Enhanced Plastics Recycling by Cyclone Media Separation

Malcolm R. Gent, Mario Menéndez, Javier Toraño, and Susana Torno, E.T.S.I.M.O., University of Oviedo

CONTACT

Contact: Malcolm R. Gent
Organization: E.T.S.I.M.O., University of Oviedo
Postal Address: C/Independencia 13, 33004 Oviedo, Spain
Telephone: (34) 985 10 42 59
Facsimile: (34) 985 10 42 42
Email: gentmalcolm@uniovi.es

EXECUTIVE SUMMARY

The combustion of certain types of plastics to reduce the high volumes of plastics in wastes and recovering energy entails potential environmental risks of producing toxic or carcinogenic gases. Recovery of plastics as a manufacturing feedstock is proposed as an optimum solution. Due to there being a vast range of types of plastics, many with very similar physical properties, their material recycling frequently requires the application of a combination of processing methods to optimize product purity and market value.

Virtually all automated industrial plastics recycling processes use density separation methods as a preparatory cleaning and/or pre-concentration phase for subsequent processing methods, or in some instances, to produce a marketable product. Commercial applications are usually restricted to particles of 6.4 to 10 mm and throughput tonnage is limited due to rates of separation. With 24% to 69% by weight of ASR being <6.4 mm, and effective recycling of metals from WEE requiring shredding to <3 mm, considerable amounts of plastics presently must be disposed of otherwise. Cyclone type density media separators (DMS) such as those used for processing coal can obtain density separations was interpreted to offer a substantially greater plastic recycling capacity (up to 325 t h^{-1} or more) while processing a wider particle size range (0.5 mm up to 120 mm). The low-density product of cylindroconical type DMS cyclones is known to tend to be of high purity whereas the high-density fraction of the cylindrical type DMS is purest.

Tests were designed to evaluate the application of cylindrical type cyclone DMS for recycling plastics. A suite of different types of coloured plastics of known compositions were prepared from refuse. The samples were washed, dried, their densities determined to 0.02 g $^{cc-1}$, and then fragmented with a variable speed impact crusher to produce deformed fragments similar in form to shredder residue and with a 1.0 to 10 mm range of particle sizes.

Crushed calcite was selected and evaluated as a non-contaminating material for use in DMS for plastics. Separation tests were conducted with medias of water and calcite suspensions. Results demonstrate that a much wider variety of range of plastics particle sizes could be effectively separated than presently accomplished by other density separation processes. Purities and recoveries of plastics obtained were similar or better than those reported for established static type separations. A combination of plastics with as little as 0.09 g $^{-1cc}$ difference in density were separated into high-density fraction with ≈100% purity and >98% recovery and a low-density product with a >90% purity and 100% recovery. Reprocessing the low-density product produced a low-density product with 99.95% purity and 99.26% recovery.

It is shown that feeding a low-density product of a cylindrical DMS cyclone along with the separation media into a second DMS cyclone and re-circulating the intermediate-density product of the latter with new feed material into the first can optimize product purities of both density fractions to ≥99.98% and attain 100% recoveries.

Industrial scale versions of cyclone density media separators are interpreted as suitable for processing >0.5 mm to 120mm plastic wastes to produce high purity density separation products. Operating costs are interpreted to be significantly lower than established plastic density separation processes but require a large scale of operation is indicated.

INTRODUCTION

Reduction of the high volumes of plastics in wastes presents a challenge for the effective management and reduction of plastic wastes destined to landfills. The combustion of several types of plastics as a means of recovering energy, especially those containing halogens, includes the potential environmental risks of producing toxic or carcinogenic gases. Being a product derived from petroleum or gas, they have a potential market value considerably higher than that of fossil fuels with their recovery and separation for reuse as a manufacturing feedstock representing a substantial economic advantage over all other solutions.

Recycling of plastics into commercial products by low cost methods such as those based on physical properties is complicated by the vast range of different types of plastics presently in use and new types are being continually developed. Since many having very similar physical properties, a combination of separation processes is frequently required. Such separations can be problematic as the high purity of recycled products generated is an essential parameter for their use and determines market value. Effective separations are best accomplished when a separation is limited to the wastes corresponding to individual product types or manufacturing sectors or even sections of these as the variety of plastics present is generally limited to only a few types. However, the plastic wastes produced in some sectors such as those corresponding to municipal solid wastes (MSW), automotive shredder residue (ASR), and waste electronic and electrical equipment (WEEE) are especially complicated due to the range in physical dimensions, types of plastics present and the historical as well as sociological evolution in types used.

In the cases of ASR and WEEE, the recovery of plastics is becoming especially complicated by the ever-increasing variety of plastics and fillers that are being developed, many of which are thermosets that are incompatible with the re-useable thermoplastics. The increasing complexity resulting from the technological development of plastics is demonstrated by the evolution of electrical cable insulation or sheath compositions (Table 1) which constitute part of these wastes. A search of the literature (e.g. Globalspec, (2009) and Technocables, (2009) as well as consultation of electrical cable experts (Hodge, J., 2009, *personal communication*, BASEC) indicates that since the 1960/80s there has been a vast increase in types of materials used for these applications.

Present automated sorting, flotation, triboelectric, differential fragmentation, density and solvent extraction recycling methods being developed are effective and can generate products with properties matching or approximating those of virgin materials but have limited throughput capacities, require feeds with a limited range of types of plastics and a high content of marketable plastics to be economically viable. As the lowest cost recycling process, density separation methods are presently used in virtually all the automated industrial plastics recycling processes as a cleaning and/or pre-concentration and/or preparation phase for subsequent processing methods, or in some instances, to produce a marketable product.

Density separation methods presently used for recycling plastics are based on particles of plastics floating or sinking in a separation media of a given density, usually under the force of gravity. Since the process uses a feed with a lamellar displacement of the separation media, production capacities are limited due to: equipment limitations of maximum particle sizes; liberation size of different materials present; and especially the low rates of separations of smaller particles. Commercial operations are usually for 6.4 to 10 mm particles (Jody and Daniels, 2006) and as such, throughput tonnage and particle size capacity is limited to <½ t $^{h-1}$ (MBA Polymers, 1998). With 24% to 69% by weight of ASR being <6.4 mm, and effective recycling of WEE requires shredding to <3 mm. As such, considerable amounts of plastics presently are not recovered.

Table 1: Comparison in none metallic materials and their densities used for sheaths and insulation in electrical cable from the 1960s-80s and the present

Plastic type	Materials used in the 1960s-80s	Materials used at present	Range in densities (g cc^{-1})	Typical density (g cc^{-1})
Polyethylene foam	X	X	0.03-0.30	0.2
Ethylene propylene diene M-class rubber		X	0.86-0.95	0.88
Paper	X	X	0.69-0.83	0.80
Very low density polyethylene		X	0.880-0.916	0.905
Cross linked polyethylene		X	0.920-0.945	0.935
Low density polyethylene	X	X	0.918-0.93	0.932
Medium density polyethylene	X	X	0.926-0.940	0.935
High density polyethylene	X	X	0.941-0.965	0.94
Polystyrene	X	X	1.03-1.07	1.06
Polyamide (6, 66 & 11)		X	1.06-1.16	1.14
Cross-linked polyethylene		X	1.15-1.28	1.15
Chlorinated polyethylene		X	1.09-1.25	1.16
Polyurethane	X	X	0.4-1.2	1.20
Polychloroprene rubber		X	1.23-1.5	1.32
Silicone rubber		X	1.25-1.50	1.30
Polyvinyl chloride	X	X	1.37-1.42	1.39
Polyethylene terephthalate		X	1.35-1.40	1.37
Ethylene-vinyl-acetate		X	0.927-1.97	1.40
Ethylene-propylene rubber		X	1.2-1.47	1.4
Polyoxymethylene		X	1.41-1.42	1.42
Chloroprene rubber		X	≈1.47	≈1.47
Ethylene vinyl-acetate		X	≈1.49	≈1.49
Mica tape	X	X	≈1.5	≈1.5
Nitrile butane/Acrylonitrile-butadiene rubber		X	≈1.5	≈1.5
Polychloroprene		X	≈1.55	1.55
Styrene-butadiene rubber		X	1.45-1.70	1.6
Rubber	X	X	1.52-≈1.6	1.6
Chlorosulfonated polyethylene		X	1.64	1.64
Ethylene tetrafluoroethylene		X	≈1.74	1.70
Fluorine-ethylene-propylene		X	≈2.15	≈2.15
Polytetrafluoroethylene		X	2.07-2.20	2.17

Due to the technical complexities of separating complex MSW, ASR and WEEE plastics mixtures, a variety of separation processes may be required to effectively separate the different types present. The complexities and costs of commercial recycling of such wastes results in such operations being in large part a question of the economics of scale of operation and the value of products generated is dependant on their purity. It is suggested that processing technologies proven in sectors recovering materials at a low cost and with a low value per tonne, or low content may be especially applicable to the plastics recycling sector.

Density media separation (DMS) cyclone technology used in the mineral processing sector could be applied to substantially extend recycling capacities by increasing the range of plastic particle sizes recovered and the volumes treated. DMS is used in the automobile shredder industry to recover non-ferrous metals but DMS cyclone operation for plastics recycling has not been used to date. The centrifugal forces developed within DMS cyclones facilitates the sink-float process of separation, resulting in the capacity to treat a wide range of particle sizes (0.5 up to 120 mm) with a high throughput and low operating cost (typically ~0.241 €t^{-1}, Fernández Maguregui, Equibemine, *Personal communication,* 2008). DMS cyclones are especially relevant for treating large volumes of coal with particles finer than those processed with the conventional static type density separators. However, unlike operating requirements for coal, plastics have a much higher potential market value; tend to have more acicular, platy or lath like forms; and density separations must be near perfect so as to optimize product purity. Results of tests conducted to evaluate the application of DMS cyclones for recycling plastics are presented here.

TESTING OF A DMS CYCLONE FOR THE RECOVERY OF PLASTICS

There are a number of different types of DMS cyclones, with the most common having a conocylindrical form (Figure 1a) identical to hydrocyclones but oriented at ≈30º from the horizontal. A cylindrical type (Figure 1b) was selected for this study due to it not requiring the particles to be treated passing through the pumping circuit and it producing a lower media density offset due to the lower media pressures used. Of this type of separator, the LARCODEMS was selected as the manufacturers specifications and reported industrial operations (McCulloch and Baillie, 1998 and Baillie *et al.*, 1997) report it to be able to process the widest range of particle sizes (0.5 to 120 mm) and with low Ecart Probable (half the difference in densities where there are 25% and 75% probabilities of a particles of those densities report to a low or high-density product fraction) values of 0.006 to 0.044.

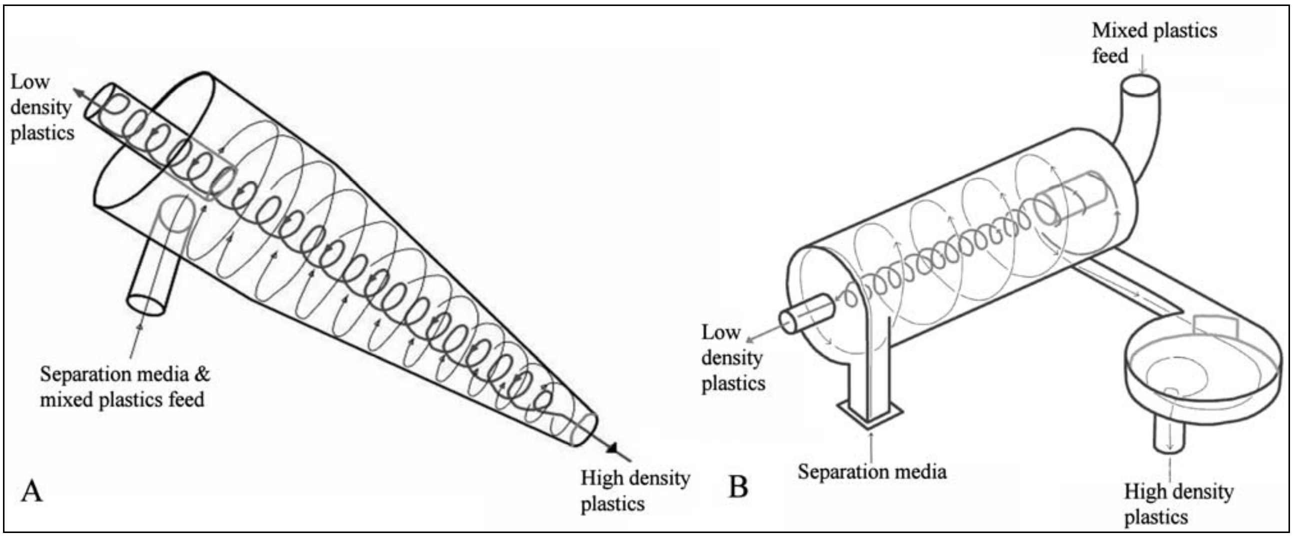

Figure 1: Media separation flow paths in conocylindrical (A) and cylindrical (B) type DMS cyclones (modified after Gent et al., 2009a, b)

Factors of primary importance in evaluating the possible application of DMS cyclone density separation of plastics for industrial scale applications include: the range of particles that might be treated collectively; the quality of the separations obtained; the physical-chemical (hydroscopic) effects of plastics; the separation media characteristics; and the devices configuration. The tests conducted were designed to evaluate both the use of a low cost suspended particle media typically used as fillers in plastics and to ascertain the effectiveness (purity and recovery) of separations of waste plastics by density and particle form. Due to the environmental and technical complexities involved using chemical solutions as the separation media in industrial recycling, a ground mineral typically used as fillers in plastics was selected to create a suspension in water for use as the separation media. Ground calcite was selected but other low cost minerals such as feldspar, barite, quartz, magnesite or magnetite could be used.

Description of the LARCODEMS

Although designed for treating coal, the LARCODEMS has also been proven suitable for treating iron ore. It is presently supplied in six versions with manufacturers recommended processing capacities and maximum particle sizes varying in proportion with the cylinder diameter of the devices. All have an excessive capacity for laboratory scale tests, with the smallest (300 mm diameter) having a calculated 9 t h^{-1} plastics capacity. A demonstration model with an ≈125 kg h^{-1}

capacity was selected for these tests despite it not including some of the standard operating design characteristics nor necessarily conforming exactly to the proportions of the industrial versions.

The device consists of a cylindrical separating chamber inclined at 30° from the horizontal. The separating media is injected tangentially at the lower end, forming a vortex with a central air core. Dry or moist material to be separated is fed at the top end to flow into the vortex. Dense fragments must settle through the ascending separating media circulating around the inner circumference of the cylinder to exit through the upper port (underflow) while the lower density material floats down the surface of the vortex to exit at the lower port (overflow). Analysis of the manufacturers recommended operating specifications for processing coal show that there is an exponential relationship between the maximum plastics processing capacity (y_c) in kg h^{-1} (Equation 1) and maximum treatable particle size (y_s) in mm (Equation 2) relative to cylinder diameter (x) in mm. These equations fit the data with correlation coefficients (R^2) of 0.9938 and 0.9926 respectively. As such, any increase in separation cylinder diameter has a substantial effect on both throughput capacity and maximum size of particles that may be processed.

Eq 1 $y_c = 0.00009x^{2.0869}$
Eq 2 $y_s = (0.000006x^2) - (0.0734x) + 6.9574$

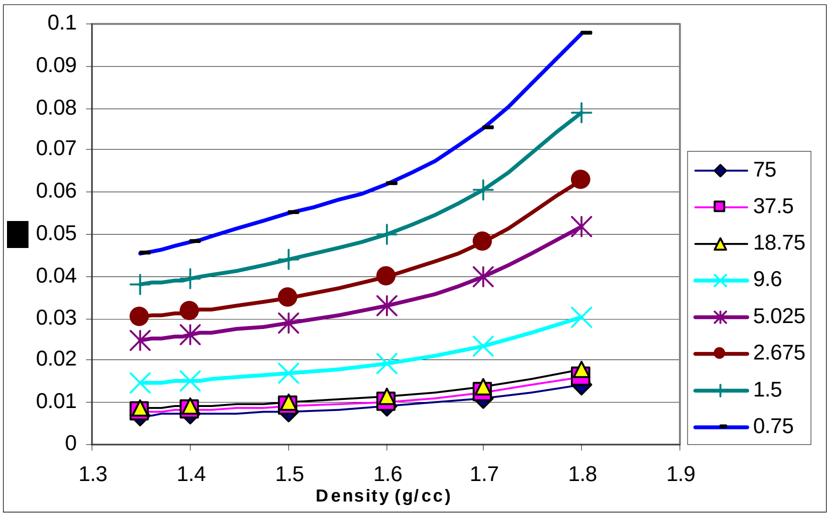

Figure 2: Evolution in Ep values for coal by particle sizes treated relative to density of separation

Analysis of results (Baillie et al, 1997) from industrial coal processing tests also show that the Ecart Probable (Ep) values improve with reduction in density of the separation conducted (Figure 2) and with increase in particle size. All the Ep values reported are considered very favourable for the densities and particle sizes of the types of waste plastics normally produced. However, in the recycling of plastics for use in the manufacturing sector where there is the highest market value and strictest requirements of product purity, Ep values are not especially significant as they do not indicate at what density all particles are recovered in one fraction of a separation.

Development of a Separation Media Suspension

The adequate selection of the separation media can have an important impact on the quality of both the separations obtained and the product produced. Chemical solutions used as separation medias have substantially greater viscosities when used in high concentrations, must be thoroughly washed from products, and create residual waste streams that are difficult to treat. Suspensions of finely ground, low cost, inert mineral particles such as magnetite in the case of coal DMS processes is a well established means of creating density separation medias but care must be exercised in their selection so as to avoid detrimental viscosity and separation media density offsets. Centrifugal forces developed in DMS cyclones operating with mineral suspensions tend to concentrate the coarser suspension particles which results in offsets in the separation medias reporting with the low and high-density products. Although investigations by Bevilacqua et al. (2000) with separation medias composed of suspensions of clays with 67% <2 µm are encouraging, excessively fine (<10 μm) particles tend to dramatically increase the media viscosity, resulting in difficulties in the separation of fine or plate-like particles. An ideal mineral suspension for DMS processes should have a minimum of ultrafine (<10 μm) particles to avoid increased media viscosities and an absence of excessively coarse particles so as to minimize any media density density offset. The greater the mineral density used, the smaller the desired maximum particle diameter.

A crushed <72 μm limestone was selected as a potentially suitable material for creating a density separation media. Tests conducted at densities of 1.02 to 1.175 g cc^{-1} found that the density offset increased with separation medias up to ≈1.10 g cc^{-1} (Figure 3) but reduced at greater densities due to the media viscosity restricting the settling of coarser particles. Analysis of the proportions in grain sizes of particles in a 1.10 g cc^{-1} separation media reporting to the high and low-density product ports (Figure 4) show that no classification of particles less than 10 μm occurred, very little for those from 10 to 48 μm, and above 48 μm all particles report to the underflow. As such, a separation media of crushed limestone operating under similar conditions should not produce a significant density offset if composed of particles <48 μm.

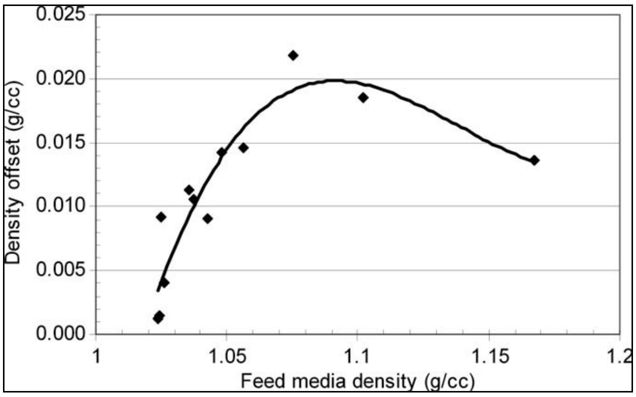

Figure 3: Evolution of a crushed calcite separation media density offset with increase in media density (Gent et al. 2009a)

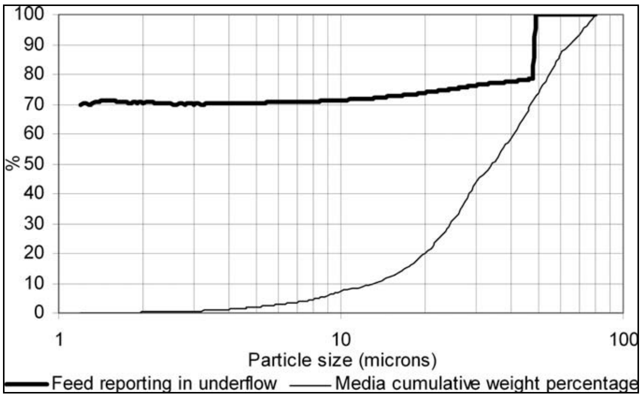

Figure 4: Partition coefficient of the crushed limestone media reporting to the underflow (dense product) obtained with a 120 mm diameter LARCODEMS and cumulative grain size distribution obtained of a <72 μm crushed calcite separation media (Gent et al. 2009a)

Sample Preparation

A suite of eight types of plastics of known compositions and different colours was prepared from refuse. Samples were washed, dried, their densities determined, and then fragmented with a variable speed impact crusher to produce deformed fragments with a range of particle sizes from 0.5 to 10 mm which were screened into discreet size fractions. In some instances a complete range of grain sizes could not be obtained for some plastics due to their fragmenting readily.

Table 2: Characteristics of test materials used

Plastic type	Density (g/cc)	Colour	Aspect ratio Average	St. Dev.	Maximum
Polyurethane	0.060	beige	-	-	-
Polyurethane	0.940	black	-	-	-
Polypropylene	0.858	black	3.2	2.1	6.7
Polypropylene	0.876	white	1.40	0.2	1.6
Polypropylene	0.908	brown	-	-	-
Low density polyethylene	0.913	transparent	1.46	0.2	1.7
High density polyethylene	0.941	black	-	-	-
High density polyethylene	0.946	green	6	3.2	12
High density polyethylene	0.967	blue	-	-	-
High density polyethylene	0.975	grey	-	-	-
High density polyethylene	0.982	pale blue	-	-	-
Polystyrene	1.028	black	3.9	2.4	9.1
Polystyrene	1.055	brown	3.9	2.4	9.1
Polystyrene	1.031	white	-	-	-
Polystyrene	1.042	yellow	3.9	2.4	9.1
Acrylonitrile butadiene styrene	1.179	beige	7.6	11.3	50.0
Acrylonitrile butadiene styrene	1.190	grey	1.5	0.4	2.8
Polymethyl methacrylate	1.189	red	3.1	1.7	8.2
Polymethyl methacrylate	1.190	blue	3.1	1.7	8.2
Polymethyl methacrylate	1.192	green	3.1	1.7	8.2
Polymethyl methacrylate	1.196	yellow	3.1	1.7	8.2
Polybutylene terephthalate	1.326	white	1.9	0.7	3.3
Polyvinyl chloride	1.693	brown	15.6	17.5	64.0

- Not determined

Their densities (Table 1) were determined with a theoretical precision of ±0.002 g cm^{-3} by averaging of three measurements of their mass and liquid displacement. A more complete set of plastics with intermediate density values, especially between 1.00 and 1.15 g cm^{-3} would have been preferred but repetitive attempts to collect suitable plastic wastes within these values were unsuccessful. The aspect ratios of the particles indicated are defined as the ratio between the maximum (Dmax) and minimum dimensions (Dmin).

Test Procedure

Samples sets of 0.35 to 2 kg were prepared from the plastics of different colours such that differences in density corresponded to colours that could be sorted manually. Approximately 400 fragments of each particle size fraction of each type of plastic were used except for some of the larger (>5 mm) size fractions. Separation tests were conducted with a constant media flow rate of 72 l s^{-1} with approximately 32% of the media reporting to the low density port. The samples processed were collected on screens below the exit ports, washed to remove any media material adhering to the fragments, dried and sieved by particle size. Each sized product fraction was manually sorted by colour and weighed (±0.0001 g) so as to determine on a percentile basis the purity and recovery of the density fractions produced.

Test Results

Separation tests conducted with a mixture of eight types of plastics using water as the separation media show a very sharp separation of particles with 0.046 g cc^{-1} difference in density but with a slight loss in recovery of the 2.0 to 2.5 mm particles (Figure 5). The high density fractions typically were found to have purities of 99.888% to 99.995% with recoveries of 98.707% to 99.430%. Separation tests with the same plastics conducted with crushed <45 μm crushed calcite suspension as the separation media lack sufficient near media density values to precisely define the separation but do indicate traces of fine (<2.5 mm) particle size low-density plastics with densities within ≈0.042 g cc^{-1} of the density of the separation media reporting to the dense fraction and a slight loss in recovery of high-density particles with lower density values. The high density fraction was typically found to have a purity of 99.713% with a recovery of 99.798%. The purity of the low-density products obtained in these separations is largely a function of the proportion of particles with values near that of the separation media density, with no particles having densities >0.126 g cc^{-1} of the separation media reporting with the low-density product. Subsequent investigation found that the separations may have been adversely affected by the presence of very fine air-bubbles originating from the media pressure by-pass cascading into the media tank in proximity to the media pump lowering densities of the separation media.

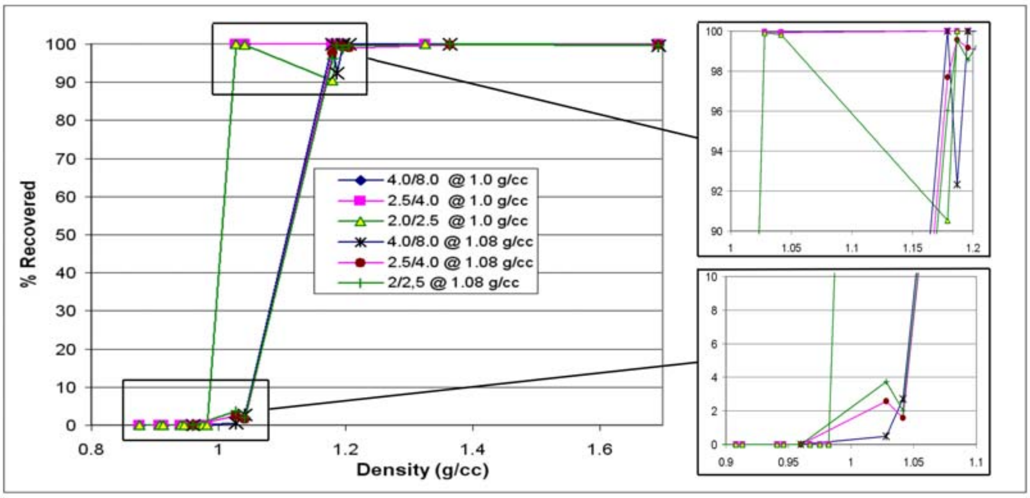

Figure 5: Partition curves representing the probability of a particle of a given density and size reporting to the dense product fraction with separation medias with densities of 1.0 and 1.08 g cc^{-1}

Plastics recycling operations are distinct from that of mineral processing operations where the recovery and purity of only one density fraction is normally of importance. In waste plastic recycling, both density products may be marketable. The value of plastic products obtained is determined largely by their purity. Although very little has been published on the market value relative to purity of various types of recycled plastics Dodbiba and Fujita (2004) indicate that a 99.5% purity is required for reuse of plastics in a circulating system as virgin plastics and that 95.0% purity is acceptable for reuse of plastics in a circulating system for low quality plastics. In all probability, substantially higher purity levels are preferred by the manufacturing sector and should entail correspondingly higher values and market acceptance.

There is a tendency for all separation process to have an inverse relation between product recovery and product purity. To compensate for this, many separation methods for minerals including those based on density separations use reprocessing of separation products either to optimize a product recovery or purity. Repetitive DMS processing to recover pure plastic at densities >1.00 g cc^{-1} with the LARCODEMS was found to be effective for this purpose but implied a complex flow process with a number of devices and recirculation of several partially separated product streams required.

All DMS operations are based either on the dense fraction sinking from a mixed plastic feed to form a high-density product such as in conventional cylindrical type cyclone separations, or on the low-density fraction floating from a mixed plastic feed to generate low-density product such as for conventional (conocylindrical) DMS cyclone separations. It was postulated that a combination of these two processes could be applied to maximize low and high-density product purities and recoveries. Compared to the use of a combined conocylindrical and cylindrical DMS cyclones process, a design (Figure 6) based of conventional cylindrical DMS cyclone with the low-density product being fed with the separation media into a second cylindrical DMS cyclone and the mixed high-density product from this re-circulated back with new plastics to be separated into the first separator should be preferable for industrial operations as it simplifies device maintenance, differences in pump pressures required, media density offset effects, etc.

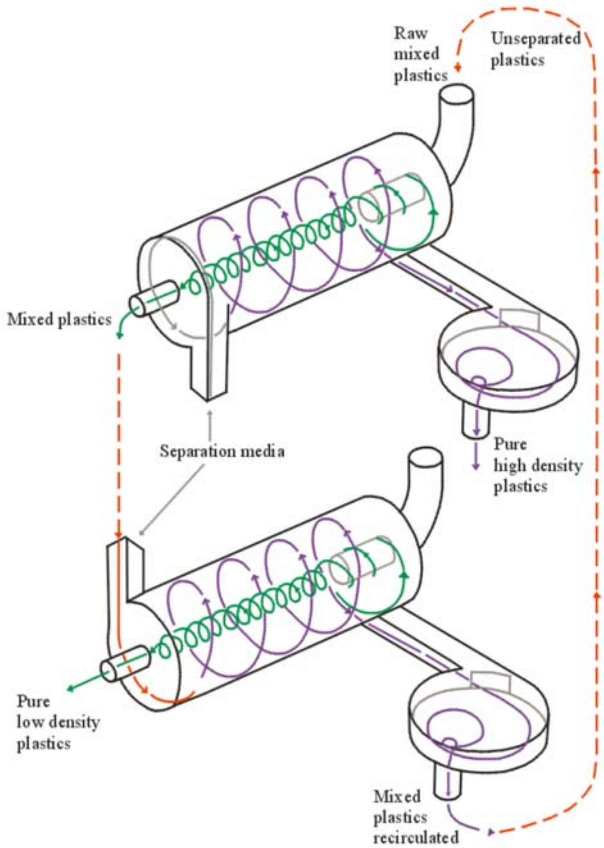

Figure 6: A proposed DMS configuration for plastics with recirculation of the unclassified fraction for optimizing plastic purities separations with total recovery of both low and high-density fractions with LARCODEMS type DMS cyclones

To test this hypothesis, the demonstration model of a conventional LARCODEMS type separator was modified to permit the feeding of plastics to be separated either directly into the vortex or along with the separation media via gravity feed. The media pressure by-pass was also modified to reduce the presence of fine air-bubbles in the media. The first test of this concept was conducted with a separation media of water (1.0 g cc^{-1}) and a 0.96 kg sample with equal proportions by weight of Polystyrene (PS) with densities of 1.028 to 1.042 g cc^{-1} and high density polyethylene (HDPE) with densities of 0.948 to 0.960 g cc^{-1}. The sample material used consisted of 0.7 to 8 mm PS fragments with a maximum surface area to thickness ratio of 4:1 and 0.5 to 12 mm HDPE fragments with a maximum surface area to thickness ratio of 19:1. Fragments substantially larger than those corresponding to the diameter of the separation cylinder were used in this test to ascertain if the devices particle size limitation applies to flake-like particles which correspond in volume to smaller equidimentional particles.

The sample was washed and fed damp into the top of the LARCODEMS. The high-density product was removed and the low-density port product was then fed along with the separation media into the base of the LARCODEMS. The products were dried, manually sorted by plastic type and weighed. Although improvements in design were found recommendable, the results for the precise separation of plastics with 0.068 to 0.094 g cc^{-1} are considered very encouraging.

PS of 99.999% purity and a recovery of 97.898% was obtained in the first sink from feed separation and HDPE with a purity of 99.990% and a recovery of 98.353% was produced in the first float from feed separation. Only 1.870% of the original feed was unclassified and in an industrial separation process would be re-circulated back to the first separator to be treated along with new raw plastics to be separated. These results suggest that the devices processing size limit of particles with a flake-like form is significantly larger than the limits designated by the manufacturer for minerals. It is emphasized that these results were obtained with a modified demonstration version of the LARCODEMS, its optimum media and plastics feed rates are yet to be ascertained and it lacks many of the operational components of an industrial model which might further improve on the results obtained.

In an industrial operation, mixed plastics as 0.5 to 120 mm fragments with a real mean density of 1.1 g cc^{-1}, could be theoretical processed in a 1.36 m diameter LARCODEMS at a rate of 306 t h^{-1} or more. The need to operate several such devices so as to continuously produce a number of separations at different densities combined with the large throughput capacity and the importance of conducting other types of physical or solvent extraction implies a large scale of operation requiring very large volumes of waste plastics to be treated. Such conditions could probably only be met at a limited number or recycling centres located in or near major metropolitan centres.

CONCLUSIONS

A significant proportion of recyclable plastics are not presently being recovered for reuse from ASR and WEEE due to the particles sizes in these wastes being too fine for most physical separation processes presently used. The evolution of new types of thermoset plastics such as used in electrical cables is further complicating the possibility of separating re-useable thermoplastics in these wastes.

Density separation is commonly used stage by industrial recycling processes but the particle size range and throughput is severely limited. Separation tests of waste plastics conducted with a cylindrical type DMS cyclone demonstrates that DMS cyclones are suitable for conducting separations of plastics by density. Industrial mineral processing experience indicates that this technology is applicable for recycling large volumes of plastic particles with a wide range of sizes. Furthermore, suspensions of an adequate particle size range using a variety of low-cost ground mineral compounds can be used to create effective density separation medias instead of chemical solutions for the separation of plastics. A combined sink from feed and float from feed DMS cyclone separation process can be used to produce density separations with virtually no misclassifications of both high-density and low-density fractions with density differences of $\leq$0.068 to 0.094 g cc^{-1} at purities of >99.9% and >98% recovery. This process could achieve 100% recovery by re-circulating the fraction not separated.

DMS cyclone separation represents a low cost, high throughput method to produce plastic separates, either as a finished product or as a concentrate for subsequent processing by other separation processes. The application of this technology is interpreted to be most applicable to major metropolitan centres where the high throughput capacity can be optimized.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the generous donation of the LARCODEMS demonstration model by JMC Engineering Ltd. without which this investigation could not have been conducted.

REFERENCES

Baillie, D., Shah, C., Heley, A. (1997): Coal preparation – Three-Product ‘LARCODEMS’ Separator Demonstration, Installation and Performance Testing, EUR 17155. Office for official publications of the European Communities, Luxembourg.
Dodbiba, A. and Fujita, T. (2004): Progress in separating plastic materials for recycling, Physical Separation in Science and Engineering, 13 (3-4): 165-182.
Fernández Maguregui, C. (2008): Equibemine, Madrid, Spain.
Gent, M., Menéndez, M., Toraño, J., Diego, I. and Torno, S. (2009a): Cylinder cyclone (LARCODEMS) density media separation of plastic wastes, Waste Management, 29: 1819-1827.
Gent, M.R., Menendez, M., Toraño, J. and Diego, I. (2009b): Recycling of plastic wastes by density separation, prospects for optimisation, Waste Management and Research, 27: 175-187.
Globalspec (2009): http://electronic-components.globalspec.com/Specifications/Electrical_Electronic_Components/Wires_Cables/Power_Cables (5/5/2009)
Hodge, Jeremy (1998): Chief Executive, British Approvals Service for Cables (BASEC), Milton Keynes, UK.
Jody, B.J. and Daniels, E.J., 2006. End-of-life Vehicle Recycling: The State of the Art of Resource Recovery from Shredder Residue. ANL/ESD/07-8,. National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161, USA. http://www.es.anl.gov/Energy_systems/CRADA_Team_Link/publications/Recycling_Report_(print).pdf, accessed 15/4/2009.
MBA Polymers, Development of Hydrocyclones for Use in Plastics Recycling, 42 p., 1998, www.americanchemistry.com/s_plastics/doc.asp?CID=1588&DID=6047, accessed 20/4/2009.McCulloch, J. and Baillie, D. (1998): Developments in LARCODEMS media processing technology. In: Partridge, A.C. and Partridge, I.R. (eds.): XIII International Coal Preparation Congress, Australia, 4-10 October, pp.467-468. Australian Coal Preparation Society, Australia.
Technocables, http://www.technocables.com/tech-spec.PDF (23/5/2009).
Bevilacqua, P., De Lorenzi, L. & Ferrara, G. (2000); Rheology of low density suspensions in dense media separation of post-consumer plastics. Coal Preparation, 21, 197–209.