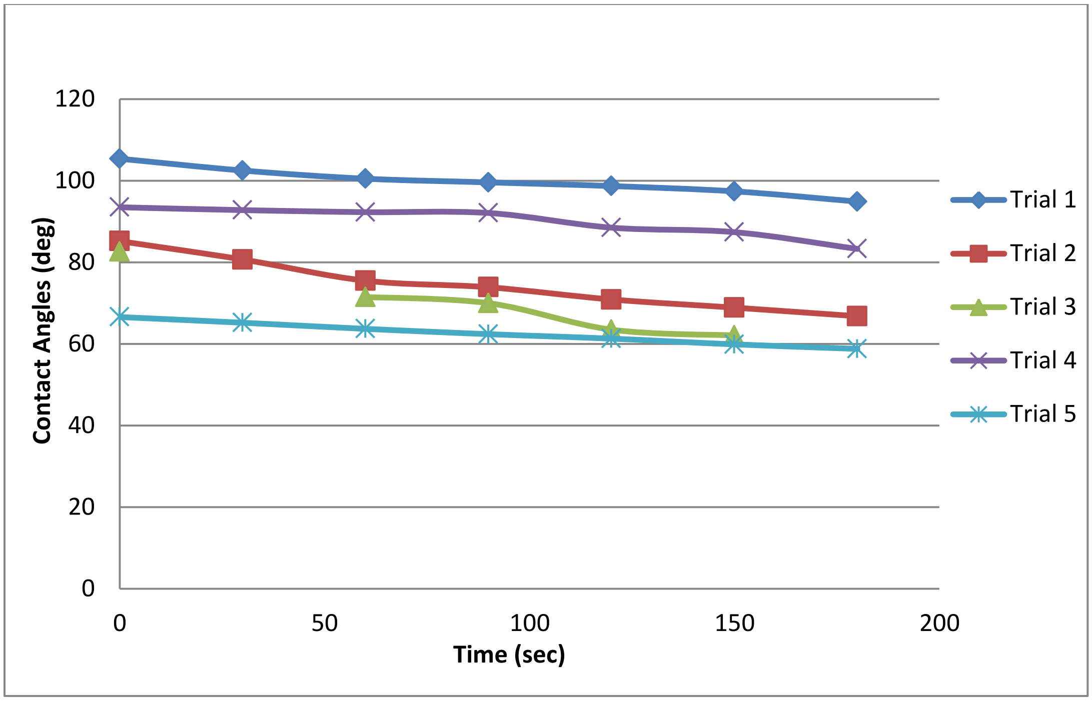


FIGURE 49 - PP Trend of Inside Samples Soaked in Triton X-100 for 10 Min

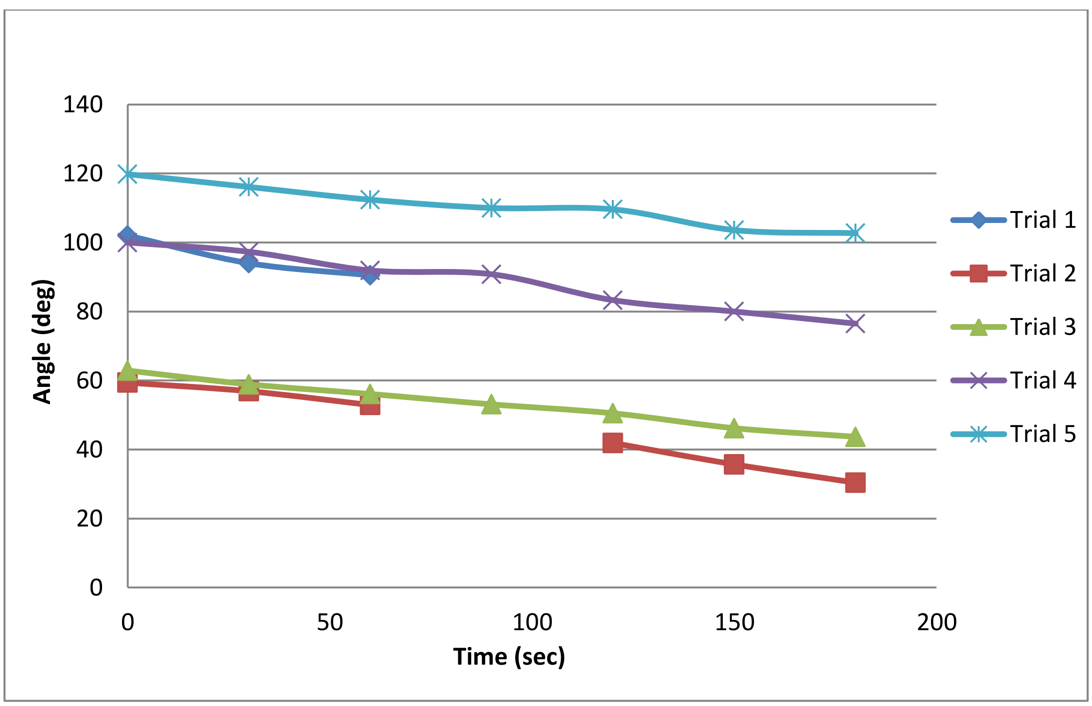


FIGURE 50 - PE Trend of Inside Samples Soaked in Triton X-100 for 10 Min

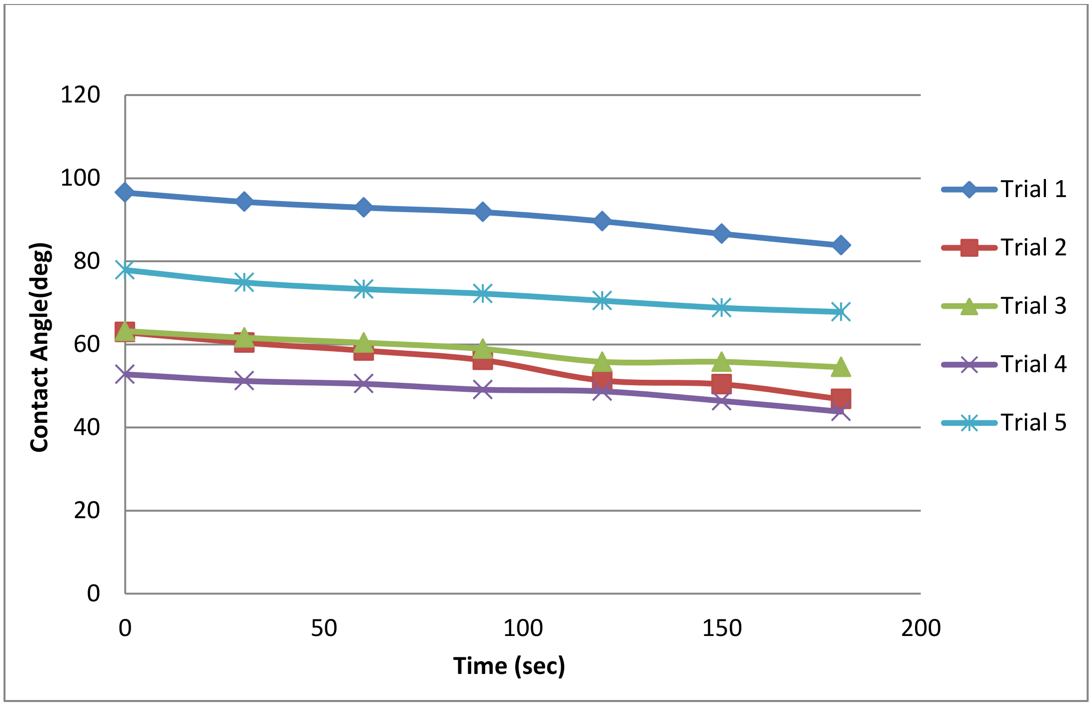


FIGURE 51 - PP Trend of Inside Samples Soaked in Triton X-100 for 15 Min

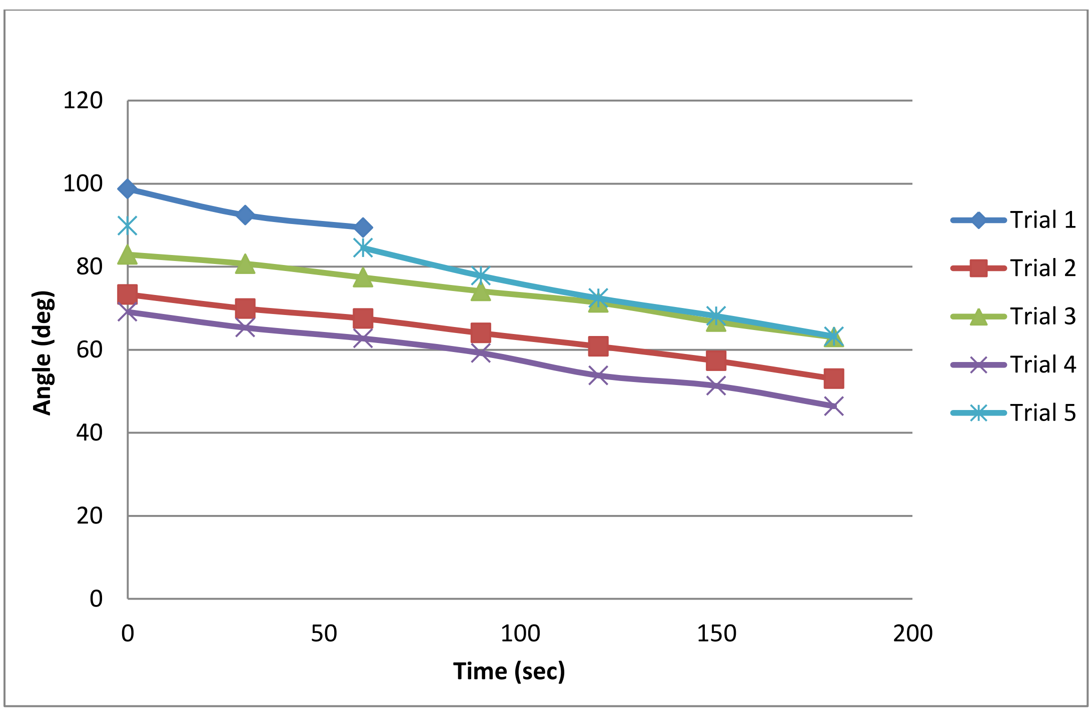


FIGURE 52 - PE Trend of Inside Samples Soaked in Triton X-100 for 15 Min

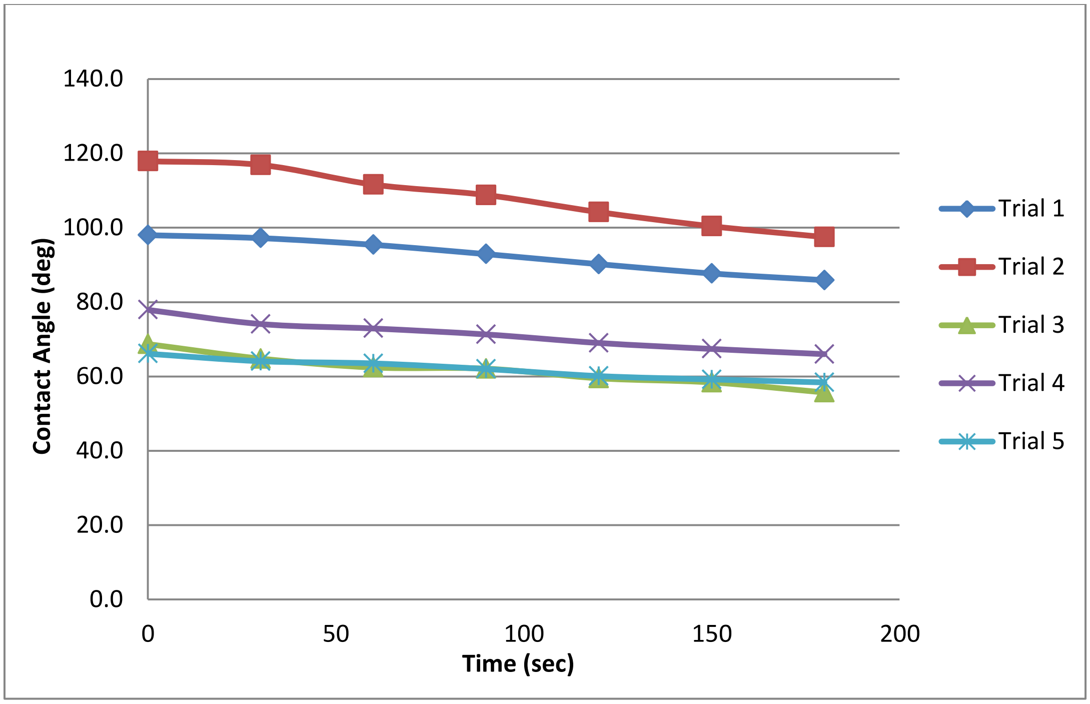


FIGURE 53 - PP Trend of Inside Samples Soaked in Triton X-100 for 20 Min

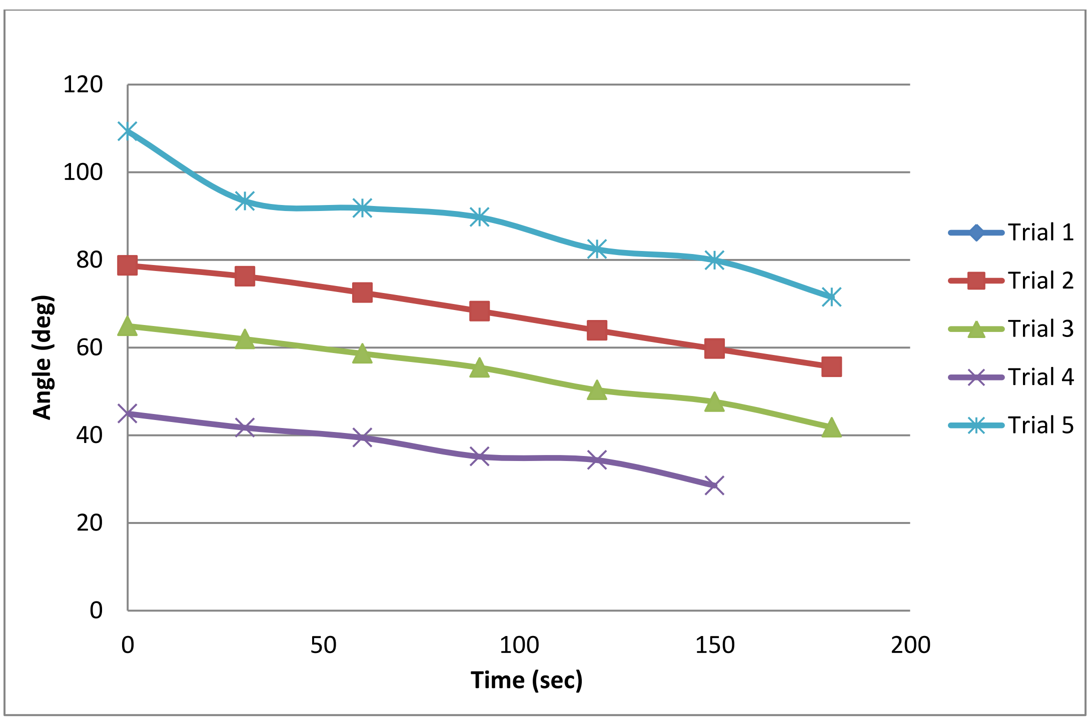


FIGURE 54 - PE Trend of Inside Samples Soaked in Triton X-100 for 20 Min

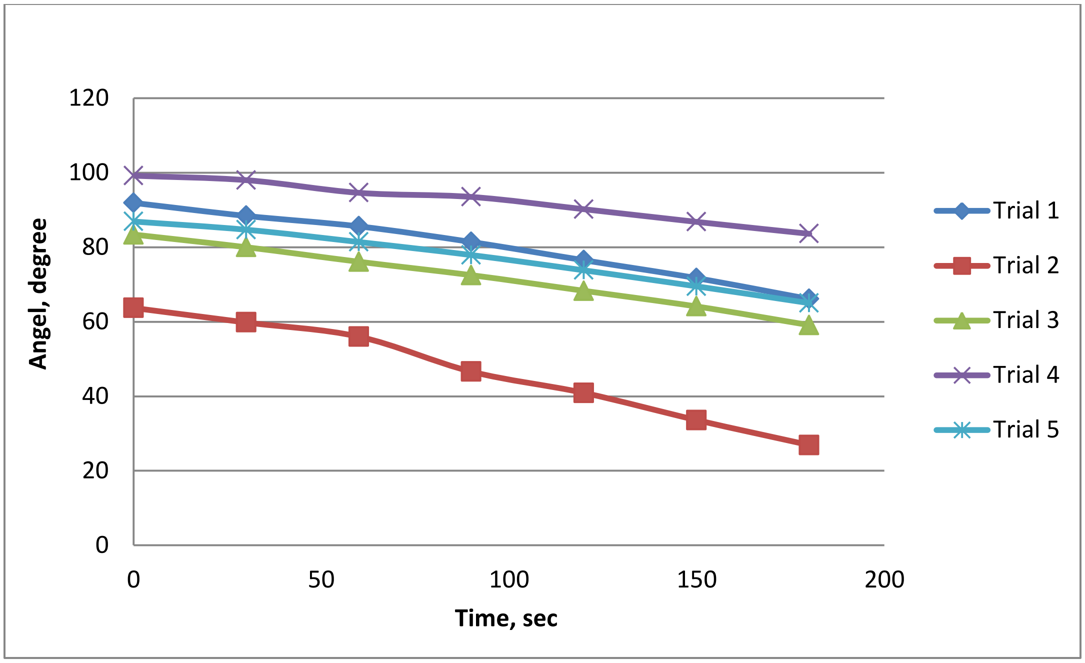


FIGURE 55 - PE Soaked in EcoSurf for 5 Min

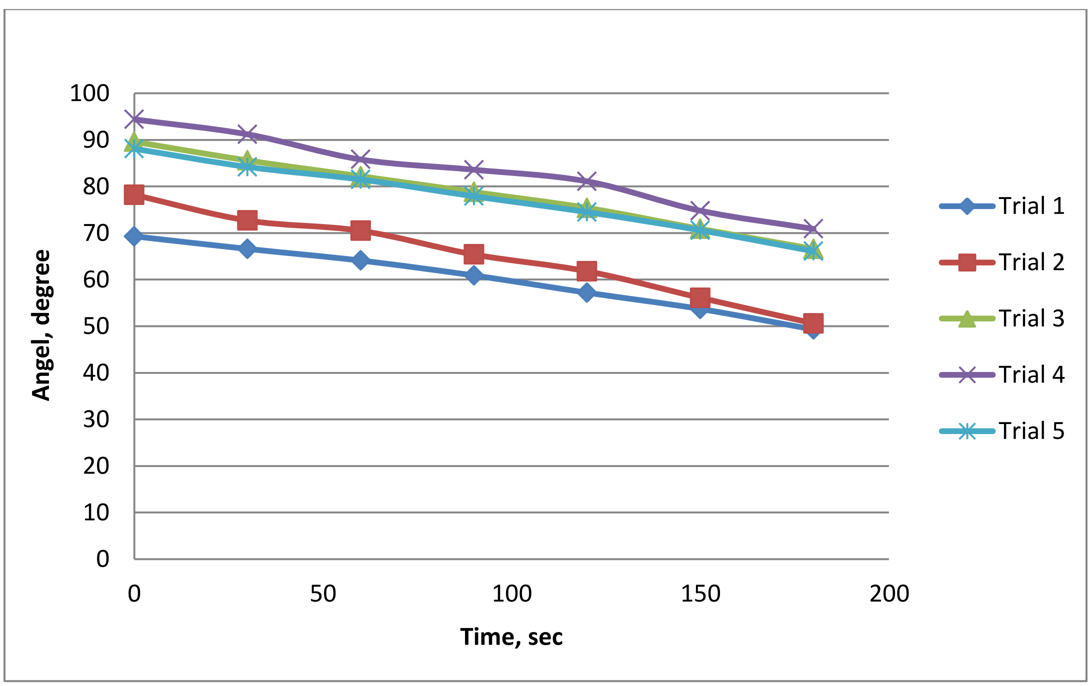


FIGURE 56 - PE Soaked in EcoSurf for 10 Min

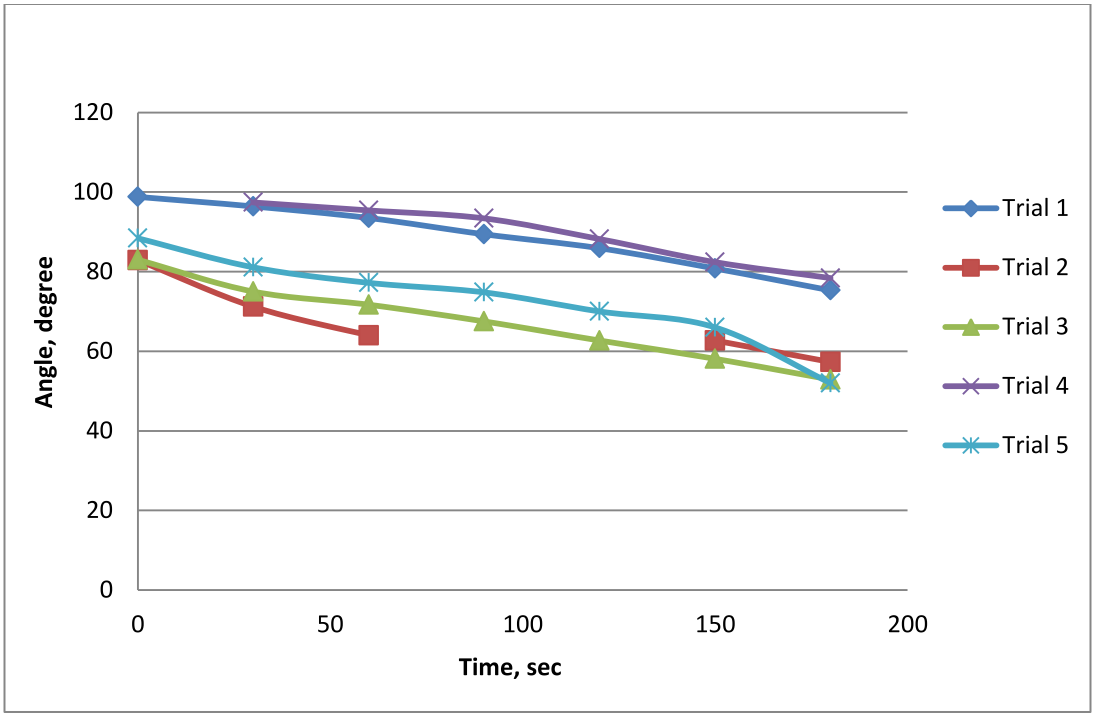


FIGURE 57 - PE Soaked in EcoSurf for 15 Min

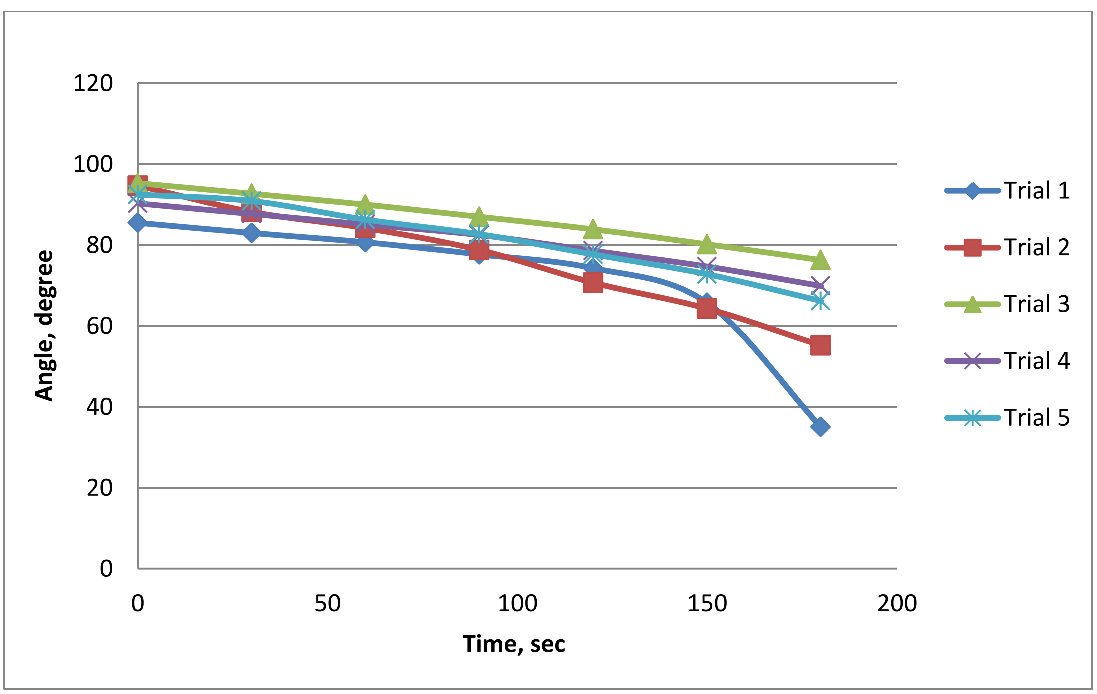


FIGURE 58 - PE Soaked in EcoSurf for 20 Min

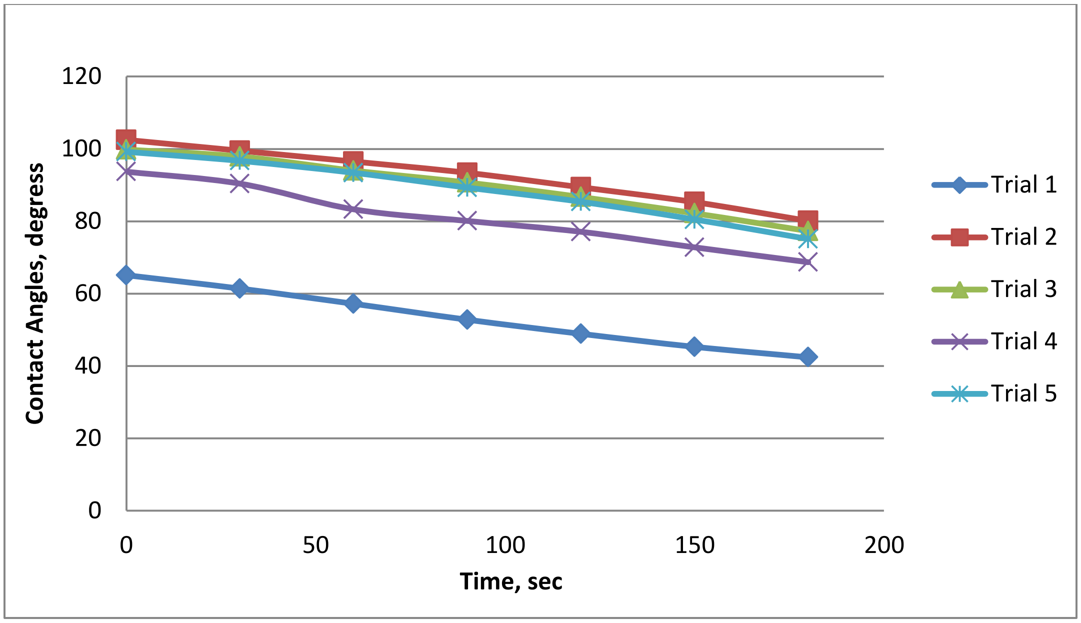


FIGURE 59 - PP Soaked in EcoSurf for 5 Min

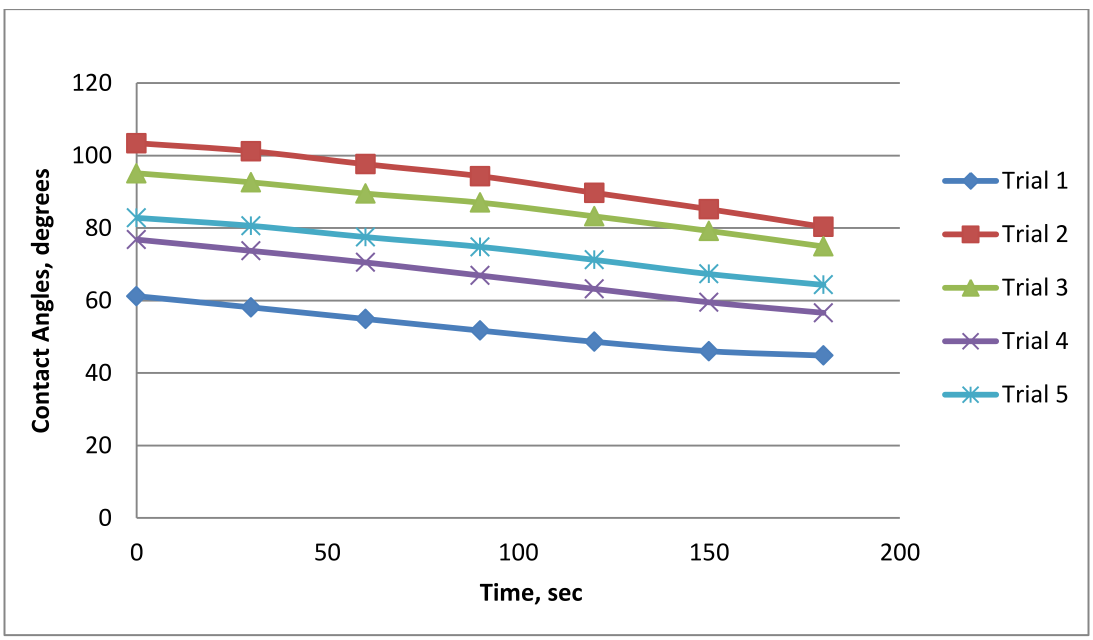


FIGURE 60 - PP Soaked in EcoSurf for 10 Min

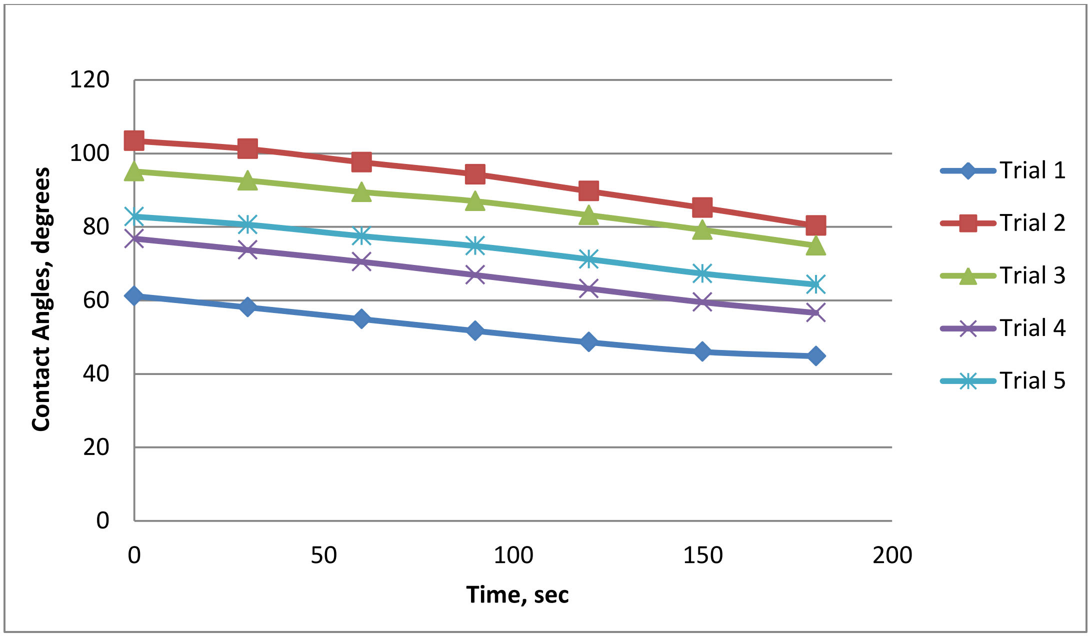


FIGURE 61 - PP Soaked in EcoSurf for 15 Min

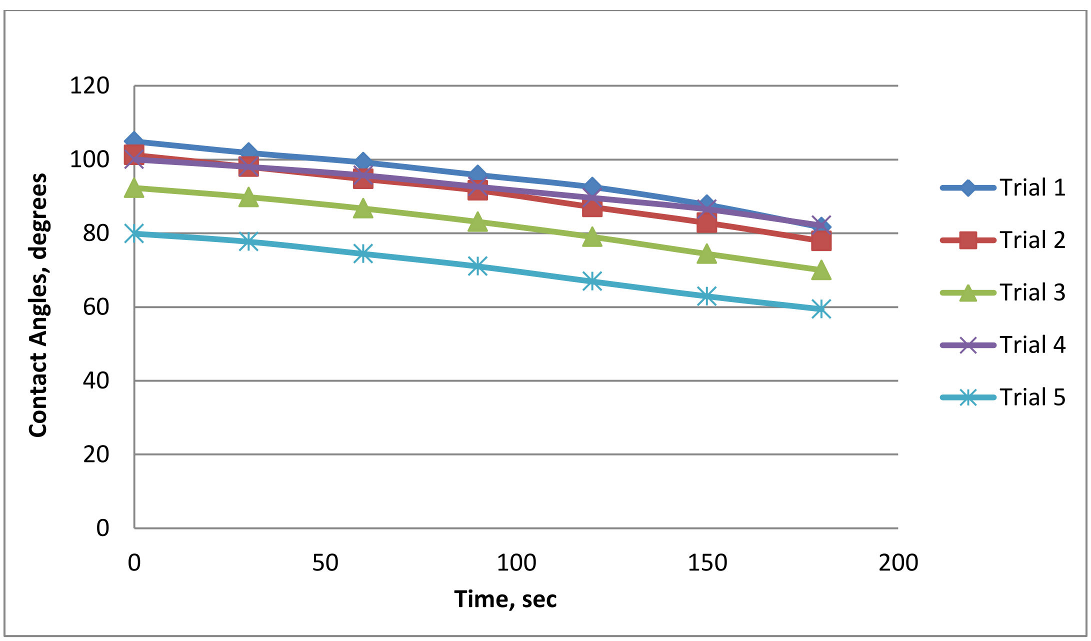
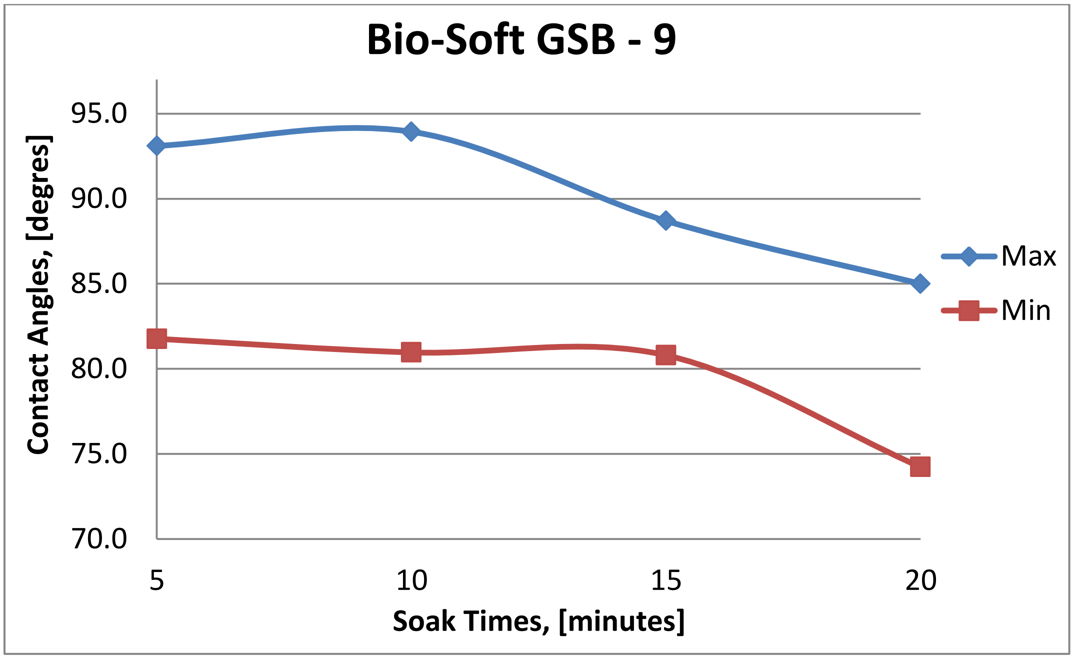
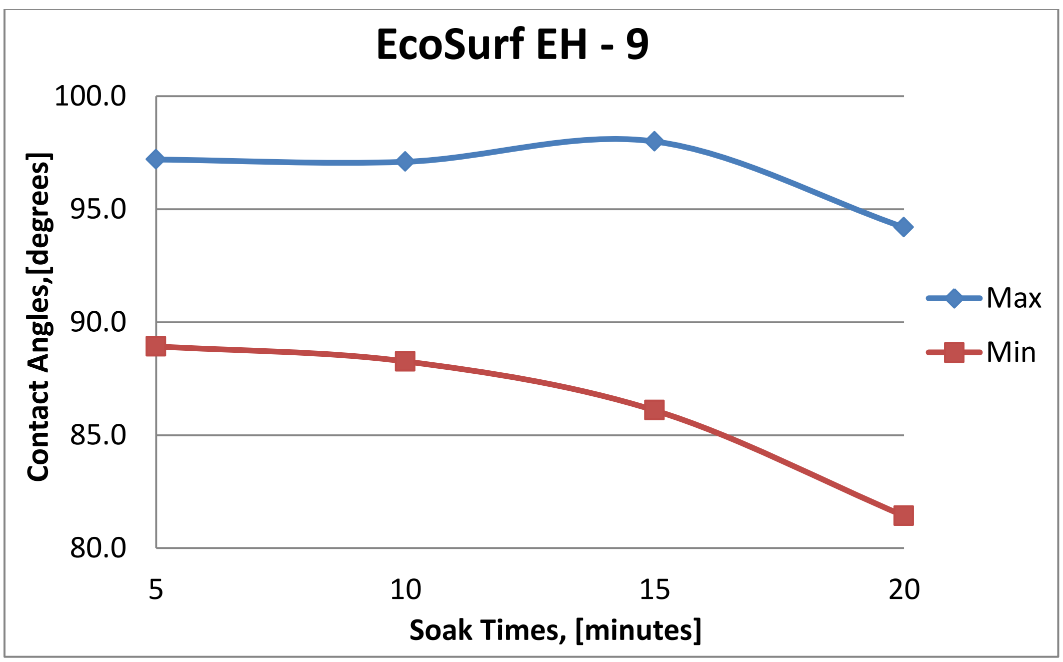
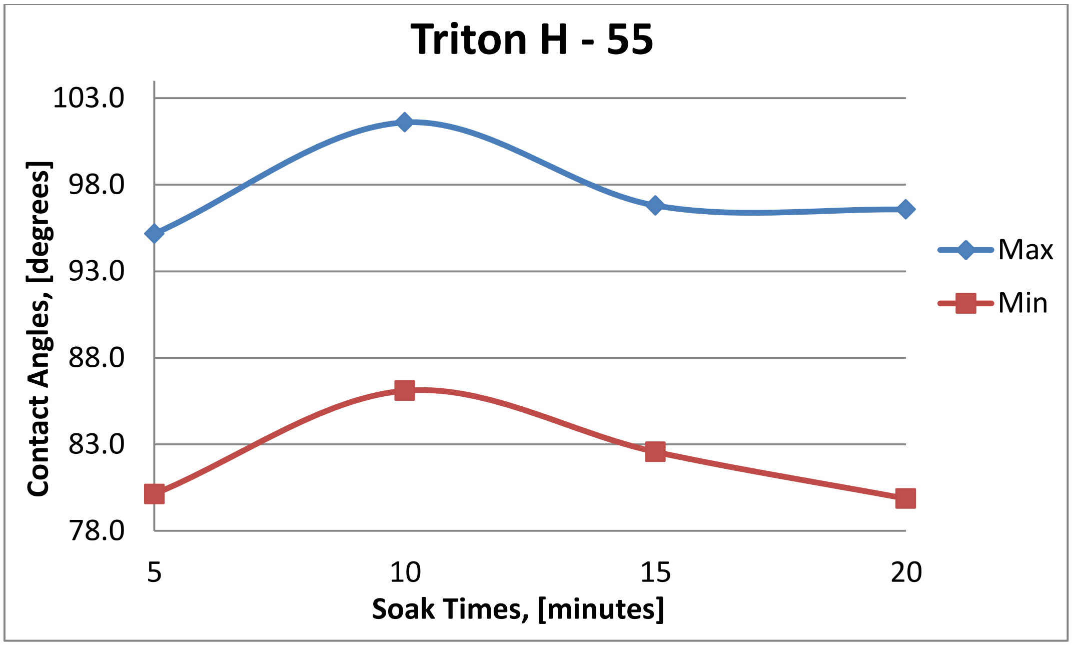


FIGURE 62- PP Soaked in EcoSurf for 20 Min


Bio-Soft GSB - 9
95.0
90.0
85.0
80.0
75.0
70.0
Contact Angles, [degres]
5
10
15
20
Soak Times, [minutes]
Max
Min


EcoSurf EH - 9
100.0
95.0
90.0
85.0
80.0
Contact Angles,[degrees]
5
10
15
20
Soak Times, [minutes]
Max
Min



Triton H - 55
103.0
98.0
93.0
88.0
83.0
78.0
Contact Angles, [degrees]
5
10
15
20
Soak Times, [minutes]
Max
Min

APPENDIX III

Particle Size Calculations

Tower Designs:

		(1)	(2)	
	V	25000	100000	ft3/min
	d	8	14.5	ft
	h	12	12	ft
	A	50.27	165.13	ft2
	u :	497.4	605.6	ft/min
	u :	**252.658977**	**307.6370903**	**cm/sec**

	CHICKEN	BEEF	PORK	
Density:	**0.840**	**0.866**	**0.5917**	**g/cm3**

Constants:

g	**980**	**cm/sec2**
Cd	**13.0610835**	

Temperature Range:

	T = 100F	140F	
ρ(H2O)	62.00	61.38	lb/ft3
ρ(H2O)	**0.992**	**0.98208**	**g/cm3**
μ(H2O)	0.682	0.470	cP
μ(H2O)	**0.00682**	**0.0047**	**g/cm-sec**

Assuming Laminar Flow (Re < 1,000)

$$\rho_{Fat}\left(\frac{\pi d_p^3}{6}\right)g - \rho_{water}\left(\frac{\pi d_p^3}{6}\right)g - C_D\left(\frac{\pi d_p^2}{4}\right)\frac{U_f^2}{2}\rho_{water} = 0$$

v = *Water*

L = *Fat*

Check:

Re 1.83752

$$Re_p = \frac{d_p v_p \rho_g}{\mu_g}$$

Diameter of Particles:

	Lower Bound	Upper Bound	
Chicken	0.00005	0.00006	cm
Beef	0.00005	0.00006	cm
Pork	0.00005	0.00006	cm

Diameter of Particles:

	Lower	Upper Bound	
Chicken	500	600	nm
Beef	500	600	nm
Pork	500	600	nm

Force Balance Calulation for Solver

	Lower Bound	*Upper Bound*
Chicken	*-0.00081201*	*-0.0011576*
Beef	*-0.00081201*	*-0.0011576*
Pork	*-0.00081201*	*-0.0011576*

VITA

Pamela Arnold is a graduate of J. B. Speed School of Engineering at the University of Louisville where she studied Chemical Engineering. She focused in areas of Engineering Management, while expanding her love for music by taking courses such as History of Rock-and-Roll and Music in World Cultures. During her time at the University, she was able to complete three cooperative opportunities with two chemical companies. These co-ops allowed her to discover the field that she wanted to pursue upon completion of the program. After graduation, she will begin a Material Developer Role with Kimberly Clark.