ELECTROSTATIC SEPARATION OF MIXED PLASTICS WASTE

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Abstract
A major environmental problem is mixed plastics waste. Because of the incompatibilities of the properties of different polymers, mixed waste is either land filled or reused in low value applications such as plastic wood. The barrier to economic re-use of these materials is separation into pure components. Recycled pure plastics can be used in place of virgin material and thereby much of the original value of these polymers can be gained. A dry, low cost, non-polluting process originally invented at The University of Western Ontario has been successfully scaled up to a commercial size of one tonne/hour. Several applications of this technology are explored.

Electrostatic Separation Process

A dry electrostatic process[1] was developed in the Applied Electrostatics Research Centre of The University of Western Ontario. When two dissimilar non-conducting particles come into contact, charge is transferred and one of the particles becomes negatively charged and the other positively charged. The charge polarity is determined by the so-called triboelectric series, A short version of that series[2] is given in Table 1. Any polymer higher in the table in contact with one lower in the table will charge negatively. Thus for example, PE will charge negatively in contact with PET, but will charge positively in contact with PVC.

Table 1. A Triboelectric Series for Some Plastics

PTFE, Teflon	negative charging
PVC, polyvinyl chloride	V
PE, polyethylene	V
PP, polypropylene	V
PS polystyrene	V
PET, polyethylene terephthalate	V
Lexan	V
Acrylic	positive charging

Chopped dry particles (5-10 mm size) of mixed plastics are fed continuously into the upper end of a slightly tilted, slowly rotating drum (Figure 1.). As the particles tumble over each other, they become charged due to the many and repeated contacts. The quantity and polarity of the charge on each particle depends on the contacts with other particles in the mixture. Because of the tilt of the drum, the particles migrate to the exit end of the drum where they fall through a strong horizontal electric field. The negatively charged particles are drawn toward the positive electrode while the positively charged particles are drawn toward the negative electrode. In this way in a mix of say PE and PP, the negatively charge PE product falls onto a conveyor near the positive electrode and is drawn off while the PP product is similarly drawn off on the negative side. The material that falls in the middle of the tower, a mixture of PE and PP, can be recycled through the process to increase the yield of products.

Figure 1. Schematic of electrostatic separation

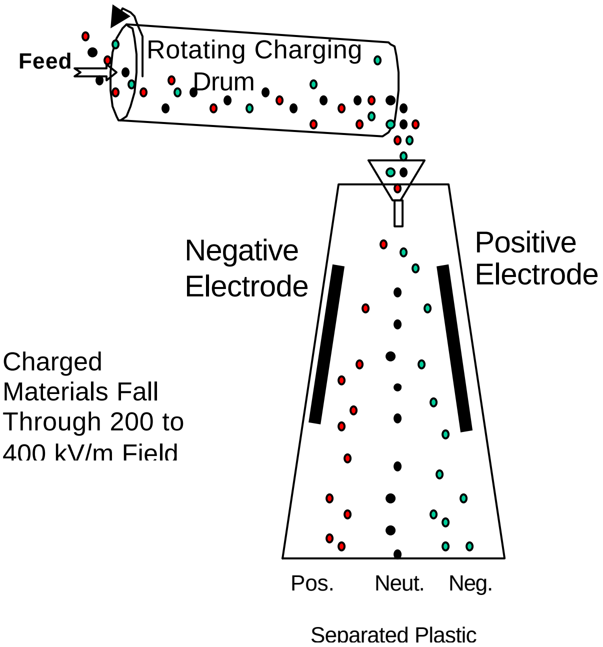

Figure 2. Photo of Separation Unit

Because this is an electrostatic process, moisture control is critical. An example of this is a PE/PP mixture. When dry, as seen in Table 1, the PE will charge positively while the PP charges negatively. This is reversed if the materials are at a moisture content which is in equilibrium with air at 50% R.H. and the PP then tends to charge positively while the PE charges negatively. Moisture can be controlled by a brief drying of the particles and by maintaining the relative humidity of the air surrounding the separation unit to below 50% R.H. A study sponsored by the American Plastics Council and carried out by MBA Polymers on the separation process was flawed in that the humidity during most of the separations exceeded 60% R.H. and the surface moisture content of the materials was too high.

Figure 2 is a photograph of the full sized, 1 tonne/hour commercial unit. The charging drum can be seen at the top of the photograph with the exit end pointed toward the viewer. The charged plastic particles fall from this exit end into the distribution funnel visible at the top of the separation tower. The function of the funnel is to direct the particles into a stream along the axis of the tower where they enter the strong electric field. This field spreads the particles in a direction perpendicular to the electrodes according to charge to mass ratio as suggested in Figure 1. The separated polymers which fall near the electrodes would be conveyed to product bins while the mixed material which falls in the middle of the tower would be recycled back through the process to increase the yield. The energy costs for running this unit are miniscule, approximately 800 watts for the ½hp motor to rotate the drum and 30 watts for each of the H. V. power supplies. Thus, to actually separate the materials, the cost is less that $0,001/kg. The major costs are shredding, grinding and drying in the preparation of the materials for the separations. These will be discussed later in the specific examples.

Binary 50:50 mixtures of polymers will generally be separated to above 99% pure streams with ~80% yields. Binary 90:10 mixtures yield a stream of 99.9% purity for the major component with similar or greater yield for the major component. The minor component can be purified but requires a second pass through the process. Multiple component mixtures can be separated since there are always dominant negative and/or positive charging polymers in any mixture. When these are removed, the charging of the remaining components can be completely different which allows the unraveling of complex mixtures albeit with multiple passes through the process. Because of the relatively low cost and small foot print for the separation units, where capacity is needed, a cascade of separation units is quite feasible.

Examples of Separations

a) Polyethylene(PE)/polypropylene(PP)

PE/PP mixtures are technologically challenging in that the density of the two polymers is essentially the same and they are very similar chemically; i.e., both contain only carbon and hydrogen. They differ only in the relative amounts of CH_2 versus CH_3 groups. The actual PE used in these separations was red while the PP was a mixture of yellow and light blue pieces. The materials were ground to 5-10 mm size in preparation for separation. Although PE and PP are not materials that will absorb large amounts of moisture, this mixture proved to be very instructive concerning the effects of moisture. Even when the material was at equilibrium in moisture content with air at 50% R.H. at 20-25^{0}C, sufficient surface moisture was on the particles that charging was affected, PE would tend to charge positively, PP negatively. Further, there seemed to be almost as much separation between the two colours of PP (yellow and light blue) as the PP from the PE. When the particles were dried excellent separations were obtained as shown in Table 2. The purities exceeded the target of 95% for a single pass through the process and the yields were very good (Table 2). These yields could be increased further if the actual purity of the products were lessened by adjustments to the process. The remaining mixed material was shown to be separable on a second pass so the yields only reflect a decrease in throughput, not waste material.

Table 2. PE/PP Separations.

Feed Comp, wt, %		Product Composition or Yield. %.			
		PE		PP	
PE	PP	Comp.	Yield	Comp.	Yield
50	50	99.8	70	99.7	80
10	90	~75		99.9+	85
90	10	99.9+	80	~70	-

Economic Analysis

This is an example of commodity thermoplastics – large volume, low cost plastics. Because of this, the quantities available for recycling would allow the equipment to be operated for 2 shifts/day (processing about 3,000,000kg/year). Three compositions are examined, a 50:50 mix, and mixtures of 90:10. The rated capacity of the separation unit is 1 tonne/hour so that for the 50:50 mix with the 70 and 80% yields respectively, 350 kg of PE and 400 kg of PP are produced per hour. The current values for recycle PE and PP are US$0.16 and US$0.07/lb convert to US$0.35 and US$0.15/kg respectively. Table 3 analyses the potential revenue of

Table 3. Revenue from PE/PP Separations

Description	50:50	10:90	90:10
PE, kg/hr	350	-	800
Value, $US/kg	$0.35	-	$0.35
PE Total value/hr.	$122.50	-	$280.00
PP, kg/hr	400	850	-
Value US$/kg	$0.15	$0.15	-
PP Total value/hr	$60.00	$127.50	-
PE + PP, value/hr	$182.50	$127.50	$280.00
Total/day, 2-8hr shifts	$2920.00	$2040.00	$4480.00
Total/year, 250 days	$730,000	$510,000	$1,120,000

the PE/PP separations using yield values obtained from separations in the commercial sized unit. Total value of products for this single pass operation varies from US$510,000 to $1,120,000 per year depending on the composition of the mixture with value increasing with PE content. The major operating cost is materials processing. The material must be ground to 5-10 mm particle size, then dried. These costs are common to any process needed to recycle plastics and have been estimated at US$0.10/kg or US$75.00/hr based on the 750 kg of product generated every hour. For the year these costs total US $300,000 leaving gross revenue of between US$210,000 and US$820,000 per year. This should be sufficient to cover any leasing and capital costs for equipment with a reasonably short pay back period.

b) Automotive tail light assemblies

Table 4. Automotive tail light separations

Separation Material	Yield per 1000 kg	
	PMMA, kg	ABS, kg
Original	220	350
PMMA Rich	198	-
ABS Rich	-	300

The tail light assemblies are an example of higher value engineering plastics. They consist of polymethyl methylacrylate (PMMA) and acrylonitrile butadiene styrene (ABS) in roughly a 40:60 ratio. For successful reprocessing of the material, particularly the PMMA, a very pure product is required (>99.9% pure) so the material must be purified in two steps. The purity requirements for the ABS are not quite as high but this material was also run twice through the process. In the initial separation, yields of PMMA and ABS are 55% and 58% respectively. In these second passes, higher yields of 90% and 86% are obtained. Details of the separations are given in Table 4. Yields are calculated based on 1000 kg of the original material. Since the re-separation of the PMMA and ABS rich fractions requires time, this needs to be considered in calculation of throughput in the overall separation scheme. Almost 500kg must be re-processed per 1000 kg of original mix to obtain the required purities. This effectively decreases the total throughput by one third. Thus output per hour of purified product is 130 kg PMMA and 200 kg of ABS.

Economic Analysis

Virgin PMMA and ABS have values of ~US$3.00 and US$1.20/lb. Recycle market prices for these polymers have not been established. For evaluation purposes, the recycled materials will be assumed to have values of US$1.50 and US$0.50 /lb. This value may be realized if the recycled materials are substituted for virgin materials, even at the expense of some additional processing costs. One shift operation will be assumed. This would require finding about 800,000kg of mixed plastic per year based on single shift operation and 250 days/year. This is based on 1000kg/hr capacity with 40% recycle operating 2/3 of the time. (The remaining time is used for the purification step). The value of product is shown in Table 5. The operating cost to generate this value is mainly the cost of grinding and shredding the assemblies. Because of the smaller amount of material which must be prepared for separation, the operating costs are estimated to be ~US$200,000. Thus a gross profit of about $800,000 can be realized.

Table 5. Value of Automotive Tail Light Recycle

Description	**Values**
PMMA produced/hour	130 kg
Value PMMA/kg	$3.30
Value PMMA/hour	$429.00
ABS produced/hour	200
Value ABS/kg	$1.10
Value ABS/hour	$220.00
Total value/hour	$649.00
Total value/year	$1,038,400

Conclusions

A low cost, dry, electrostatic process has been developed to a commercial scale for recycling mixed plastics waste. The process can be applied to almost any mixture with the economics being tied to the value of the plastics in the mix. Particularly attractive candidates for the technology are scrap and off spec products from manufacture since these are generally clean and usually a mix of only a few polymers. Product with very high purity can be produced. These products can be used in place of virgin materials. For both low cost commodity plastics and the higher value engineering thermoplastics, the Plas-Sep Limited process can be viable economically.

References

1. I. I. Inculet, G. S. P. Castle, J. D. Brown, “Electrostatic Separation of Mixed Plastic Waste” U.S. Patent #5,289,922, 1993.
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