# Confectionary coating using an electro-hydrodynamic system

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*Abstract* - **In the chocolate coating industry, cocoa butter is a high value ingredient. Due to high cost, shortage of supply and blooming, hard butters are frequently used as cocoa butter replacers. An electrohydrodynamic system (EHD), which forms fine droplets with a relatively narrow size distribution, may be beneficial in confectionary coating to reduce cost and to increase quality because complete and even coverage can be achieved. The objective of this research is to optimize the use of EHD by altering the resistivity and viscosity of different types of confectionery coating using different levels of lecithin. Non-EHD and EHD coating systems using confectionary coating made of cocoa butter equivalent, lauric cocoa butter or cocoa butter with different percentages of lecithin were analyzed. Droplet size, width of coating area, thickness, and minimum flow rate to produce complete coverage was measured. The voltage supplied for EHD coating system was 25kV. As lecithin content decreased, resistivity of all samples decreased. Viscosity of the sample is affected by the interaction of lecithin and fat when they are mixed together. The minimum viscosity was at 0.5% lecithin. EHD coating was more efficient than non-EHD as smaller droplet size and thinner coating was formed. Due to repulsive forces between the like-charges on the droplets during EHD, it spread over wider areas which lead to higher minimum flow rate to get complete coverage. Under EHD, the effect of resistivity dominated the droplet size. The droplet size for all samples significantly increased at the highest resistivity with 0 and 0.05% lecithin addition. There was no trend between resistivity and droplet sizes for any of the fats under non-EHD since electrical resistivity should not be important because there are no electrical charges applied during the coating. The lowest coating thickness was observed at the minimum viscosity with 0.5% lecithin addition. The fit for minimum flow rate to viscosity is better than resistivity because viscosity affects how well products flow. Under both EHD and non-EHD system, at low lecithin content with higher viscosity, the minimum flow rate to get complete coverage was always low.**

***Keywords: electrohydrodynamic, resistivity, viscosity, lecithin***

## INTRODUCTION

Confectionary coatings are coatings formulated with a fat system other than cocoa butter. These cocoa butter replacement fats are commonly called hard butters. Several hard butters have been developed which duplicate the characteristics of cocoa butter, such as cocoa butter equivalent and lauric cocoa butter. Cocoa butter equivalent has the same fatty acid composition (palmitic, stearic, and oleic) as cocoa butter but with different proportions of the fatty acids [1]. Lauric cocoa butter has a different fatty acid composition because it contains a high percentage of lauric acid (40-50 %) but it has physical similarities to cocoa butter [2].

One of the emerging technologies in food manufacturing is the utilization of liquid electrohydrodynamic (EHD) systems for coating foods with oils, emulsifiers, and flavors. The areas that are most important in this system are control, quality, and cost reduction [3]. The fundamental principle governing the disintegration of a liquid in an EHD system is that its surface area and thus surface energy, is continually increased by electrical forces until an instability occurs and disintegration of the liquid surface takes place [4]. Atomization follows from, in many cases, the formation of filaments of mother liquid, which then disintegrate to produce droplets [4].

Resistivity and viscosity play a large role in an EHD coating system [5]. The resistivity of commonly used food oils is very high, preventing them from atomizing in an EHD coating system. Depending on the equipment used as well as the viscosity of the sample, the resistivity range for atomization varies. A liquid with a resistivity outside the range of $10^5$ to $10^9$ Ωm may not atomize [5]. Others reported the range to be even narrower: $10^6$ to $10^8$ Ωm [6, 7]. Therefore, it is very important to maintain the resistivity in the correct range in order to achieve good atomization during electrostatic coating [8]. The most common solution is to add ionic materials to decrease the resistivity of the food oil into the atomizable range, such as emulsifiers like lecithin, alcohols, seasoning and coloring agents [9].

Apparent plastic viscosity determines pumping characteristics, filling of rough surfaces, coating properties and the sensory characteristics of the chocolate mass [10]. Apparent yield stress is a material property denoting the transition between pseudo-solid and pseudo-liquid behaviors and determines the thickness and uniformity of chocolate coatings. Both apparent viscosity and yield stress are dependent on fat and lecithin content [11].

The objective of this study was to establish the effect of different lecithin levels and fat types on the physical properties resistivity, viscosity and yield stress of the samples and the effect of these physical properties on the final spray quality including droplet size, width of coating area, thickness, and minimum flow rate to get complete coverage under EHD and non-EHD.

## MATERIALS AND METHODS

### *A. Sample preparation*

The sample consisted of 52.66% cocoa butter or cocoa butter alternatives, 37.38% granulated sugar and 9.96% natural cocoa powder. A cocoa butter equivalent made from sunflower/safflower and palm oils (Palmy MM7E) and a lauric cocoa butter substitute made from fractionated palm kernel oil and hydrogenated palm oil (Palkena SAC) (Fuji Vegetable Oil, Inc, Savannah, GA) were used; 0, 0.05, 0.5, 1, 2 and 5% of soy lecithin were added. The amount of sugar was adjusted according to the amount of lecithin added.

A TDC Liquid Electrostatic Coater (Terronics Development Corporation, Elmwood, IL) was used with a nozzle containing a 0.016" thick metal electrode. During coating, the samples were sprayed at 0 or 25kV at 60°C.

*B. Droplet size measurement*

Samples were pumped at 23 g/min to the coater. The samples were sprayed onto a 15 cm × 15 cm glass slide, maintained at room temperature, placed on a conveyor belt moving at 600 cm/min. The sprayed glass slide sample was photographed and analyzed using Photoshop 6.0 (Adobe Systems Incorporated, San Jose, CA). The number of total pixels and black pixels were determined. Before calculating the black pixels, droplets were selected. Selected samples were read. The number of droplets on the glass slide was counted manually. Average droplet sizes were then calculated.

*C. Width of coating, thickness, and minimum flow rate measurement*

The width of coating area measurement was conducted by spraying the sample at a flow rate of 145 g/min on to aluminum foil at a conveyor belt speed of 16 cm/min. The spread or width of spraying was measured from the furthest drop of spraying on both sides.

The thickness measurement was conducted by spraying the sample at a flow rate of 145 g/min on to aluminum foil at a conveyor belt speed of 16 cm/min. For the thickness measurement, each aluminum foil section coated with sample was cut to 50 cm in length in order to determine the average chocolate thickness at 5 different locations. The thickness of each piece was measured using a vernier caliper and the average of 3 readings was taken.

For the coverage measurement, the samples were sprayed with a range of flow rates onto aluminum foil at a constant conveyor belt speed of 16 cm/min to determine the lowest flow rate that produced complete coverage with no holes. Complete coverage means that the sample must cover an area at least 14 cm wide and 20 cm in length with no holes formed during spraying. After the sample hardened, complete coverage of the sample was measured.

*D. Resistivity measurement*

The electrical resistivity was measured using a resistivity cell (Electrostatic Solution Ltd., Southhampton, UK), electrometer and a voltmeter at 40, 45, 50, 55, 60, and 65 °C. Five g of sample was put into the resistivity cell, and they were heated to the desired temperature. The voltage used was 125 V. The resistivity of the sample was calculated using: Resistivity = (k*I)/V, where k is the cell constant = 0.014V, I is the current (A), and V is the Voltage (V). The resistivity measurement was in triplicate.

*E. Viscosity and yield stress measurement*

Viscosity was measured at 60°C using a controlled-stress rheometer fitted with a concentric cylinder geometry. After pre-shearing for 15 min at 60ºC, the viscosity was measured at increasing shear rate from 5 $s^{-1}$ to 1125 $s^{-1}$. The viscosity used was at the shear rate calculated to occur in the nozzle. The experiment was in triplicate.

The yield stress was measured at 40ºC as a function of increasing shear rate from 5 to 50$s^{-1}$ (ramp up) over 120 s, then decreasing from 50 to 5$s^{-1}$ (ramp down); within each ramp, 50 measurements were taken. The yield stress was taken as the shear stress at 5s-1 on the ascending shear rate ramp and the experiment was in triplicate.

One-factor and two-factor analysis of variance (ANOVA), followed by a Tukey HSD test and regression analysis test by a Tukey HSD test with p=0.05 was also performed.

## RESULTS AND DISCUSSION

### *A. Lecithin content*

The resistivity range for oil atomization is between $10^5$ and $10^9$ Ωm [7, 8]. The resistivity of food fats is generally high and the resistivity of the confectionery coating was between 3.7 x $10^8$ and 1.4 x $10^9$ Ωm, which is at the upper limit for atomization. Addition of 1% lecithin decreased the resistivity by 1 to 2 logs, while addition of 5% lecithin decreased the resistivity by almost another log (Fig.1). The resistivity of pure lecithin was 3.1 x $10^6$ Ωm, which is only slightly lower than the resistivity of the sample made from lauric butter with 5% lecithin added, thus increasing the lecithin content further should not greatly affect the resistivity. Lecithin is an emulsifier and is frequently added in confectionery coating to decrease viscosity and yield value [11]. Lecithin is an ionic material and so can also be used to reduce resistivity [8]. The addition of 13% lecithin to soybean oil reduces resistivity by 3 logs, from $10^{11}$ to $10^8$ Ωm [12]. Therefore, as lecithin content increased, the resistivity of all samples significantly decreased.

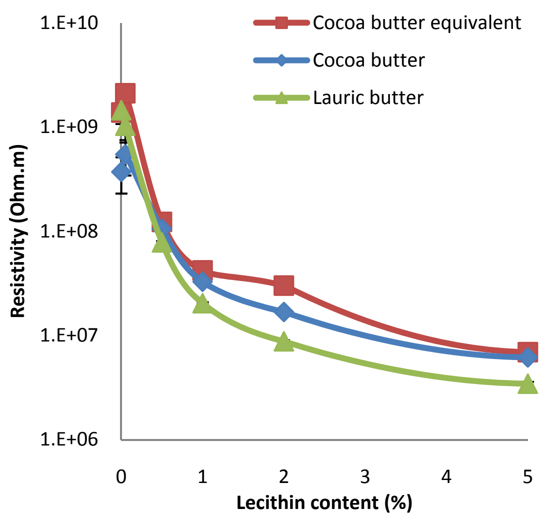


Fig. 1. Resistivity vs. lecithin content at 60°C

Pure lecithin has a high viscosity, 61.5 Pa.s, which is significantly higher than pure fat, which has a viscosity from 5.5 to 11.9 Pa.s. However, lecithin and fat interact so that the viscosity of most samples with lecithin added was significantly lowered than either pure fat or pure lecithin (Fig 2). The hydrophilic fragment of lecithin anchors sucrose in the confectionery coating and the lipophilic part penetrates the lipid phase; as a result, lecithin reduces internal friction [11]. The minimum viscosity in chocolate is at 0.5% lecithin; while, above this point, lecithin can induce thickening [11]. This behavior was observed in these samples (Fig.2). The viscosity decreased at 0.5% lecithin, increased at 1% lecithin and decreased again as more was lecithin added. Similar behavior was observed for yield stress.

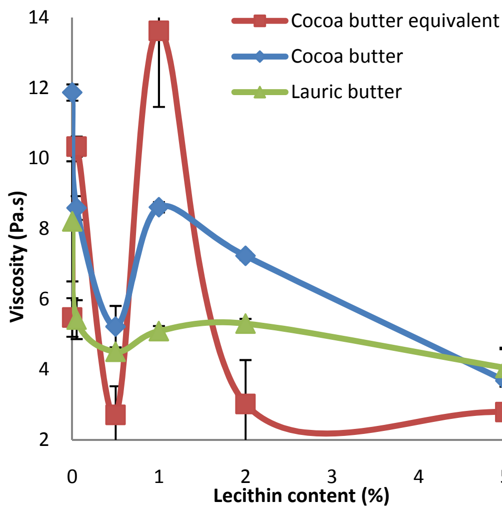


Fig. 2. Viscosity at shear rate 40s$^{-1}$ vs. lecithin content at 60°C

*B. EHD vs. non-EHD coating*

With EHD coating, the droplet size of all samples was significantly smaller than with non-EHD coating (Fig.3). The droplet size range for EHD is from 4.0 to 21.6 mm$^2$/drop and for non-EHD is from 60.5 to 111.1 mm$^2$/drop. During EHD, electrical charge is supplied to the surface of the liquid and these charges distribute themselves along the surface of the liquid spaced in such a fashion as to maximize the separation between like charges due to the repulsive forces between them. These repulsive forces between the like-charges attempt to force the like-charges to separate from each other. Coulombs law governs these repulsive forces and as such their magnitude is directly proportional to the number of charges available and inversely proportional to the distance between these charges. The force countering the attempt of these repulsive forces to break up the liquid surface is surface tension attempting to hold the liquid surface together. As the repulsive forces grow stronger than the surface tension, the liquid is broken up into small droplets [5]. Therefore, the droplets produced in EHD are smaller than in non-EHD coating. Having smaller droplets is important in the coating industry because more even and thinner coverage can be achieved with lower cost.

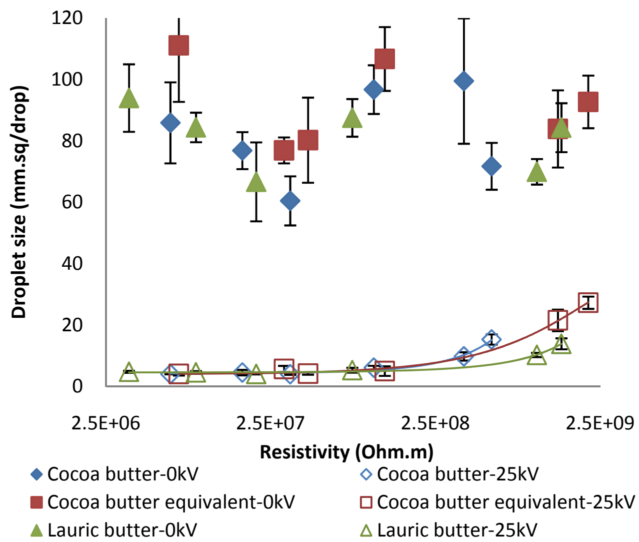


Fig. 3. Resistivity vs. droplet size with EHD and non-EHD

During EHD, the coating spread over a wider area than in non-EHD coating. This is caused by the repulsive forces between the like-charges on the droplets as well as the smaller droplets produced during atomization; therefore it was able to spread over a wider area. The spread for non-EHD coating was 14 to 15 cm, whereas the spread for EHD coating ranged from 46 to 173 cm. Therefore, the thickness of all samples by EHD coating was significantly thinner and the minimum flow rate to get complete coverage for all samples was significantly higher than non-EHD coating.

*C. Droplet size*

Under EHD, the average droplet size was constant at 4.7 $mm^2$ for samples with resistivity from 3.5 x $10^6$ Ωm to 1.1 x $10^8$ Ωm, which is produced by 0.5 to 5% lecithin addition (Fig. 3). The droplet size significantly increased when resistivity increased above 3.7 x $10^8$ Ωm, which occurred in the 0 and 0.05% lecithin samples. In the EHD system, the ability of a sample to atomize is dependent on its electrical resistivity [13]. When the resistivity is high, the time required for the charge to transfer through the liquid is too long for good atomization [14]. Therefore, a bigger droplet size is expected. As the resistivity of the confectionery coating approaches the upper limit for atomization, the droplet size increases. In a study of chocolate spraying with EHD, a significantly larger droplet size was also observed for the sample with the highest resistivity [12].

There is co-linearity between lecithin content, resistivity and viscosity. As lecithin content increases, resistivity decreases (Fig. 1) and viscosity generally decreases, except the decrease at 0.5% lecithin is much greater than at the higher lecithin contents (Fig. 2). This property can be used to partially separate the effects of resistivity and viscosity on coating quality. As viscosity increased with EHD, the droplet size generally increased; however, the fit is not nearly as good as the fit to resistivity (Fig. 3, 4). Samples with the largest droplet size do not have the highest viscosity, while they do have the highest resistivity. In a study with soybean oil, resistivity was found to have the second greatest effect on coating reproducibility, after voltage, while viscosity was only significant through its interaction with voltage [3]. As viscosity increases, the mobility of the charge-carriers decreases [15], thus droplet size is expected to increase, but the effect of resistivity clearly dominates in these samples.

Under non-EHD, large droplet sizes with a large standard deviation were formed (Fig. 3). There was no trend between resistivity and droplet size for any of the fats. Electrical resistivity should not be important in non-EHD, since there are no electrical charges applied during the coating. There was also no trend between viscosity and droplet size for any of the fats though we would have expected viscosity to be important (Fig. 4).

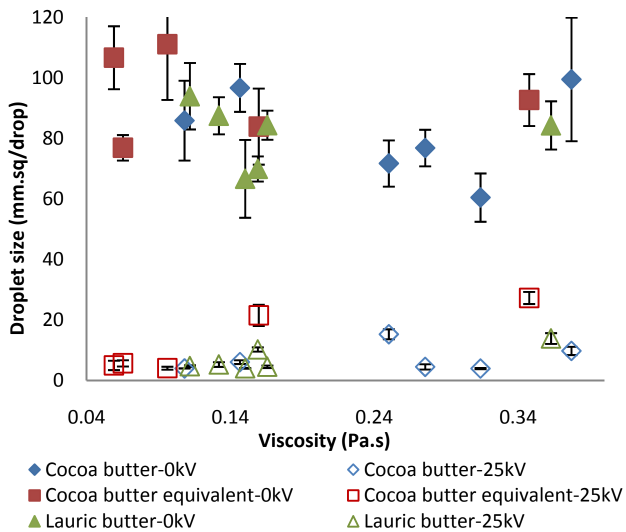


Fig. 4. Viscosity vs. droplet size with EHD and non-EHD

*D. Width of coating area*

Under non-EHD coating, the width of coating for all samples was the same, from 14 to 15 cm, and thus was not affected by resistivity or viscosity. However, the width of coating for EHD ranged from 46 to 173 cm (Fig. 5). During EHD, the spread of droplets is mainly affected by resistivity. Similar to the droplet size results, the width decreased significantly as resistivity increased. Unlike droplet size, the effect of resistivity was logarithmic for the entire range, rather that being unimportant below a cut off value. During EHD coating, as the resistivity of the samples decreased, the mobility of charge-carriers increases which leads to good atomization and smaller droplet size [3]; therefore it was able to spread over a wider area.

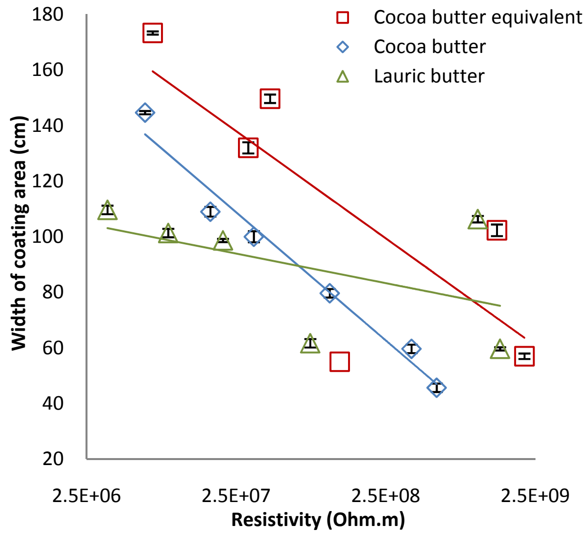


Fig. 5. Resistivity vs. width of coating area with EHD system

*E. Thickness*

The thickness of the sheet of confectionery coating sprayed on the conveyor belt generally increased as resistivity and viscosity increased for all samples. However, neither property completely explained the results. The thickness should increase as droplet size increased and width of the coating decreased, since larger droplets spread over a smaller area should produce thicker coating. Droplet size and width are most strongly affected by resistivity. However, the lowest thickness for each fat type was produced by the addition of 0.5% lecithin which also produces the lowest viscosity (Fig. 6, 2). The highest coating thickness for cocoa butter and lauric butter was at 0% lecithin and for cocoa butter equivalent was at 1% which was also the highest viscosity.

Thus viscosity plays an important role in the coating thickness. At high viscosity, larger formation of droplet size is expected; therefore, the coating thickness is expected to increase as well. In a study of water and glycerol mixtures having different viscosities, samples with high viscosity had the largest droplet size [16]. Viscosity affected the shape of the droplets; as a result, fewer and larger droplets prevailed in the more viscous sample.

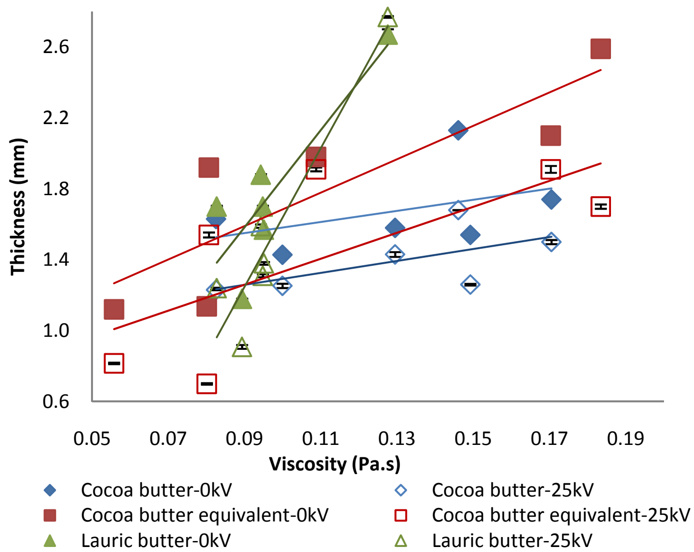


Fig. 6. Viscosity vs. thickness with EHD and non-EHD

*F. Minimum flow rate to achieve full coverage*

The minimum flow rate to produce continuous coating coverage with no holes was also measured. Again, both resistivity and viscosity correlated. However, the fit for minimum flow rate to viscosity is better. At low lecithin content (0 and 0.05% lecithin) with the highest resistivity, the minimum flow rate was always low (Fig. 7). However, it was also low for some samples with 0.5 to 5% lecithin. The highest minimum flow rate was observed for samples with 0.5% lecithin added which has the lowest viscosity (Fig. 7). Under both EHD and non-EHD, the minimum flow rate to get full coverage at 0.5% lecithin ranged from 159 to 207 g/min. Viscosity affects how well product flows; so it is an important property to determine the minimum flow rate to achieve full coverage during coating.

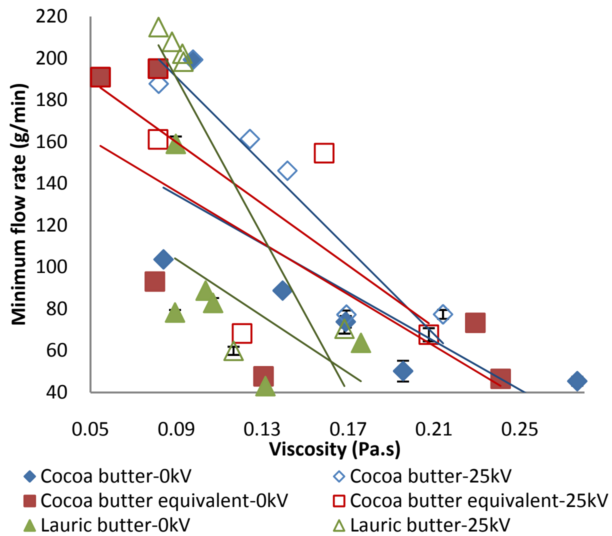


Fig. 7. Viscosity vs. minimum flow rate with EHD and non-EHD

## CONCLUSIONS

As lecithin content decreased, resistivity of all samples decreased. Viscosity of the sample is affected by the interaction of lecithin and fat when they are mixed together and the minimum viscosity was at 0.5% lecithin. EHD coating was more efficient than non-EHD as smaller droplet size and thinner coating was formed. Due to repulsive forces between the like-charges on the droplets during EHD; therefore it was able to spread over wider areas which lead to higher minimum flow rate to get complete coverage. Under EHD, the effect of resistivity dominated the droplet sizes. The droplet sizes for all samples significantly increased at the highest resistivity with 0 and 0.05% lecithin addition. There was no trend between resistivity and droplet sizes for any of the fats under non-EHD since electrical resistivity should not be important because there are no electrical charges applied during the coating. The lowest coating thickness was observed at the minimum viscosity with 0.5% lecithin addition. The fit for minimum flow rate to viscosity is better than resistivity because viscosity affects how well product flow.

## ACKNOWLEDGEMENT

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## REFERENCES

[1] W. Ham, “Trends in edible oil fractionation,” Trends in Food Sci. and Tech, vol 6, pp. 121-126, 1995.

[2] S.A. Norberg, “Chocolate and confectionery coating. In: Gunstone FD, editor,” Modifying lipids for use in food. Oxford: Woodhead Publishing, pp. 494, 496. 2006.

[3] J. Abu-Ali and S.A. Barringer, “Optimization of liquid electrostatic coating,” J Electostat., vol 66, pp184-189, 2008.

[4] A.G. Bailey, “Electrostatic atomization of liquids,” Sci Prog, vol 61, pp. 555-581, 1974.

[5] J. Abu-Ali, “Food coating applications in electrostatic atomization, nonelectrostatic coating and electrostatic powder coating,” Doctoral thesis, The Ohio State University, Columbus OH. p 194, 2004.

[6] S.E. Law, “Physical properties determining chargeability of pesticide sprays. In: advances in pesticide formulation technology,” monograph series no 254, HB Scher, Editor. Washington DC: Amer. Chem. Soc., pp. 219-230, 1984.

[7] J.B. Wilkerson and L.D. Gaultney, “Electrostatic atomization of vegetable oil for pesticide spraying,” ASAE paper no. 891524, 1989.

[8] J. Abu-Ali and S.A. Barringer, “Method for electrostatic atomization of emulsions in and EHD system,” J. Electrostat., vol 63, pp. 361-369, 2005.

[9] R. Evans and G. Reynhout, “Electrostatic deposisiton of edible liquid condiment composition upon edible food substrates and thus-relaed products,” US Patent 6,010,726, 2002.

[10] E.O. Afoakwa, A. Paterson, M. Fowler and J. Vieira, “Relationship between rheological, textural, and melting properties of dark chocolates as influenced by particle size distribution and composition,” Eur. Food Res. Technol., vol 227, pp. 1215-1223, 2008.

[11] E. Nebesny and D. Zyzelewicz, “Effect of lecithin concentration on properties of sucrose-free chocolate masses sweetened with isomalt,” Eur. Food Res. Technol., vol 220, pp. 131-135, 2005.

[12] J. Abu-Ali, “ Food coating applications in electrostatic atomization, nonelectrostatic coating, and elecptrpstatic powder coating,” Ph.D. dissertation, Dept Food Sci., The Ohio State Uni., Columbus, OH, 2004.

[13] A.V. Gorty and S.A. Barringer, “Electrohydrodynamic spraying of chocolate,” J. Food Process. Preserv., in press, 2011

[14] T.K. Burayev and I.P. Vereshchagin, “Physical processes during electrostatic atomization of liquids,” J. Fluid Mech., vol 1, pp. 56-66, 1972.

[15] I. Adamczewski, “Ionization, conductivity and breakdown in dielectric liquids,” Taylor & Francais LTD, London, 1969, p. 439.

[16] Jayasinghe, S.N. and Edirisinghe, M.J. Effect of viscsoity on the size of relics produced by electrostaic atomization.