ELECTROSTATIC SEPARATION AND RECOVERY OF MIXED PLASTICS

Chuanfu (Chuck) Xiao, Laurence Allen III and Michael B. Biddle, MBA Polymers, Inc.
Michael M. Fisher, American Plastics Council

Abstract

A triboelectric separator manufactured by Plas-Sep, Ltd., Canada was evaluated at MBA Polymers, Inc. as part of a project sponsored by the American Plastics Council (APC) to explore the potential of triboelectric methods for separating commingled plastics from end-of-life durables. The separator works on a very simple principle: that dissimilar materials will transfer electrical charge to one another when rubbed together, the resulting surface charge differences can then be used to separate these dissimilar materials from one another in an electric field.

Various commingled plastics were tested under controlled operating conditions. The feed materials tested include commingled plastics derived from electronic shredder residue (ESR), automobile shredder residue (ASR), refrigerator liners, and water bottle plastics. The separation of ESR ABS and HIPS, and water bottle PC and PVC were very promising. However, this device did not efficiently separate many plastic mixtures, such as rubber and plastics; nylon and acetal; and PE and PP from ASR.

All tests were carried out based on the standard operating conditions determined for ESR ABS and HIPS. There is the potential to improve the separation performance for many of the feed materials by individually optimizing their operating conditions. Cursory economics shows that the operation cost is very dependent upon assumed throughput, separation efficiency and requisite purity[1]. Unit operation cost could range from $0.03/lb. to $0.05/lb. at capacities of 2000 lb./hr. and 1000 lb./hr.

Background

When various materials are rubbed together, one or more materials become positively charged, and the other(s) become negatively charged or remain neutral. A triboelectric separator sorts materials based on surface charge transfer phenomenon. Several references to triboelectric separation have appeared in the literature (Norman L Weiss, 1985; Johannes Brandrup, 1996).

A triboelectric separator manufactured by Plas-Sep, Ltd., Canada was evaluated at MBA Polymers, Inc. (MBA) as part of a project sponsored by the American Plastics Council (APC) to explore the potential of triboelectric methods for separating commingled plastics. In the Plas-Sep triboelectric separator shown schematically in Figure 1, particles are allowed to contact one another in a rotating aluminum drum to allow charging and then are directed to fall through an intensive horizontal electric field. The angle of the tube can be changed to alter material residence time. Negatively charged particles are pulled toward the positive electrode and positively charged particles are attracted toward the negative electrode. In this way, positively charged material is separated from negatively charged material.

Generally, material charging is based on relative position in a triboelectric series. Table 1 lists a triboelectric series reported by Plas-Sep Limited. According to this series, PET is positively charged in a mixture of PVC and PET, while it becomes negatively charged in a mixture of PET and PP

Experimental

Table 2 summarizes the material mixtures that MBA Polymers, Inc. evaluated for this project.

Particle size appears to be very important to triboelectric separations, so an effort was made to study this. If particles are too large (much larger than 4-5 mm according to Plas-Sep) they will not be deflected sufficiently by the field. If particles are too small, they will tend to accumulate on the electrodes themselves, causing other falling particles to be somewhat insulated from the horizontal field.

The thickness of plastic chips might be another important factor for triboelectric separation, although we didn't look into it during this study. Film-like chips have higher surface area per unit volume, which would produce higher surface charge per mass as compared to non-film chips. The characteristics of film chips, such as lightweight, high surface charge and slow falling velocity would ultimately lead to more deflection in the electric field. Film plastics might yield an improved separation in a triboelectric separator based on this analysis.

Different grinders and processes were required for different material streams, particularly if metal was

[1] In this paper, purity is defined as the weight percentage of an individual material (component) in a sample.

present and/or the original parts were large. The sample was ultimately ground to ≤8 mm (5/16") nominal using a granulator. The grinding process actually produces a wide range of particle sizes, so that sieving was necessary to narrow the distribution of the samples.

The samples were screened into the following size ranges:

- 0-2mm [<9 mesh]
- 2-4mm [9-5 mesh]
- 4-6.3mm [5 mesh – 6.3 mm (1/4")]
- 6.3-8.0mm [6.3mm (1/4")-8.0mm (5/16")].

The samples were marked carefully with the appropriate material type and size range.

Samples of different plastics were then fully blended at the desired mix ratio to make sure that the sample was evenly distributed and homogeneous before using. In many cases this was not necessary because the original sample was in the desired or "real world" ratio.

Batch experiments were conducted using the Plas-Sep machine. A known quantity of feed material (about 7 pounds) was blended and placed into the charging drum. The drum was then rotated at about 32 rpm, to accomplish triboelectric charging. Charged materials fell through the intensive electric field and were deflected by the field according to their relative charges and particle sizes.

A chamber with twelve compartments was fabricated by MBA to collect and fractionate the falling particles, after they had passed through the electric field, see Figure 2. After collecting the material that fell into each compartment, each fraction was weighed and taken to MBA's identification laboratory for composition analysis. Because most of the samples investigated by MBA are "real world", they were not color-coded, and infrared identification was performed on a particle-by-particle basis to determine the polymer distribution in each fraction. This was a time-intensive process, but this enabled the use of real world samples and the results are very valuable.

Separation efficiency can be evaluated based on the purity and weight distribution at the specified test conditions.

Using color-coded computer ABS/HIPS as feed, a series of tests with various separation conditions was conducted using the Plas-Sep triboelectric separator. The objective of condition testing was to determine the general operating parameters that were critical to the separation. The feed variables included material percentage composition, particle size and moisture content. Variables for the operation included electrode voltage, charging time, feed rate, and air humidity.

Identifying small plastic chips by resin type is a time-intensive task. When possible, weight distribution plus color comparison were used for process optimization. ABS and HIPS were of different colors so that we could easily compare the purity of plastics in each compartment for different runs. The weight distribution along the chamber was indicative of separation performance. For a 50/50 ABS/HIPS mixture, a bimodal weight distribution would indicate a favorable separation. This means the materials fell into two distinct piles and that the weight percentage in the middle area of the chamber was small. Thus, an optimal separation should produce high purity products at both sides and low weight percentage in the middle chamber(s).

Condition Testing and Analysis

Charging Time

In triboelectric separation, material charging can be a very critical parameter. Uncharged material tends to drop in the middle of the chamber. When two materials are brought in contact, they may be charged due to rubbing together. Theoretically, without rubbing, charging might be too low. On the other hand, overcharging might cause the two materials to be overly attracted to one another and become inseparable when free-falling between the electrodes. Long charging time also slows the process and hurts economics. Appropriate charging time required determination by testing.

Figure 3 summarizes the results of various running times. It should be noted that a precise charging time could not be easily determined, because the materials exited over a period of time. Seven pounds of feed material discharged from the drum consecutively in a few seconds or minutes, although the material was fed to one end at the beginning. For convenience, a total runtime was used as an indicator of the mean charging time when the weight of feed material remained constant.

By changing tilting angles of the rotating charging drum, runtime ranged between 0 and 8-1/2 minutes for a seven-pound sample. Zero charging does not exist in reality because materials in contact are charged by agitation or mixing. Zero charging here is defined as an operation without using the rotating charging drum. In this case, material was fed directly to the electrical field.

As shown in Figure 3, weight distribution changes slightly from 0 to 3-1/2 minutes of runtime. The peak to the left represents a concentration of positively charged particles – ABS in this experiment. When

runtime reaches 8-1/2 minutes, the separation performance becomes less favorable. More materials drop in the middle of chamber. The product purity for the long runtime was actually the lowest of all. Thus, overcharging is not preferred.

By visually comparing the purity of products, 1 min. 42 sec. runtime and zero charging gave the best performance. Considering the operation inconsistency of hand feeding, 1 min. 42 sec. runtime was applied in the subsequent experiments.

Electrode Voltage

Figure 4 shows separation results at various electrode voltages. At low voltages (-33/+33 and -40/+40 kV), more materials drop in mid chamber. At 50/50 kV, less material is accumulated in mid chamber. When voltages increase to 60/60 or 68/68 kV, materials become more evenly distributed along the chamber, and a new peak is formed at the right side. More HIPS report to the positive electrode. After taking purity into account, 60/60 kV was considered the best voltage for ABS/HIPS separation.

Particle Size

Figure 5 depicts a relation between weight distributions along the chamber vs. particle size of feed materials. For a fine material, 1-2 mm in diameter, the purity of products was low for both ABS and HIPS products. A weight peak slightly moves toward the positive electrode. When particle size increases to 4-6.3 mm and 6.3-8 mm, most particles drop in the middle chamber. Deflection of material toward either electrode is much lower. For a 2-4 mm material, two peaks can be clearly seen. The middle chamber contained less material. This means that most of the ABS and HIPS deflected toward the electrodes. The 2-4 mm sample was the highest in both purity and recovery of target ABS and HIPS products. Thus, materials with 2-4 mm size were used in the further experiments, verifying Plas-Sep Limited's recommendation.

Polymer-polymer Ratio

For post-use plastics, composition of target plastics may vary from lot to lot. The separator should be adaptable to accommodate such variation. The following test was designed to check if the separator is robust enough to handle composition variation.

Figure 6 presents the results from the composition investigations. As the ratio of ABS/HIPS increases from 10/90 to 90/10, the weight distribution changes dramatically accordingly with the shift of peaks. Generally, the purity of ABS and HIPS products is relatively stable with the composition change. However, the recovery (yield) of ABS and HIPS products did vary with percentage compositions. According to the color difference of the products from compartment to compartment, it was shown that separation of a low ABS/HIPS ratio was more favorable than a high ABS/HIPS ratio. When the ratio of ABS/HIPS was 70/30 and 90/10, more materials dropped in mid chamber and the splitting line between ABS and HIPS became unclear. The separation was still acceptable, but the efficiency was a bit lower (more mixed material to be recirculated through the process). The percentage composition of real-world material will vary with different source materials. A 50/50 ratio was used for the experiments, unless a different ratio was suggested by the "real world" samples. As shown in Figure 6, a 50/50 ratio was not the optimal one. However, it might be appropriate to test the separation potential of many binary plastic mixtures with a triboelectric separator.

Separation Testing and Discussions

The parameter investigations were very useful in determining general operating conditions and sensitivities. The following operating parameters were chosen for the next project stage based on the investigations with ABS/HIPS:

Charging time – 1 min 42 sec total runtime
Electrode Voltages – -60/+60 kV
Particle Size of Feed Material – 2-4 mm
Percentage Composition – Any, but the optimal composition is <70/30

Evaluations were undertaken using the operating parameters from the testing discussed in the previous section. The first test was ABS/HIPS separation, including a one-stage separation and a multiple-stage separation. Then, several different plastic mixtures were tested. The results for several mixtures are reported here. The optimal operating conditions established for ESR ABS/HIPS separation were used in the subsequent testing.

A. IT Plastics-Electronic Shredder Residual

a) ABS vs. HIPS – One-Stage Separation

ESR ABS/HIPS separation was discussed in the preliminary section. Teal ABS was sorted from gray HIPS as demonstrated in many experiments. The results shown in Figure 7 represent the best separations based on preferred operating parameters. The following operating conditions were used:

Particle size of feed:	2-4 mm
Sample weight for each run:	7 lbs.
Electrode voltages:	-60 /+60 kV

Charging time: 1 min 42 sec[2]

For the 50/50 (ABS/HIPS) mixture, the bimodal weight distribution was the first indication of a favorable separation. The first peak was located at compartments 4 and 5, and the second peak is at compartments 11 and 12. In this single run, the highest purity of HIPS in one compartment was 98.85% while the highest purity of ABS reached 92.69%.

b) ABS vs. HIPS – Multiple-Stage Separation

The objective of multiple-stage testing was to determine the potential minimum stages required for a commercial operation to achieve both high purity and high recovery. Separation efficiency, number of stages, product purity and recovery are interrelated. When separation efficiency is high, fewer separation stages are needed and vice versa. In several commercial operations, such as found in the mining industry, three or more stages are applied for a typical electrostatic separation process (B. A. Wills, 1979).

As shown in Figure 8, ABS purity was upgraded from 54.68% to 71.06% after one stage, while HIPS purity was elevated from 45.32% to 71.36%. The product purity is certainly dependent on the splitter location. Basically, purity and recovery should determine a cut point where both are acceptable. In this testing, the cut point of the splitter was set according to the color difference by visual judgment.

In the second stage: purity of ABS: 71.06%→87.65%, purity of HIPS: 71.36%→90.11%. In the third stage: purity of ABS: 87.65%→98.20%, purity of HIPS: 90.11%→98.03%.

When purity increases, it becomes harder to further upgrade it. It is difficult to get an extremely high-purity product in a single stage with an acceptable yield. Therefore, multiple-stages might be the best solution. As with many processes, one reaches diminishing returns at some point.

Recovery rates of the ABS and HIPS are also important. Examine the 3rd stage-a and 3rd stage-d, and consider just the two high volume product streams (ABS and HIPS, respectively). If the middling were not recirculated back to the previous operations, 54.66% of ABS was recovered at a purity of 98.20% while 46.61% of HIPS was recovered at a purity of 98.03%. In a commercial operation, the middling would likely be circulated back to the previous stages as shown in the Figure. This demonstrates how the recoveries of ABS and HIPS in a closed circuit would be much higher than those obtained in an open circuit.

A three-stage process can produce HIPS and ABS purities of over 98%. Yields should be determined in a closed-circuit process, but are estimated to be over 80%.

c) ABS vs. PC/ABS

Experimental results indicated that no effective separation was achieved between ESR ABS and PC/ABS using the Plas-Sep triboelectric separator.

d) ABS, PC/ABS and PC/ABS FR (flame retardant grades)

Figure 9 indicates that ABS, PC/ABS and PC/ABS FR can be separated, although the separation efficiency was very low in a one-stage separation. Purities of ABS, PC/ABS and PC/ABS FR are increased from 33.3% in the feed material, to 77.6%, 69.5% and 44.5% respectively. Multiple stages would not be very efficient for this mixture if the separation efficiency in a single stage is this low.

B. Automotive Plastics

a) Radiator End Caps

Acetal, as a minor component, is commonly found in this end-of-life stream. The sample studied had been density sorted, acetal was added back into the mixture to simulate the material before it went through a density separation. Density separation could not remove all of the acetal. In this triboelectric separation study, a favorable separation between nylon and acetal from radiator end tanks was not seen.

b) PP vs. PE (ASR)

Some triboelectric separation between PP and PE obtained from a density separation of ASR was observed in Figure 10. However, most of the PP and PE particles reported to the middle chambers and separation was not favorable overall. Plas-Sep has reported very good separations with PE/PP mixtures from other sources (Jim D. Brown, 1998). Perhaps surface contamination on this ASR stream makes this separation more challenging.

C. Refrigerator ABS vs. HIPS

Refrigerator ABS and HIPS can be more or less enriched as indicated by the testing. Unfortunately, most materials were accumulated in mid chamber so this separation is probably not practical from an efficiency standpoint.

[2] Total runtime – from the time of the charging drum starting to run to the end of material dropping

D. Water Bottle

In a PC/PVC (95/5) mixture, PVC was easily pulled from PC. A ratio of 95/5 PC/PVC was used to simulate a real-world sample from this stream.

As shown in Figure 11, a PC purity of 99.51% is observed after a one-stage separation. A 90% recovery of PC can be obtained if 99% purity is the separation target. In a closed circuit and multiple-stage process, higher purity and recovery can be anticipated.

E. Additional Considerations

Improving Separation Conditions

In this study, various plastic samples were prepared by cleaning, grinding, screening and blending. Sample preparation and identification consumed the majority of the time. Thus, only ESR ABS and HIPS were fully tested while many other materials were run through the separator under the operating conditions determined for good ABS/HIPS separation. We assumed that if the feed material was potentially separable, a reasonable separation could be observed, even though the best separation parameters for that material were not determined. When no separation was observed, we assumed that the mixture is inseparable with triboelectric separation. This approach is appropriate for this initial feasibility study.

Humidity

Weather conditions in the San Francisco area changed from day to day, particularly during the fall and winter months when these studies were done.

On very humid days, ESR ABS and HIPS separation seemed to be affected in some of the tests. On the other hand, it was also demonstrated that separation under a 50% relative humidity was acceptable for ABS/HIPS separation. Due to the unclear effect of humidity on different materials, some “inseparable” mixtures might become somewhat more separable at a lower humidity.

High humidity was also observed in separating water bottle PC and PVC. However, a promising separation was still observed. This may imply that air humidity is not always critical for all materials. Dehumidification of the room for a triboelectric separator is probably warranted, but we do not believe that it would have made a dramatic difference in any of our tests based on what our researchers observed from normal humidity changes in our process area.

We were not able to install humidity control for this limited feasibility project. For further studies, an isolated room with dehumidifiers to lower the humidity to less than 45% might be worthwhile.

Sample Collection

During this study, a chamber with 12 equally divided compartments was fabricated to collect separated products. The experimental results from this chamber have produced valuable data. However, the 11 splitters caused extensive chip bouncing among the compartments. In a commercial operation, such bouncing would be reduced because only one or two splitters would be used instead of 11.

Feeding and Discharging of Materials

Continuous feeding and discharging capability was not included in the basic triboelectric separator used in this study. Thus, all experiments were conducted in a batch mode. The actual capacity of the unit was not determined, but Plas-Sep suggested in verbal communications that it should be able to process between 1,000 and 2,000 pounds per hour.

Real World Samples

While most of the samples tested came from actual end-of-life recycle streams that had been processed by MBA Polymers, Inc., only one tertiary plastic mixture was tested. Most of the samples were binary mixtures. Real-world samples might contain more than three plastics in a single mixture.

Cursory Economics

Table 3 presents an economic evaluation based on a single-stage unit with a capacity of 1000 lbs./hr. and a two-stage unit with a capacity of 2000 lbs./hr. Yields of 70% and 75% respectively were assumed.

The economic were developed with the following important assumptions:

- These economics are NOT for a stand-alone system. It is assumed that this system is added to the end of an existing recycling line that has already size-reduced the plastics to roughly ¼” or less particles, liberated the various contaminants, and removed the non-plastic materials. This is also important because only one operator is assumed to be necessary and only parts of maintenance (primarily for regular blade removal and sharpening) and supervisory staffs are needed. If this is a stand-alone operation, the operating costs could be much higher just due to material handling and supervision issues.

- It is assumed that the average yields and throughputs are consistent.
- The capital costs are ballpark estimates based on MBA experience with various types of equipment. The use of used equipment could reduce these numbers. Installation costs can also vary dramatically, so these were not formally considered. The capital cost numbers are inflated slightly to include very low cost installation.
- The plastic material requires no pretreatment other than one-step granulation and fines removal. Screening and recirculation were assumed to be unnecessary. These operations can dramatically reduce throughputs through the size reduction step and decrease yields (more fines created and rejected). Please keep in mind, however, that MBA performed significant screening in many cases to control particle size variation for these tests.
- It is assumed that material is delivered to this system in small enough particles that only a single granulation stage is required. If large chips are supplied, a two-step granulation will likely be required, which would increase capital and maintenance costs.
- No electrical costs were included. The electrostatic systems will consume very little electricity, but the grinders can consume meaningful amounts depending on utility costs and efficiency of cutting (blade sharpness, etc.). The horsepower ranges are expected to be 75-100 for the 1000 lbs./hr system and 150-200 for the 2000 lbs/hr system. Electrical rates in CA are much higher than in other parts of the country. The dehumidification system might also require substantial energy.

For a capacity of 1000 lbs./hr., the projected cost on a product basis is about $0.05/lb., while the total cost falls to $0.034/lbs for 2000 lbs./hr capacity unit with two stages. If the yield is lower or more separation stages are required, the costs will be higher. This analysis is most sensitive to throughputs and yields; therefore, a more detailed analysis of the capital costs is probably not necessary at this time.

Summary

The testing of a triboelectric separator for plastic-plastic separation produced some promising results, even though many of the plastics tested could not be separated at high efficiencies in the preliminary study.

The technique has some material requirements such as dry particles, particles with appropriate size range (2-4 mm in diameter), and the apparent need for low air humidity in the operation area. All of these limitations can be addressed by specific process adaptations.

Based on the feasibility testing described in the paper, we found:

(1) The Plas-Sep device separated ESR ABS from HIPS. The highest purity of ABS and HIPS was 98% or higher.

(2) Separation of ESR ABS, PC/ABS and PC/ABS FR has potential, but the separation efficiency was very low.

(3) ASR materials are more complicated than ESR and more heavily contaminated. The separation trials of most ASR mixtures, such as rubber vs. plastics and nylon vs. acetal, were not successful. A slight separation of PP from PE from ASR was observed, however, separation efficiency was not high.

(4) A real-world refrigerator liner mix with 70/30 of ABS/HIPS was tested. A promising separation was not seen. Further research may be required to find why refrigerator ABS and HIPS perform differently from ESR ABS and HIPS.

(5) A highly promising separation was seen in the test of separating water bottle PC from PVC with a mixture of 95% PC and 5% PVC.

(6) Air humidity is a critical parameter for some feed materials. The separation of water bottle PC and PVC was not very sensitive to air humidity.

(7) Further studies may be required to improve the separation of individual materials and to check the feasibility of separating more complicated feedstock. The capacity of this device was not determined because feeding and discharging equipment was not included.

(8) Packaging/non-durable plastics were not included in this study. According to the triboelectric separation principle, however, there is a potential to separate some selected packaging/non-durable plastics. Further investigation is recommended.

(9) Operation cost of a triboelectric separator is closely related to its throughput and the purity requirements of the products. Based on cursory economics, the unit cost varies from $0.034/lb. at 2000 lb./hr. to $0.051/lb. at 1000 lb./hr.

Acronyms

ABS	Acrylonitrile-Butadiene-Styrene Copolymer
APC	American Plastics Council
ASR	Automobile Shredder Residue
ESR	Electronic Shredder Residue
FR	Fire Retardant
HIPS	High-Impact Polystyrene
IT	Information Technology
PA	Polyamide (nylon)
PC	Polycarbonate
PE	Polyethylene
PET	Polyethylene Terephthalate
PP	Polypropylene
PS	Polystyrene
PUR	Polyurethane
PVC	Polyvinyl Chloride

Table 1. Triboelectric Series for Some Polymers
(Adapted from introductory material of Plas-Sep)

Teflon	Negatively Charging
PVC	
PET	
PP	
PE	
PS	Positively Charging

Table 2. List of Samples for Triboelectric Separation

Sources	Material Types	Compositions
ASR	Rubber vs. Plastics	50/50
ASR	PP vs. PE	As received
ESR	ABS vs. PC/ABS	50/50
ESR	ABS, PC-ABS, PC-ABS FR	1/3 each
ESR	HIPS vs. ABS	Varies
ESR	PC vs. Rubber	3.2% and 2% rubber
Radiator End Caps	Nylon vs. Acetal	98/2 (Approximate)
Refrigerators	ABS vs. HIPS	70% ABS, 30% HIPS
Water bottle	PC vs. PVC	95% PC, 5% PVC

References

1. Adams, Charles K., *Nature's Electricity*, Tab Books, 1987
2. Brandrup, Johannes, *Recycling and Recovery of plastics*, Hanser/Gardner Publications, Inc., Cincinnati, 1996
3. Brown, James D., *An Industrial Electrostatic Separation Process*, Plas-Sep Ltd., 1998.
4. Personal communication with Dr. James Brown of Plas-Sep Ltd., Canada, 1998
5. *US Patent 5,289,922*, Mar. 1, 1994
6. Weiss, Norman L., *SME Mineral Processing Handbook*, Vol. 1, Society of Mining Engineers, 1985
7. Wills, B. A., *Mineral Processing Technology – An introduction to the practical aspects of treatment and mineral recovery*, Pergamon Press, 1979.

Table 3. Cursory Economics for Triboelectric Separation

Items	**Capacity:** 1000 lbs./hr. **Yield:** 70% **Pounds/yr.:** 3,570,000	**Capacity:** 2000 lbs./hr. **Yield:** 75% **Pounds/yr.:** 7,650,000	**Notes**
Size Reduction to 2-4 mm ($)			
Feed	12,000	14,000	
Granulator	50,000	80,000	
Fines removal system	16,000	20,000	
Triboelectric System – Stage I ($)			
Takeaway	18,000	18,000	
Recirculation	12,000		
One Separator	100,000	100,000	
Dehumidification	40,000	40,000	
Triboelectric System – Stage II ($)			
Takeaway		18,000	
Recirculation		20,000	
Two separators		200,000	
Dehumidification		20,000	
Capital Subtotal	248,000	530,000	
$/yr.	49,600	106,000	
$/lb.	**0.0139**	**0.0139**	
Labor, $/hr.			
1 Operator, 100% time	11.00	11.00	$11/hr.
Foreman, 25% time	5.00	5.00	$20/hr.
Maintenance, 20% time	3.60	3.60	$18/hr.
Subtotal	19.60	19.60	
$/lb.	**0.028**	**0.0131**	
Disposal Costs, at $60/ton			
$/lb. of product	**0.009**	**0.008**	
Totals ($/lb.)	**0.051**	**0.034**	

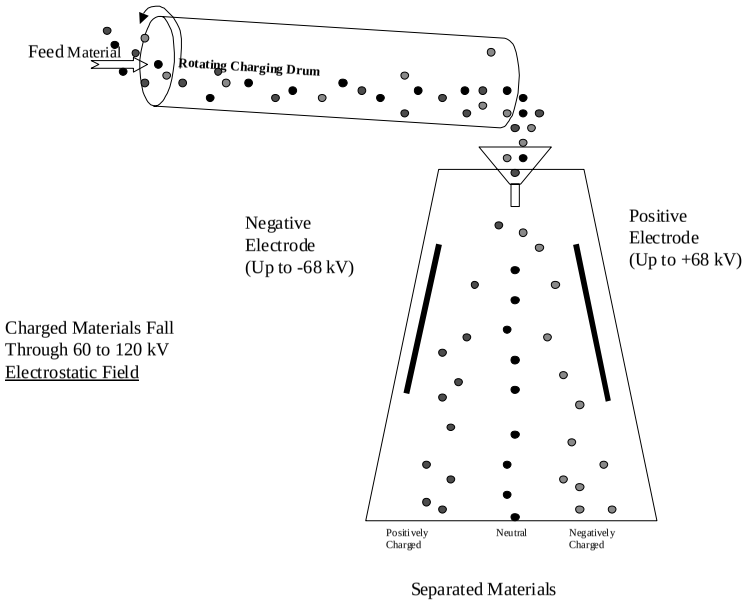


Figure 1. Schematic of Plas-Sep Triboelectric Separator

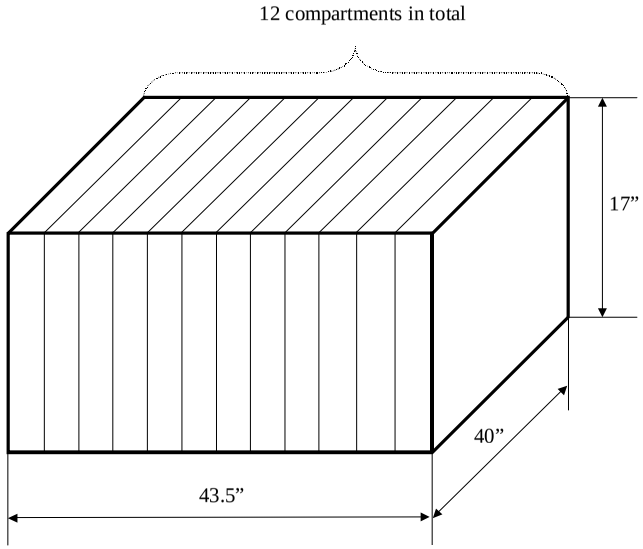
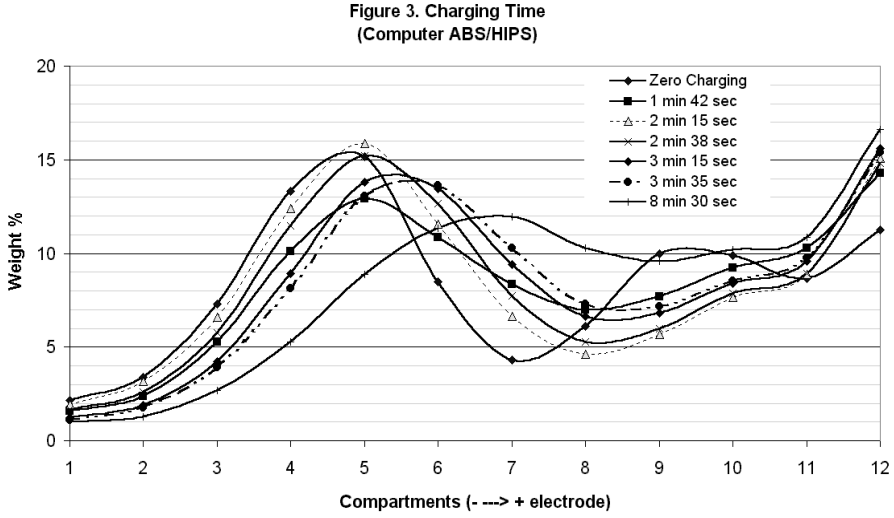


Figure 2. Sample Collection Chamber



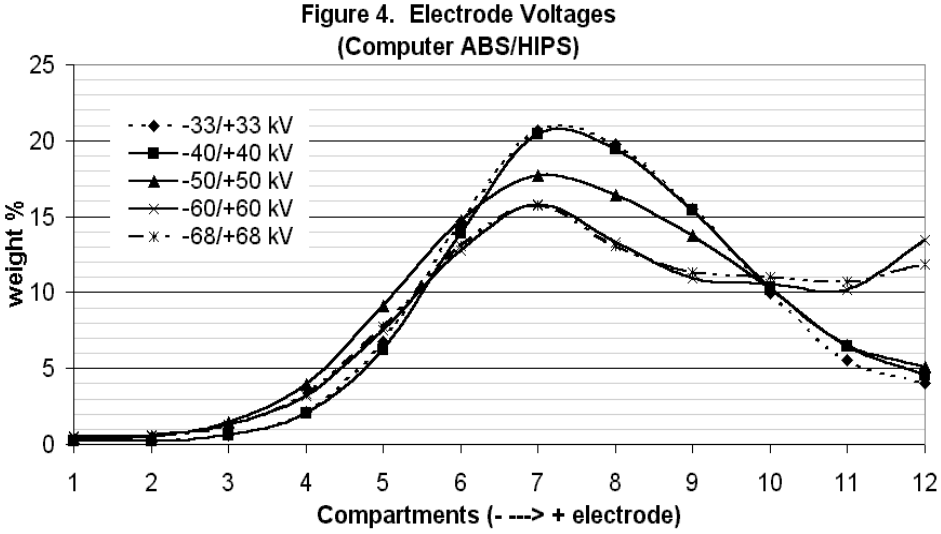


Figure 5. Various Particle Sizes of Feed Materials (Computer ABS/HIPS)

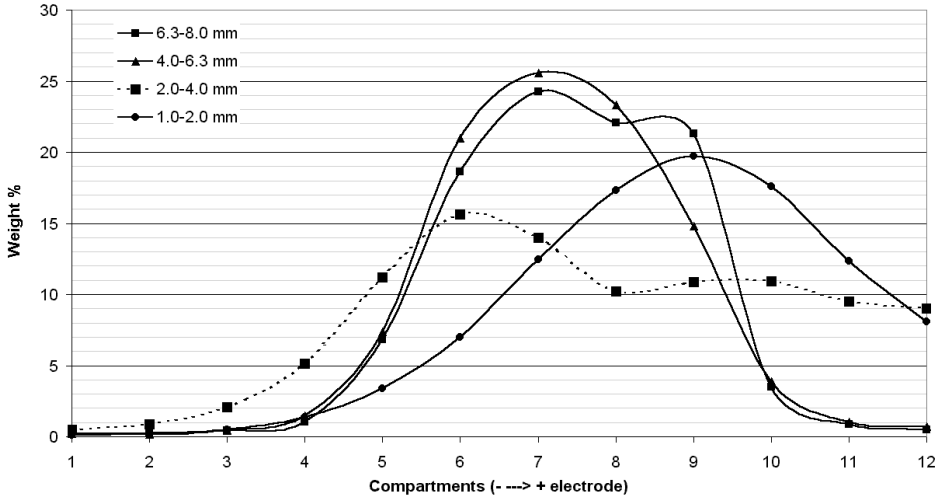


Figure 6. Percentage Composition of ABS/HIPS (Computer)

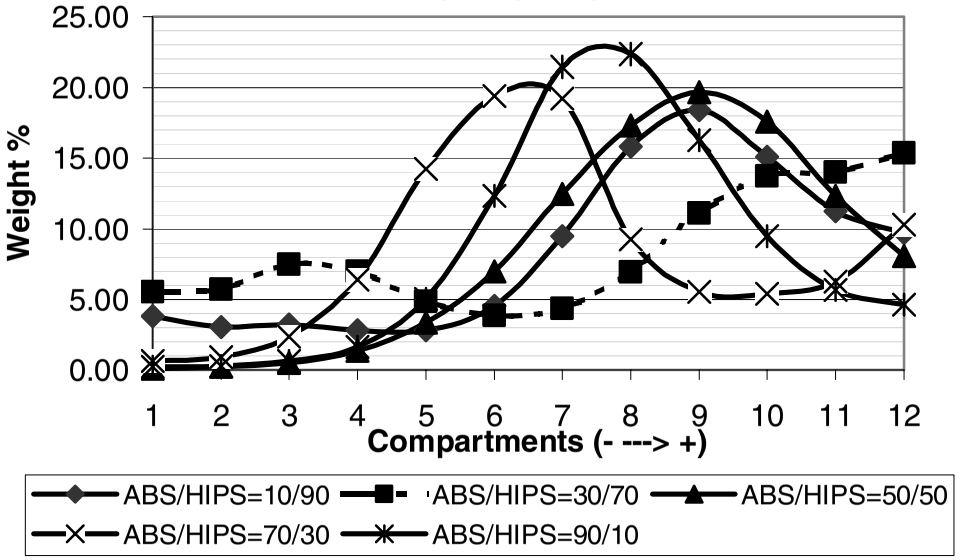
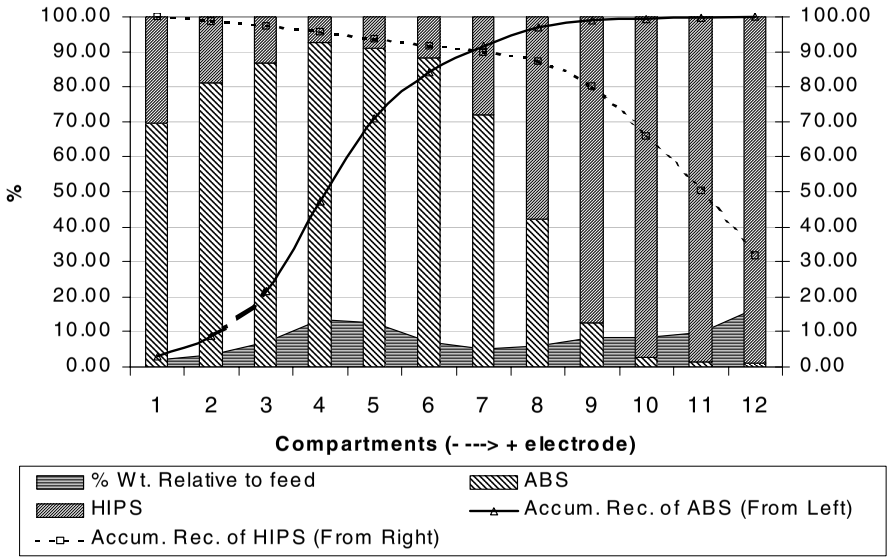


Figure 7. ESR ABS vs. HIPS (50/50)



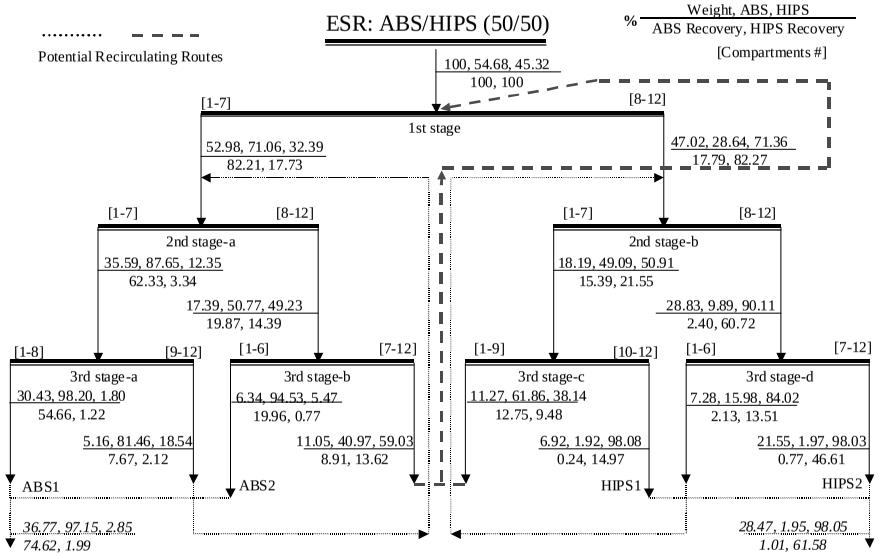


Figure 8. Multiple-Stage Separation of ESR ABS/HIPS under Triboelectric Separator

Figure 9 ESR ABS, PC/ABS and PC/ABS FR (1/3 each)

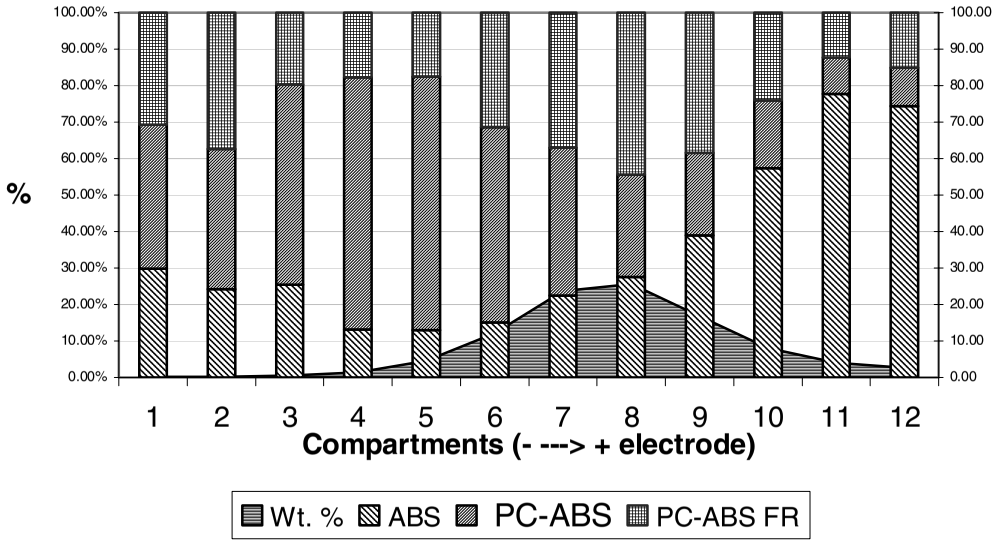


Figure 10 ASR PP vs. PE

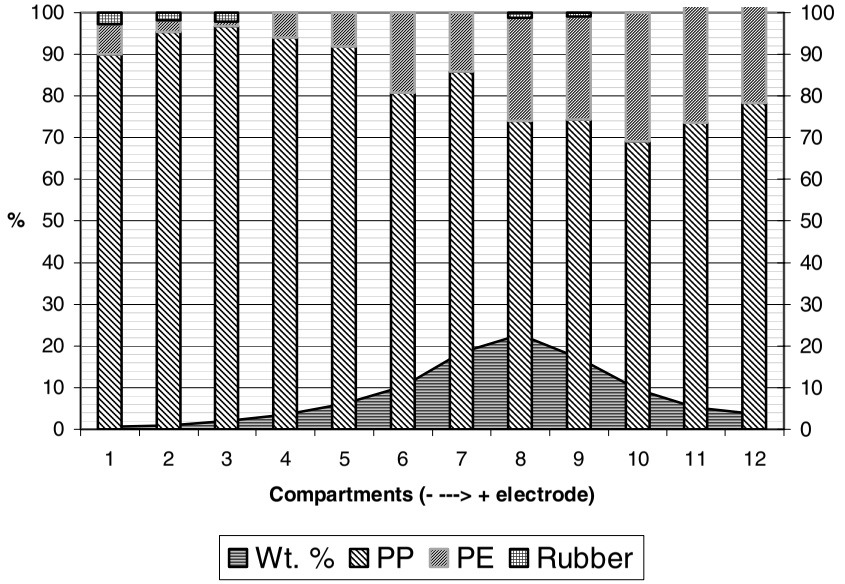


Figure 11 Water Bottle: PVC vs. PC