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The Elimination of Electrostatic Accumulation on Polypropylene Cup, Produced By Injection Molding Machine: The Influence of Relative Humidity and Its Characteristics

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Abstract*—Electrostatic accumulation on polypropylene cup which is produced by Injection Molding machine, cause cup has electric force and the consequence is cup cannot fall by itself. This problem can disturb the application of cup in filling drinking machine. The elimination of electrostatic accumulation has been done by relative humidity control in cup productions. By 67 – 69 % relative humidity, the speed of filling drinking machine will increase from 180 – 200 rpm to 220 – 250 rpm (cup 180) and from 80 – 100 to 140 – 160 rpm (cup 225) in different machine. The pair of cups with electrostatic force could be fall fluently in 6.7kV maximum surface potential electric (in same or different charge) and 3.0kV surface potential electric in a single cup. Charge decay time, when electrostatic could be controlled is about 7 days depend on storage and characteristics of cup with optimum relative humidity is 33 – 40 %. Electrostatic accumulation on polypropylene cup will increase because of its characteristics. They are surface temperature of cup, shape of cup and the use of TiO_2 additive in cup.*

Keywords *— electrostatic, filling drinking machine, injection molding machine, polypropylene cup, relative humidity*

I. INTRODUCTION

Polymer is a branch of chemical industry which has a lot of application with multiple functions. One of them is plastic packaging. Plastic packaging has some advantages; they are light, flexible, heat seal, colored, and cheap. Material of plastic is an insulator. An insulator is a material that against electric and do not allows it to flow. The electrostatic comes from a friction and collisions of plastic particle each other or adhesion of the material to the walls of the processing equipment [1]. That's why there are electrostatic accumulations in production process to produces plastic packaging. In Injection molding machine that produces plastic packaging in cup form, electrostatic accumulation is also happened. The pair of cups with electrostatic force have a pulling power and makes cup cannot fall by itself. This phenomenon spontaneously reduces speed of falling drinking machine and their output will decreased.

The accumulation of electrostatic on polypropylene cup could be solved by some methods: grounding system of equipments, radioactive ionization, adds antistatic agent and relative humidity control [1]. The conductivity of polymer surface will increase with relative humidity control. An increase of the atmospheric humidity strongly influences the charging behavior of polymers. The electron pair transfer mechanism generated by the higher amount of water in system. In presence of water, the mobility of charge corner on the polymer surface is raised. A high number of charge carries presented on the surface increases surface conductivities and decreases the surface resistivity [2]. From this phenomenon, its important to know the influence of relative humidity in cup, could be problem solving of falling drinking machine.

Accumulation of electrostatic in polymer will be not reduced forever, because it has charge decay time (a time when electrostatic still controlled) [3]. By controlling relative humidity in production process, the limit of time when electrostatic still controlled will be known with decides maximum potential surface charge of cup which is not disturb the application of cup in filling drinking machine. Characteristics of cup consist of surface temperature, shape of cup, and color of cup (used TiO_2 additives as colored agent). Those characteristics maybe give an influence to the accumulation of electrostatic in cup, and it's so important to the producer of cup to design their cup. Research had been done about variation acidic in black carbon surface significantly gives an influence in capability of pigment [4].

II. MATERIAL AND METHODS

II.1. Material

Material and equipments which used in this research are polypropylene cup, additive TiO_2, Injection Molding machine (Fig. 1), filling drinking machine (Fig 2), hygrometer, reytec, and field mill.

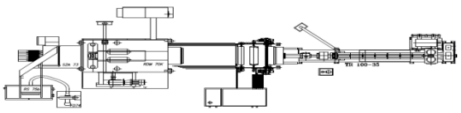

Fig. 1. Injection molding machine

II.2. Methods

In the beginning of research surface electric potential of raw material were measured. The room production was conditioned as a closed room with control of humidity, to knowing optimal condition of production process. There are three methods to knowing that condition, such as measuring surface electric potential of cup, manually falling cup, and falling drinking machine analysis. Variable of charge decay time is about 1 to 7 days. Surface electric potential of cup is measured by field mill. For accurately, distance between it and cup is about 2 to 3 cm (indicated by light sensor focus, Fig. 3).

Fig. 2. Filling drinking machine

Fig. 3. Measurement of surface electric potential cup by field mill (inner and outer surface)

The measurement surface electric potential of cup had not been done only in inner surface but also in outer surface. The optimum of relative humidity will be standard to knowing influence of cup's characteristics in accumulation of electrostatic on cup. Variables of characteristic cup are surface temperature of cup (30, 39, 48, 61°C), shape of cup (180, 225, 240, Fig. 4) and additive TiO_2 (0% produced natural cup, 1.5% produced white cup). The result of surface electric potential are converted to electric field strength with give an attention in thick of cup.

Fig. 4. Shape of cup (180, 225, 240)

III. RESULTS AND DISCUSSIONS

III.1. Raw material storage

There are four kinds of materials that used in this research. From (Fig. 5) show that, Polypropylene have negative charge and the others are positive one. It is caused polypropylene is a non polar with negative triboelectric / electrostatic series (Table 1).

Table 1. Triboelectries series [5]

PE	Polyethylene
PVC	Polyvinyl chloride
PP	Polypropylene
PET	Polyethylene terephthalate
PC	Polycarbonate
POM	Polyoxymethylene
PMMA	Polymethylmethacrylate
PA	Polyamide, nylon66

After symmetric rolling friction with any combination of (different) materials, upper one has negative charge and lower one has positive charge.

Surface electric potential of material in raw material storage is higher than another because there are too many materials that stored; therefore an electrical induction was happened. From that phenomenon, optimum relative humidity is about 50 – 55 %, and materials which have to store in raw material storage is boundaries.

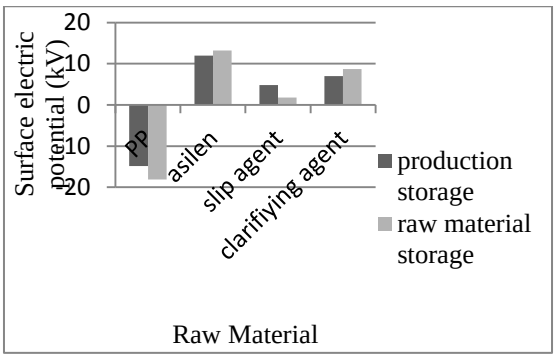

Fig. 5. Surface electric potential in storages

III.2. Optimum humidity in process production

Negative charge of polypropylene is higher than positive charge (Fig. 6). This is because polypropylene has negative triboelectric series. Polypropylene is non polar polymer, which has Lewis acidity (α) < 0.18 and Lewis basicity (β) < 0.25 (Table 2). A negative value shows dominating Lewis-Base properties, while positive values appear from surfaces with rather Lewis acidic properties. Lewis basicity β, the ability of the polymer surface to donate electron pair, controls the positive surface charge density. The acidity parameter α, the ability of the polymer surface to accept electron pairs, determines the negatives charge density [2].

Table 2. Electron pair acceptor (α) and donator (β) parameters determined for several polymer surfaces by means of solvatochromic experiments [6]

Polymer	α	β	$(\alpha/\beta - 1)$
PA	<0.86	<1.13	−0.23
PET	<0.54	<0.66	−0.19
PS	<0.29	<0.35	−0.16
PMMA	<0.52	<0.55	−0.05
PE	<0.18	<0.25	
PP	<0.18	<0.25	
POM	<0.59	<0.53	+0.12
PVC	<1.51	<0.76	+0.99

Polypropylene is an insulator. Surfaces charges in these insulating materials are ions formed by dissociation of adsorbed water molecules that accumulate under the local electrostatic potential. Atmospheric water is thus the source and sink of ions in insulators, thus contributing to potential build-up and dissipation [7]. With increasing humidity, small amounts of water can either form adsorption layer on to polymer surfaces or swell the polymer surface. The formation of water containing layers is connected with an introduction of ionic species, increasing the surface conductivity that promotes triboelectric charging [2].

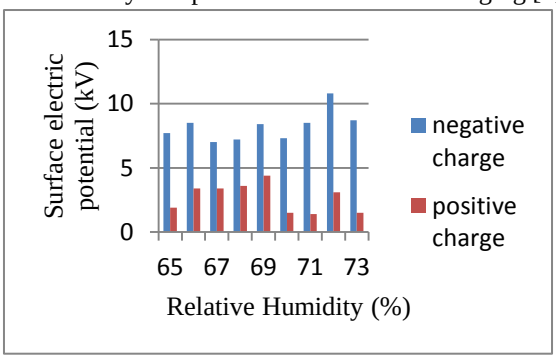

Fig. 6. Surface electric potential depends of charge

Increasing the atmospheric humidity strongly influences the charging behavior of polymer. The presence of water on polymer surface can contribute to the dissipation of charges and control the apparent charging behavior. Traces of water can support the discharging of polymer surfaces, because the water molecules are able to dissociate by themselves and form hydronium ions and hydroxyl ions [6]. Collisions between ion of water and polymer surface was happened that collisions make free charges (electron) transferred. Electron on polymer surface moved to ionic water on air and neutralized by ion charges on air. This phenomenon happened because water is a polar (which electron transfer more easily). Free charges on polymer surface (electron) are attracted by proton in water on air. In the other hand, positive charge on surface polymer was neutralized by water's electron from molecule's of air to that surface [8].

In lower moist content of air, the moisture around the polymer is accordingly less, electrostatic on surface polymer easily united because its molecule could not be moved. Therefore electrostatic of cup will be accumulated [8; 9]. With increasing relative humidity, the exchanges of ionized charge also increase and transferred to reduce their charge. Water is a good conductor, which electron move easily on the surface. A conductor become electric field if electric flow on it [8]. The surface charge will be decreased strongly by increasing relative humidity. By increasing relative humidity, conductivity of polymer increase and resistivity will decrease. However, with increasing the humidity the surface charges remains constant, while the surface resistivity decrease more and more. An increase of the atmospheric humidity decreases the surface resistivity while the total surface charges remain nearly constant [2]. Charges of surface polymer will transfer to water, which is a conductor. But conductor could not be received too much charge. On time, when the ability of conductor to catch charge was limit, the electron will be released again. For this reason, in higher relative humidity, electron ion surface polymer will be accumulated again.

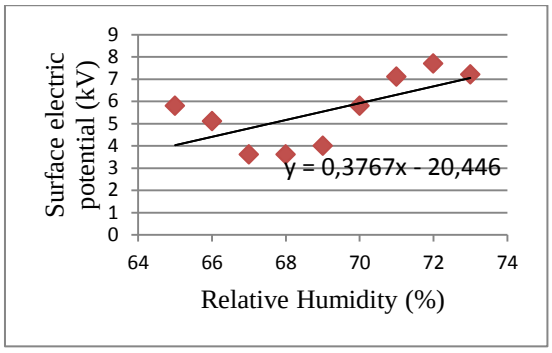

Fig. 7. Surface electric potential depends on relative humidity

From Fig. 7, to eliminate accumulation of electrostatic, optimum relative humidity on the production process is about 67 – 69% RH.

III3. The pulling power of cup against gravitation force

The duration of cup to fall could be an indicator the performance of cup in application filling drinking machine. Pay attention not only surface electric potential but also type of charge. The observation of processing cup to fall had been done by two methods, manually and application in filling drinking machine. Assumption that cup 1 is upper and cup 2 is lower (cup 2 can fall by itself as gravitation force or fall slowly because of pulling power). From three observations which had been done (Table 3-5) show that pair of cup with similar or different charge, cup 2 fall slowly if the differences of surface electric potential maximum 6.7kV and 3.0kV for single cup.

Falling process of cup in falling drinking machine is influenced by pulling power (Fig. 8-10). To solve this problem, speed of filling drinking machine must be diminished. Speeds of machine with electrostatic cup know in Table 6. By 67 - 69 % relative humidity, the electrostatic cup force will decreased, therefore speed of machine could be raised from 180 – 200 rpm to 220 - 250 (for cup 180) and from 80 – 100 to 140 – 160 rpm.

Table 3. The measurement fall of cup 240 white on 61°C (manual)

	Surface electric potential (kV)					fall	Deviation
	cup 1		cup 2			of	electric
No	pole +	pole -	pole +	pole -	time(s)	cup	potential (kV)
1	8.7		2.5		1	fast	6.2
2		6.6		1.9	1	fast	4.7
3	2.8		2.7		1	fast	0.1
4	2.9			4.8	2	slow	7.7
5	2.7			7.2	2	slow	9.9
6	8.9			2.5	2	slow	11.4
7		9.1		2.4	2	slow	6.7
8	1.7			7.8	2	slow	9.5

Table 4. The measurement fall of cup 180 natural on 61°C (manual)

	Surface electric potential (kV)					fall	Deviation
	cup 1		cup 2			of	electric
No	pole +	pole -	pole +	pole -	time(s)	cup	potential (kV)
1		1.6		0.2	1	fast	1.4
2		2.2		0.3	1	fast	1.9
3		1.9		0.3	1	fast	1.6
4		0.5	0.2		1	fast	0.7
5	2.3			0.6	1	fast	2.9
6		1.1	2.1		1	fast	3.2
7		1.7		0.2	1	fast	1.5

Table 5. The measurement fall of cup 180 white on 30°C (manual)

	Surface electric potential (kV)						
	cup 1		cup 2			fall of	Deviation electric
No	pole +	pole -	pole +	pole -	time(s)	cup	potential (kV)
1	3.5			2.2	38	slow	5.7
2	2.7			5.2	80	hard	7.9
3	4.7			2.7	120	hard	7.4
4	5.5			1.4	120	hard	6.9
5	2.6			1.7	30	slow	4.3
6	2			4.8	100	hard	6.8
7	3.3			5.6	120	hard	8.9
8	5.8			2.9	520	hard	8.7
9	2.3			3	10	slow	5.3
10	6.6			2.2	235	hard	8.8
11	4.1			2.9	240	hard	7

Table 6. Performance of filling drinking machine with electrostatic cup

No	Cup	Color	Falls	Speed of Machine (rpm)	Machine
1	180	White	fast	220 - 250	Machine A
			slow	200 - 220	
			hard	180 - 200	
2	225	White	fast	140 - 160	Machine B
			hard	80 - 100	

Fig. 8. Pair of cups condition (high electrostatic)

Fig. 9. Pair of cups condition (middle and low electrostatic)

Fig. 10. Cups in bucket of filling drinking machine (influence of electrostatic)

III4.Decide charge decay time

Surface electric potential might be accumulated after a long day in preservation process.

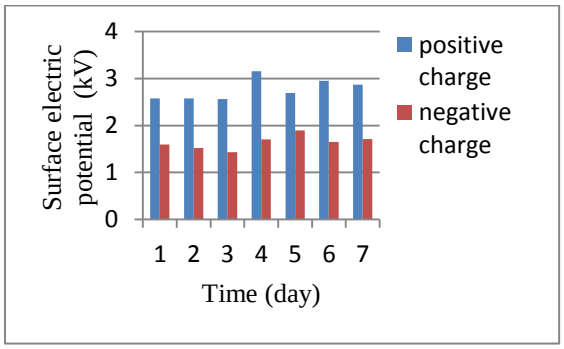

Fig. 11. Charge decay time of cup

In (Fig. 11) shows that positive charge has surface electric potential higher than negative charge. It is because of relative humidity more significant effect on the dissipation rate for positive charge [7]. In surface electric potential positive charge has charge decay time faster in lower relative humidity. That's because positive charge is easily increasing in same time of preservation. Faster decay of positive charge is due to higher cation mobility at the polymer surface. From the experiment (Table 7), 33 – 51 % relative humidity, give charge decay time about 7 days. From 47 % relative humidity surface electric potential will be increased started therefore, for recommendation keep cup in good storage with relative humidity 33 – 40 %.

Table 7. Humidity of storage in preservation

Time (day)	1	2	3	4	5	6	7
Humidity (%)	39	33	40	51	50	47	48

III5.Decide influence of surface temperature polymer

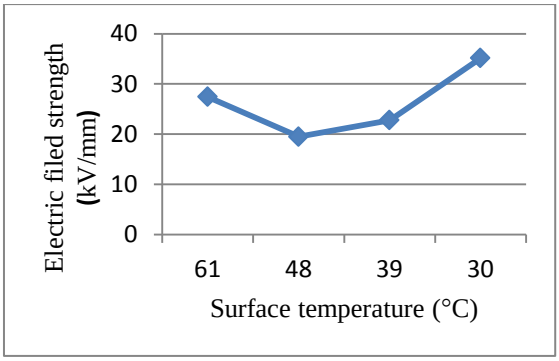

Fig. 12. Electric field strength depends on surface temperature

Fig. 12, show that electric field increased with surface temperature polymer decreased. When cup spontaneously come out from injection molding, electrostatic still accumulated. This is because friction collision and melting process of polymer. Another reason is cup at first come out not contacting with air yet. After 4 hours preservation, cup has surface temperature about 48°C. By higher surface temperature of polymer, there are electrons with faster rate in mobility. Because of that electron will transfer to the air which has 66 % relative humidity (Table 8). After days of preservation (surface temperature decreased) electric field strength increased. The conductivity polymers are disordered material with free charge carries whose mobility decreased with decreasing temperature. Polymer becomes insulating at low temperature [10].

Table 8. Surface temperature of cup and humidity of storage in preservation

No	Surface temperature of cup (°C)	Humidity (%)	Time of storage(hours)
1	61	70	0
2	48	66	4
3	39	61	8
4	30	39	24

III6.Decide shape of cup

In this experiment, we used some of cup with identification as 180, 225 and 240. Theirs dimensions shown at Table 9.

Table 9. The dimensions of cup

Cup	Height of cup (mm)	Thick of cup (mm)	Surface area (mm^2)	Angle(°)
180	91	0.23	1410.50	6.33
225	118	0.27	1752.3	6.22
240	119.5	0.29	1810.43	5.42

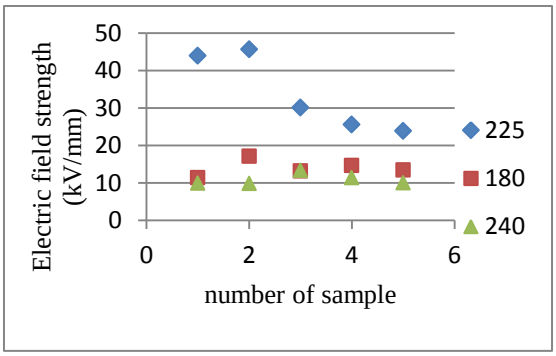

Fig. 13. Electric field strength depends on shape of cup

The influence shape / dimension of cup to accumulation of electrostatic shown in Fig. 13, that cup 225 has higher electric field strength than 180 and 240. Three reasons of that phenomenon are electric charge of a material / polymer actually on the surface. They are mostly stay on a sharp surface and have higher surface electric potential that flat one. A sharp surface is also easier to be inducted [8], the magnitude of the electrostatic charging of a given material is dependent on several parameters such as the surface area of contact, the size and shape of the material [1], sorption in thick polymer specimens is essentially irreversible due to very slow desorption kinetics. Charging state of a thick polymer specimen is thus dependent on contributions from polymer surface and polymer bulk, where the bulk contributions charges very slowly and constant [7].

III7.The influence of TiO2 (colored additive)

In Fig. 14, show that white cup with TiO_2 as a color additive has electric field strength higher than natural cup (without color additive). The synthesis of the particle responsive to electric field have included three or

more steps by which electric layers were coated (magnetic polymer particles coated by amorphous titanium), the size and its distribution of magnetic polymer particles and the thickness of the coated titanium out layer [11].

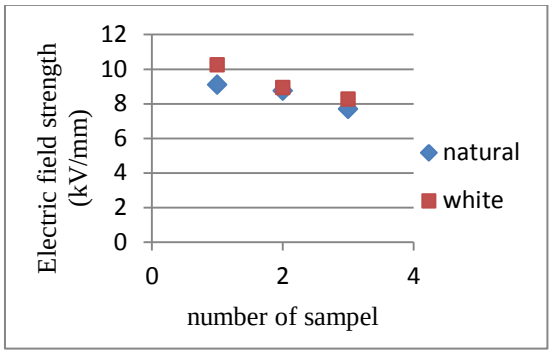

Fig. 14. Electric field strength depends on color of cup

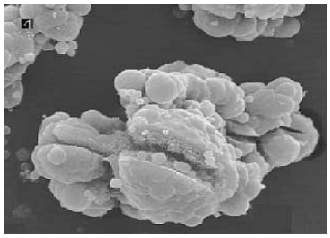

Fig. 15. The SEM images of TiO_2

Fig. 15 presents the SEM images of TiO_2 composite particle which the form of it is roughly spherical. The particles in Fig. 15 are very bumpy in surface. This is due to the thicker coating of amorphous titanium [11]. Except that reason, titanium has resistivity about 39 μΩcm -1 [12].

IV. Conclusion

The influence of humidity in electrostatic accumulation of cup, which is produced by injection molding show from reduction of surface electric potential in optimum relative humidity about 67 – 69%. In optimum relative humidity, could raise speed of filling drinking machine used electrostatic cup. The pair of cup with similar or different charge did not disturb performance of filling drinking machine in 6.7kV maximum surface electric potential and 3.0kV in single cup. Electrostatic of cup could not be disappearing forever. There are charge decay time, when electrostatic is still controlled. It is almost 7 days; in humidity of storage about 33 – 40 %. Characteristics of cup (temperature of cup, shape of cup and TiO2 additive) have influences in accumulation of electrostatic. It is important to have advance experiment to give longer charge decay time and to know the influence of printed process in accumulation of electrostatic cup.

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