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Pla.To Dry Cleaning System Trial Report

MDP017 : Domestic Mixed Plastics Waste Management Options

A review of the Pla.To Dry Mechanical Cleaning technology used for the cleaning of UK sourced household non-bottle plastic packaging.

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WRAP works in partnership to encourage and enable businesses and consumers to be more efficient in their use of materials and recycle more things more often. This helps to minimise landfill, reduce carbon emissions and improve our environment.

Written by: Keith Freegard

Axion Recycling Limited

Front cover photography: : Pla.To Dry Cleaning Unit; Cologne Germany.

Executive summary

This report describes trials carried out on the Pla.T0 dry mechanical cleaning system with various samples of UK post-consumer non-bottle packaging waste. The work forms part of the WRAP programme to investigate technologies for the recycling of this growing plastics waste stream.

The trial was conducted in Pla.To demonstration centre near Cologne, Germany, where a full system has been installed for the processing of dirty plastic material. During the trial examples of UK sourced mixed rigid plastics and dirty post-consumer films were fed into the plant in order to assess it performance as a cleaning stage in an overall recycling process.

The system was able to successfully remove paper and dirt from a heavily contaminated sample of 200 kilos of granulated flakes from mixed rigid containers. Two passes through the machine were needed to remove the very high levels (circa 50%) of wet paper and surface dirt seen in the material. A smaller quantity of undesirable heavy particles of metal and glass were removed via a separator section in the pneumatic infeed to the dry-cleaning unit.

A sample of 100 kilos of dirty flexible film flakes of 40mm particle size was also processed during the trial. The cleaning process removed 10 kilos of dirt and fibres from this material, and some drying also took place in the process air-stream.

The machine was also used to process two smaller samples of rigid container flakes which had been positively sorted using a Titech IR sorting system during an earlier trial. A sample of 13.4 kilos of sorted PP flakes was passed though the machine twice and a sample of 12.4 kilos of PET container flakes were passed once through the unit. The cleaned flakes from this small batch and some from the PE film trial were converted into samples of pelletised compound for assessment of quality and market value.

The following conclusions are drawn from this trial:-

- The Pla.To Dry-Cleaning process offers an effective route for the removal of surface dirt and paper from flakes of both rigid and flexible plastics.
- For the very high level of wet-paper and dirt seen in the mixed, rigid plastic sample used in this trial, TWO passes through the unit were needed to reduce the contamination down to 3% by mass of the plastic flakes. During the two passes through the dry-cleaner around 50% of the original input mass was removed as dirt & paper waste (wet weighed).
- When processing 40mm flakes of post-consumer, flexible films around 10% of the input mass was removed as dirt/fibres. There was also a significant drying effect in the process, which accounted for a further ~10% reduction in mass.
- Smaller sample batches of sorted PP and PET rigid flakes were successfully cleaned in the process. There was a higher level of dirt and paper removed from the PP flakes (~40%) than from the PET flakes (13%).
- Dry-cleaned samples of the rigid PP, PET and the flexible PE flakes were successfully compounded into recycled plastic pellets on a laboratory scale extruder. This demonstrates that dry-cleaned flake material represents a potential end-product for direct sale into certain polymer markets.
- Throughputs of 3 – 4 tonnes per hour are quoted for the largest Pla.To machine based upon real operating experience of equipment used commercially on PET and HDPE bottle flakes. Dirt contamination levels of around 10-15% are typical in these applications. The higher levels of contamination expected with mixed rigid food container plastic could lead to lower throughputs than this, due to the increased cleaning requirement.
- Throughputs on flexible films will be lower due to the much higher surface area to mass ratio. Around 1 tonne per hour is the best rate that could be expected on this type of infeed with 10-20% input dirt levels.
- Operating costs per tonne of infeed material compare favourably with equivalent wet washing processes. In this report, an estimate of £14.40 GBP per tonne has been made for dry-cleaning of sorted rigid flakes with a 10% level of dirt/paper at input at 3 tonnes/hr.
- Capital costs for a complete system to handle flaked rigid plastic (from an upstream granulation stage) have been estimated at £150,000 GBP installed in UK.
- The absence of any process wash-water with its associated high capital and effluent treatment costs, makes the simple dry-cleaning process a very attractive option when considering process equipment for the task of cleaning mixed post-consumer plastic waste. The simplicity of the operation means that it could be considered as a 'bolt-on' technology to existing plastic sorting plants.

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1.0 Introduction

This report describes a trial carried out on the Pla.To mechanical purifier system as part of the WRAP project to investigate potential technologies for the recycling of plastics from mixed waste plastics.

The dry-cleaning process uses a technology developed under the German DSD system to carry out surface cleaning of flaked rigid or flexible plastic materials. The primary cleaning machine forms part of a complete plant which controls infeed of material, pneumatic conveying, removal of separated dirt / dust and collection of the cleaned plastic material from the air-flow.

The trial was carried out at Pla.To's demonstration centre nr Cologne, Germany. A full plant installation is available to show the machine working in continuous operation with all the associated infeed and outfeed pneumatic conveying equipment. The trial was attended by Keith Freegard from Axion with representatives from Recoup, Scott Wilson and PPS Systems to ensure a fair representation of the trial. Axion Recycling are the UK agents for sales of the Pla.To technology and have successful delivered 5 projects using this equipment over the past 2 years.

Sample material for the trial was derived from a UK MRF in Preston and came from the same batch of material as used for the Herbold wet-washing and Flottweg separation trials, thus ensuring validity of comparisons between the three trials.

Samples of the rigid and flexible dry-cleaned films have been collected and returned to Axion's polymer laboratory for further analysis. The results of this analysis and other testing on the composition of the mixed plastics are presented in this report.

2.0 Contacts and trial attendees

The primary point of contact for the organisation and running of the trial was :-

Heinz Schnettler
Director

Office address:-
Pla.To GmbH
Frankfurter Strasse 720-726
D-51145 Cologne
Germany

Tel - +49 (2203) 9070735
Mobile :-+49 172 216 44 67

Email :- heinz.schnettler@plato-technology.de

Website:- http:// www.plato-technology.de

3.0 Aims of trial

A few days before the trial, the following statement of aims was sent to Pla.To:-

The trial will be carried out to show the capability of the **Pla.To Dry Mechanical Cleaner** technology for the cleaning of plastics from UK post-consumer waste. The plastics are derived from the mixed non-bottle fraction of rigid containers and the flexible films from household recycling collections.
The Dry Cleaner will be utilized to demonstrate its capability on the following input materials:-

1. Flexible Films to produce a high purity PE / PP film flake from the feedstock of dirty post-consumer films. (These will be pre-shredded to an agreed particle size for the trial)
2. Rigid Containers –
   a. Using pre-sorted polymer materials derived form a previous IR sorting trial on the whole containers. Focus will be on the cleaning of PET containers and PP containers from that feedstock. Material will be granulated to an agreed particle size (8 – 10mm) prior to the trial.
   b. Using a sample of mixed rigid plastics containers where the flexible films and paper contamination has been previously removed. This trial to focus upon the potential throughput for the equipment when processing rigid flakes.

The trial will be carried out first to demonstrate the best efficiency of cleaning that can be obtained with the material. Following this a further trial run should be carried out to demonstrate the capability of the equipment to work at its highest throughput, with minimal detriment to the quality of separation achieved.
The cleaning efficiency will be measured by analysis of the output stream from the machine in order to give a quantification to the following:-

- Mass Balance split into each output stream – cleaned flakes and dirt/fibre waste stream.
- The effect of multiple passes through the machine – if required.
- The average mass throughput rate for the trial when running in steady-state conditions.
- Samples will be taken to determine the residual level of dirt on the cleaned flakes, by means of off-line analysis.
- An estimate of the energy and other consumables needed to bring about the separation (e.g. compressed air, electrical power).

4.0 Description of Input Material Sample

The material was prepared from two bales of plastic waste delivered from a UK MRF in Preston. This was exactly the same material as used for the Herbold wet-washing trial and can therefore be used for a direct comparison of cleaning performance.

The material was granulated down to the specified particle size for this trial using two different designs of Herbold granulator:-

1. A model SMS 45/60-A3-2, 75 kW – with closed rotor design was used to prepare the dirty rigid flake using a 10mm screen hole size.
2. A model SMS 60/100 with 4 knife open rotor was used for the film flake granulation using a larger screen hole size to make nominal 40mm flakes.

The output flakes were packaged into big-bags and delivered to Pla.To and Flottweg for use in the subsequent cleaning and separation trials.

Fig 1 -Input Rigid Plastic Waste – before granulation

Fig 2 – Bale of films used for granulation to flake

The above materials were used to prepare two large bulk samples of rigid and flexible plastics. In addition to these the following smaller samples were also passed through the dry-cleaner system:-

- Flakes of sorted PE flexible films, ex the Titech trial
- Rigid flakes of IR-sorted PP containers
- Rigid flakes of IR-sorted PET containers

5.0 Analysis of Sample Composition

The infeed materials were analysed using an off-line infra-red laboratory instrument to determine the mixture of polymer types in the material. These results are presented in Section 8 along with the equivalent analyses of the output products. Some test work was also carried out to evaluate the level of dirt and paper contamination on the input sample plastics.

6.0 Description of Pla.To Technology

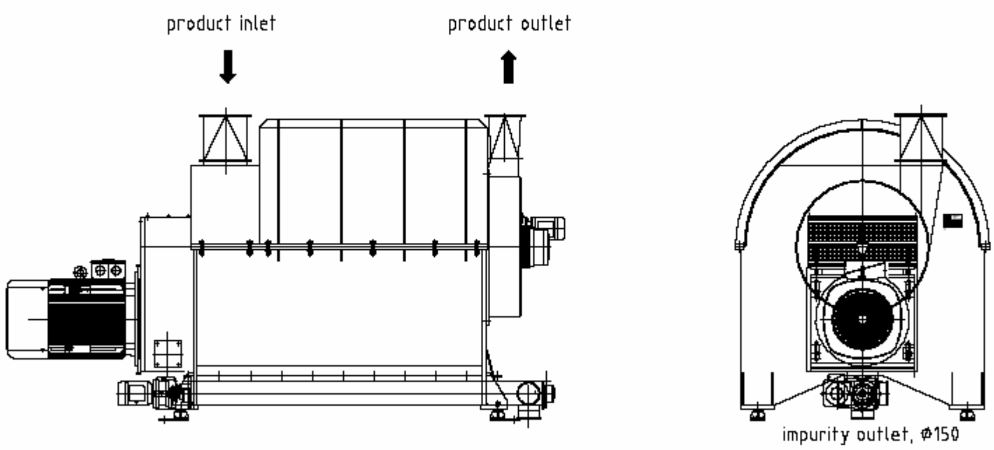
The original design concept of the Pla.To dry-cleaning process was to deliver a method to remove surface dirt and paper labels from plastic <u>without</u> the use of a water washing process. Experience within the German plastics recycling industry had shown that the main disadvantage of any water-based washing process is the high cost of additional plant and processing chemicals needed to treat the dirty effluent water to a standard that meets local environmental discharge rules. In addition to this, the use of wet-washing demands that an energy intensive drying stage is included in the overall process design, adding further recycling cost.

The engineers at Pla.To have therefore designed and developed a system that satisfies this seemingly impossible requirement – surface cleaning and paper removal without the use of large volumes of process water.

<u>Machine & Process Design</u>

At the heart of the dry-process is the primary cleaning machine – the Pla.To mechanical cleaner. This unit carries out the removal of paper and dirt from the surface of the input plastic flakes and separates the waste dirt material from the cleaned plastic stream.

Inside the Mechanical Purifier fast rotating blades create a high-energy turbine that subjects the plastic particles to rapid mechanical stress and deformation. All paper labels or cardboard sleeves are broken down to the smallest elements of paper structure - the cellulose fibre, and pass through a cleaning mesh with any removed surface dirt. In addition, the intensive turbulent movement of the particles and the multiple impacts between themselves and the machine parts, causes adhering dust and dirt to be knocked off of the plastic. This removed surface contamination, such as sugar deposits from drink products, also passes through the mesh screen to be sucked away. An integral screw-auger can be used to convey away the paper fibre & dirt mixture and the cleaned plastic stream exits the Dry Cleaner pneumatically.



General layout of dry cleaning unit– copyright - Pla.To GmbH

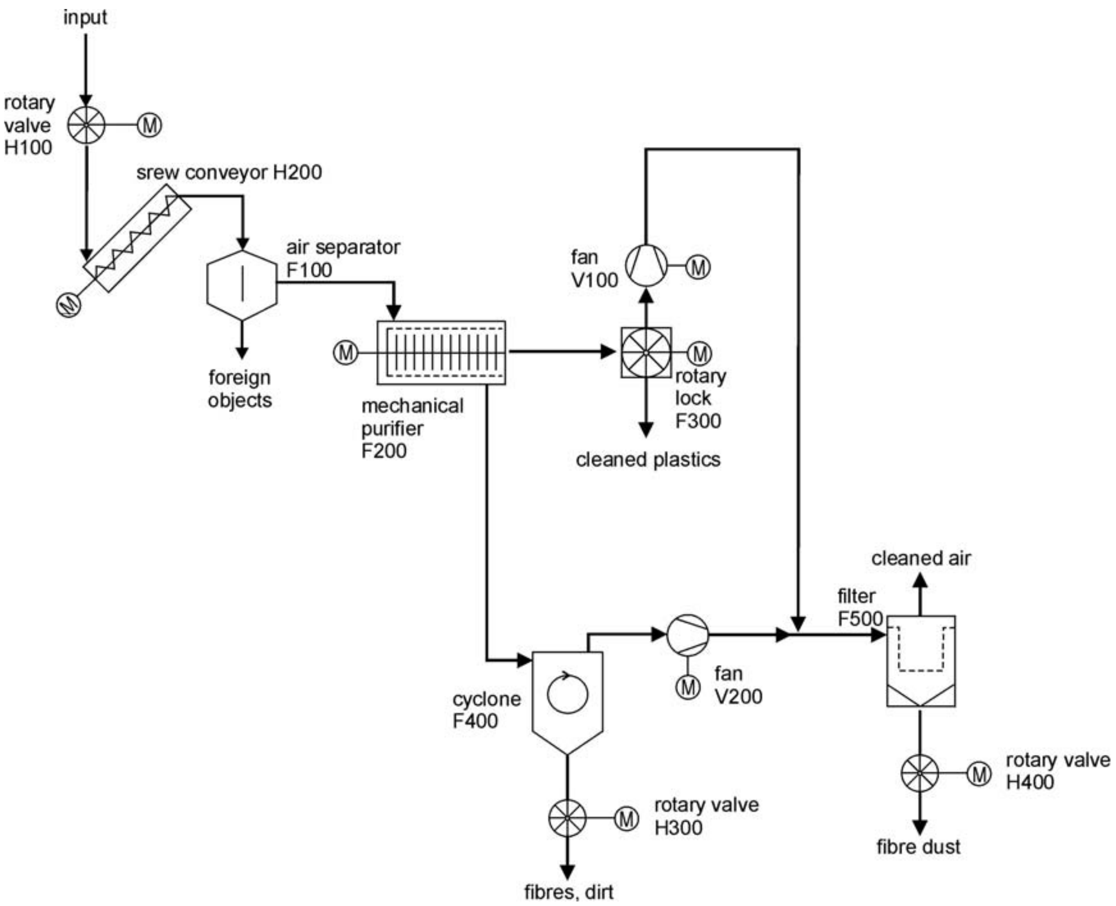
The cleaning efficiency is between 80 and 98% depending on the type and grade of contamination. Beside paper fibres and dirt, a large proportion of the label glue is also removed within the machine.

The dry cleaner is equipped with a scraper which continuously cleans the screen basket and the inner-housing of the device. The scraper forces fibres and dirt into an auger which discharges the reject out of the machine.
The machine is equipped with a central lubrication dispenser, to ensure regular supply of grease for maintenance of the central bearings. The only wearing parts which have to be replaced are inexpensive hardened steel plates on the ends of the main paddles. The replacement period depends on the type and grade of contamination and is usually several months.

A key factor for the correct operation of the dry-cleaning machine is the control of the pneumatic air flows, particle infeed and output material collection. This can only be done effectively by purchasing a complete plant system to give a well-balanced, fully-designed process to handle the cleaning operation. A complete system, as tested during this trial, will include:

- Infeed screw conveyor
- Heavy particle separator (stones, metal, glass etc)
- Dry Cleaning Unit
- Dust collection cyclone and valve / screw auger for wet waste fibres
- Product collection unit – special rotary valve or cyclone
- Pneumatic transfer fans
- Dust filtration
- Product collection bin or bagging unit

A typical installation is represented by the following simplified process flow-sheet, although final plant design and configuration will vary with the particular needs of each application:-



General process flow-sheet – copyright of Pla.To GmbH

Equipment Sizes and Throughputs

The exact throughput of the cleaning system depends upon the type of infeed plastic and the level of surface dirt and paper contamination. Thick-walled rigid containers, such as PET bottle flake, will deliver much higher throughput than thin, very dirty films, such as agricultural waste stretch-wraps. The table below gives some typical performance ranges for different infeed plastics and shows the expected throughputs for the different sizes of dry cleaner machine which are available in the product range.

	MR37-50	MR75-70	MR90-90	MR110-120
rated power [kW]	37	45-75	75-90	90-110
throughput post consumer mixed plastics [kg/h]	150-200	200-300	600-900	1000-1200
throughput PE/PP film thickness > 20 µm [kg/h]	100-150	150-300	500-700	800-1000
throughput PET-or HDPE-flakes [kg/h]	500-600	700-1000	2000-2500	3000-4000

The best way to determine the expected throughput and cleaning efficiency on any particular application is to carry out a process trial at the demonstration plant in Cologne so that actual feed-rate and output product quality can be measured.

Very heavily contaminated waste streams with high levels of paper and carton board may need two passes through a machine to achieve satisfactory cleaning performance. In these cases it is also possible to vary the hole size of the internal cleaning mesh screen in order to allow a greater proportion of the input waste material to pass into the dirt fraction.

7.0 Trial Methodology

The trial was conducted on Pla.To's demonstration plant which is located in a test centre in Bergheim near Cologne, Germany. The installed system represents a scaled-down version of a typical installation for industrial processing of rigid flakes or flexible films. This includes the feeding screw, pneumatic separator, dry cleaner, outfeed pneumatics, high-volume rotary discharge unit, dust collection and waste recovery. The actual mechanical cleaning unit fitted in the system is an MR37-50, which is the smallest version of the available machine sizes.

The approach to each trial was to feed-in a measured mass of each sample of plastic material over a timed period. The process is fully automated and once the correct balance of material feed rate and pneumatic transfer has been set, it can be left alone to do the cleaning process. Output cleaned flakes were collected in a big-bag at the exit from the discharge valve and the removed dirt and fibres were collected in a bin below the dust-cyclone. A small mass of heavy particles, which would not be good to feed into the machine, were colleted in a bin below the pneumatic separator section of the infeed duct-work.

After completion of each test the collected outputs were weighed accurately (+/- 0.1 kilogramme scales) in order to check the mass balance and then assess the level of losses or material 'hold-up' inside the equipment.

The following six trial runs were carried out:-

Trial Ref 2102 – Run 1 – Dirty flakes of rigid mixed plastic containers

One big-bag of dirty, granulated flakes was emptied out onto the floor for manual feeding (via shovel) into the feeding screw. The material was weighed in the big-bag at 197.0 kilos, with 1.7 kilos for the bag weight, this meant that 195.3 kilos of material was fed into the machine.

Visual inspection of the flaked product clearly showed a much higher level of general surface dirt and wet-paper contamination than had been seen in earlier trials, when the sample was manually prepared and delivered loose in big-bags. This infeed sample was prepared from the same baled sample that had been used for the Herbold wet washing trial earlier in February, thus allowing a direct comparison of the cleaning technologies to be made.

Based upon the earlier inspection of the mixed infeed plastic, it was decided to fit a larger screen hole size into the dry-cleaning unit than would normally be used for the cleaning of bottle flakes. A screen with 5mm holes was used in place of the normal 3mm hole size, this has the effect of allowing more of the input mass to exit through the screen and some increase in loss of plastic fines.

Samples reference 2102 A, B, C were taken during the run as follows :-

2102 – A - infeed plastic mix
2102 – B - Cleaned output plastic – single pass
2102 – C - Output dirt / paper mix
2102 – heavies – small example of the collected metal / glass items from infeed duct separator.

Photographs of these materials are shown below (note the high level of paper seen in the granulated flake input material):-

Fig 3 – Infeed Rigid Plastic flake – Run 1 Sample 2102 A (ex baled plastic waste).

Fig 4 - 2102 – B - Cleaned output plastic – single pass

Fig 5 - 2102 – C - Output dirt / paper mix

Fig 6 - 2102 – Heavies – small example of the collected metal / glass items from infeed duct separator

The mass balance of the first run was :-

2102 - Run 1	Kilos	Sample
Input Mixed	195.3	2102 A
Output Plastic	110.7	2102 B
Output Dirt	69.8	2102 C
Heavies	2.1	heavies 1
Output Total	182.6	
Losses in Trail	12.7	7%

The trial ran for 40 minutes at a steady, manual infeed rate which equates to around 300 kilos/hour of infeed. The process was not being pushed for maximum throughput at this stage.

Losses in the process are attributed to three possible causes:-

1. Hold-up of material inside the equipment, stuck to surfaces etc.
2. Exhaust of fine dust to the filter unit with the air flow from the product separator valve.
3. Evaporation of moisture to atmosphere via the high volume of conveying air in the system.

An overall loss of 7% on a batch trial of this nature is generally seen to be an acceptable result.
The output plastic was seen to be a lot cleaner and drier than the very dirty infeed, with around 35% of the input mass having been removed as fibres and dirt, but there was still some visible residual paper fibres/ dirt in the material. It was decided to give the outfeed plastic from this first run a second pass through the machine in order to reduce the level of residual dirt contamination to a more commercially acceptable level.

<u>2102 – Run 2 – Second Pass of Cleaned Plastic Output from Run 1</u>

The same approach was taken for the second run, with the following results:-

2102 - Run 2	Kilos
Input Mixed	110.7
Output Plastic	75.3
Output Dirt	31
Heavies	0.8
Output Total	107.1
Losses in Trail	3.6%

It can be seen that over the two passes through the dry-cleaning unit the total collected dirt fraction equates to 50% of the input plastic mass. The collected dry-cleaned output product from run 2 is 40% of the total dirty input mass. This high loss of material mass in the cleaning process is consistent with the losses seen in the wet-washing trial on the same sample of material and thus confirms the very high levels of dirt, paper and moisture included with the waste infeed.

There is a further loss of mass associated with drying of the material at 3.6% and, as expected, this is less than the 7% seen in run 1. Some of the fine plastic particles will also have passed through the larger hole size of the screen mesh.

The second run of material took 19 minutes to process. This gives an estimated throughput for this small machine of 330 kilo per hour on this particular run, which was not carried out at maximum load conditions.

Fig 7 – 2102 – Run 2 Output – dry-cleaned rigid flakes

An assessment will be made of the level of insoluble material in the collected 'dirt' fractions as a means to estimate the loss of plastic fines into the waste stream. The quality of the cleaning process will be tested by placing a sample of the cleaned flakes into clean water to see if it is possible to remove much more surface contamination from the plastic flakes. (see Results – section 8).

2102 – Run 3 – Dirty Flexible Films

A sample of 40mm flakes of mixed post-consumer films was prepared from a bale of dirty films waste. One big-bag of circa 100 kilos of the flakes were then passed through the Pla.To dry-cleaning unit in this trial. The results of the test were:-

2102 - Run 3	Kilos	Sample
Input Films	104.6	2102 E
Output Plastic	80.2	2102 F
Output Dirt	10	2102 G
Heavies	0.2	heavies
Output Total	90.4	
Losses in Trail	14.2	14%

It can be seen in the photograph below that the speed of feeding this material was much slower than in earlier trials. The cleaning task is related to the surface area of material to be cleaned; so for films there is a much higher ratio of surface area to mass due to the thin gauge of the polymer material compared with rigid walled containers. It was estimated that the mass throughput was around 25% of the rate seen with the rigid film flake in this trial.

This reduction in throughput between rigid bottle flake and flexible films is consistent with the performance of full-scale Pla.To equipment in industrial applications.

Fig 8 – slow feeding of flexible film flakes!

Fig 9 – 2102 Run 3 – output flexible film flakes.

Fig 10 – Dirt collected ex films

The cleaned film material appeared to be very low in residual paper or surface dirt.

The material has a very low bulk density after dry-cleaning because all the individual flakes become separated and 'fluffed-up in the cleaning machine. One big bag of uncompressed film flakes weighed 67 kilos with a volume of approx 1.5 cubic metres, this equates to around 40-50 kilos per cubic metre bulk density.

<u>Next 3 Runs on Machine – Smaller Samples of Pre-sorted Plastics</u>

For the next 3 runs in this trial samples of plastic which had been optically sorted using Titech equipment and then granulated to flake, were fed through the Pla.To unit.

The test results for these smaller batch samples were as follows:-

<u>Run 4 – Sorted PE Films</u>

2102 - Run 4	Kilos	Sample
Input Films	25.9	
Output Plastic	22.0	2102 H
Output Dirt	2.0	2102 I
Heavies	0	
Output Total	24	
Losses in Trail	1.9	7%

This material had been 'negatively sorted' as PE material on the Titech trial and then granulated at Herbold.

The visual appearance on exit form the dry-cleaner was very good, with virtually nil contamination with rigid flakes and no visible dirt or paper in the flakes. Product was also dry to the touch.

Fig 11 – Cleaned and sorted PE film flakes

<u>Run 5 – Sorted PP Rigid Container Flakes</u>

2102 - Run 5	Kilos	Percent
Input PP flake	13.4	100%
Output Plastic PP	7.2	53%
Output Dirt	5.6	42%
Heavies	0	
Output Total	12.8	
Losses in Trail	0.6	4%

Material had been optically sorted on Titech trial as whole containers, then granulated at Herbold to flake, before dry cleaning.

In a full plant application it would be normal to pass the dry-cleaned flakes through an air-aspiration unit (such as a zig-zag separator or similar). In this separation phase any residual light material, such as thin film labels or entrained dust, would be removed in an upwards, controlled air-flow. Commercial operators who use this type of process in combination with a dry-cleaner find that the quality of the cleaned flake makes it suitable for many direct-extrusion recycling applications without the need for further wet washing.

Fig 12 – Dry-Cleaned flakes of PP ex rigid containers sorting

<u>Run 6 – Sorted PET Rigid Container Flakes</u>

2102 - Run 6	Kilos	Percent
Input PET flake	12.4	100%
Output PET	10.5	85%
Output Dirt	1.6	13%
Heavies	0	
Output Total	12.1	
Losses in Trail	0.3	2%

Sorted whole PET containers at Titech; granulated at Herbold then dry-cleaned on Pla.To.

For PET flake processing the output product will inevitably contain a level of HDPE bottle caps and neck-rings. The most common route to remove these items form the PET is via a sink-float operation, due to the large difference in density between the two polymers. Often this takes place in a hot-wash system where any final traces of residual label glue can also be removed form the flake surface.

As an alternative to this wet-processing approach, successful removal of coloured or opaque flakes from the clear PET has been demonstrated in previous trials using modern colour sorting equipment. This approach would probably be fine for the PET from the mixed waste plastic, as it could yield a stream of clear PET flakes which were clean enough for some end-use applications.

Fig 13 – Dry-cleaned PET flakes

8.0 Trial Results

Off-site analysis of collected samples was carried out in Axion's laboratory in Salford, Manchester. The testing carried out included:-

- A measure of the Cleaning Efficiency
- Particle Size analysis
- Simple Float / Sink tests
- Polymer type analysis via Infra-red instrument
- Preparation of 'raw' compounds of specific materials

Cleaning Efficiency

In order to get a measure of the 'cleaning efficiency' it was decided to carry out some batch washing of the samples in water, before and after the dry-cleaning process. A weighed amount of the material was stirred in hot water and then the insoluble, clean plastics were removed and dried. This gives an indication of the amount of water soluble dirt and paper fibres that were present in each sample tested.

The results of this simple cleaning efficiency test are shown below:-

Sample Ref.	Description	Wt. Before Washing gram	Wt. After Washing gram	% loss
2102 - A	Input Rigid Flakes	47.5	37.0	22%
2102 - B	Output Pass 1	40.1	35.5	11%
2102 - C	Output Dirt/ Paper	48.75	7.57	84%
2102 - D	Output 2nd pass	61.36	59.72	3%

This shows that the input plastic flake sample had around 22% by weight of dirt/paper material associated with it (on a dry weight basis). The first pass through the dry-cleaner machine reduced the level of dirt/paper to 11% (sample 2102-B) and the second pass reduced this to around 3% residual dirt (sample ref 2102 – D).

The sample of dirt / paper collected from Run 1 was subjected to the same test to see how much of the waste material was in fact plastic fines (or insoluble material). This shows that at least 84% of the waste fraction was paper or soluble dirt and it is assumed that the rest is mostly plastic fines that had passed through the screen during the trial.

A similar test on the dirt fraction collected from the trials on flexible PE films showed that between 22 – 40% of the 'dirt/fibres' material was in fact insoluble plastic fines. This does represent a loss of fine plastic 'dust' into the waste, reducing yield of cleaned material. However it should be noted that the trial was conducted with a larger screen hole size than normally recommended due to the very dirty nature of the rigid sample.

The 'Heavies' material collected by the air-separator (see Fig 6 above) was quickly measured into 3 material types – Metal 96g, Hard plastics 185g, Glass 1g.

Particle Size

As part of the analysis we carried out a particle size distribution on some of the samples, with the results as follows:-

Sieve size :-	25.0mm	11.2mm	8mm	5.6mm	4mm	2mm	<2mm
SAMPLE							
A Run 1 Input Rigid	0%	26%	12%	18%	13%	19%	12%
B 1st pass output rigid	0%	14%	16%	18%	15%	24%	12%
Output run 2 – rigid	0%	13%	14%	21%	18%	28%	6%
C Paper/dirt output 1st pass	0%	0%	0%	0%	1%	17%	82%
E Heavies ex rigids	0%	9%	30%	42%	14%	3%	0%
G Dirt- ex films	0%	0%	0%	0%	0%	30%	70%

This demonstrates that the paper pieces in the input sample were mostly larger than 11mm as shown by the 26% of the sample on that sieve size. After cleaning it is clear that the paper has been broken down in the process, with both particle size distributions from the first and second pass being broadly the same. This indicates that very little breakdown of the plastic particles occurs in the process.
Both samples of dirt / fibres form the rigid and the films trials had small particle size being all below 4 mm size range.

Float / Sink Tests

For the samples of flexible film and the sorted rigid plastic flakes of PP and PET (from the Titech trial), we decided to carry out some simple float sink tests in water (1.00 SG) as an indicator of the purity of the material. This gave results as follows:-

Sample Ref.	Description	Float %	Sinks %
2102 - E	Dirty Film Input	86	14.0
2102 – H	Sorted PE film input	94.4	5.6
2102 - run 5	Sorted PP flake	95.4	4.6
2102 - run 6	Sorted PET Flake	0.7	99.3

It can be seen that the Titech sorted flexible PE films had a higher percentage of polyolefin material than the 'dirty / unsorted film'. (2102 – E vs. 2102 –H)

The PP flakes had 4.6% by mass of material which sank in water, possible due to label & dirt particles stuck to some of the flakes. The PET had over 99% of material which sank in water, as should be expected.

Polymer Type Analysis

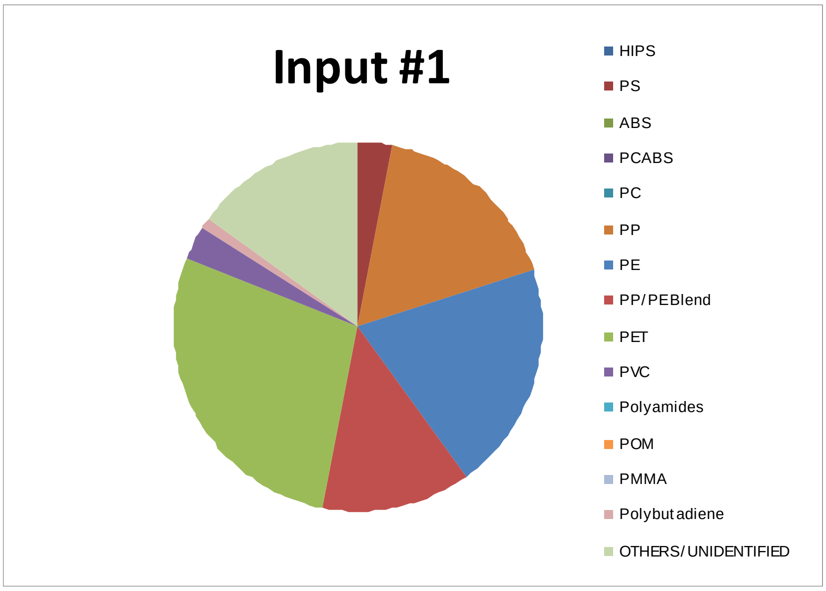
It was also decided to carry out some identification of the polymer mixtures in the materials by use of bench-top infra-red analysis of a sample of flakes. This gives information which is relevant to the overall trial programme with respect to the input polymer mixture and the potential purity of output products after the upstream separation and cleaning process.

In each test 100 flakes are chosen at random from the sample material and then individually identified using the infra-red analyser, under a grouping of common materials (e.g. PE, or PE/PP blend etc). This gives an indication of the mixture that one could expect to see in the bulk material. However attention is drawn to the fact that the sample size for such a manual test is, by necessity, small in relation to the original sample size used in the trial. For the input rigid plastic flakes used in Run 1, the test showed as follows:-

Input Rigid Plastic Flakes – 2102 – Run 1

Polymer	count	%
HIPS	0	0%
PS	3	3%
ABS	0	0%
PCABS	0	0%
PC	0	0%
PP	17	17%
PE	20	20%
PP/PE Blend	13	13%
PET	28	28%
PVC	3	3%
Polyamides	0	0%
POM	0	0%
PMMA	0	0%
Polybutadiene	1	1%
OTHERS/UNIDENTIFIED	15	15%
	100	

This table is represented as a pie-chart below;-



A similar test was carried out on a sample of the cleaned rigid flake material from 2102 - Run 1 on the Plato dry cleaner. This showed a slightly different mix of materials to the input sample, even though the process does no separation of polymer type. This underlines the importance of understanding sampling variation when taking 100 flake samples from bulk material.

Rigid Plastic Flakes - 2102 Run 1 Output		
Polymer	**count**	**%**
HIPS	1	1%
PS	0	0%
ABS	0	0%
PCABS	0	0%
PC	0	0%
PP	8	8%
PE	53	53%
PP/PE Blend	1	1%
PET	27	27%
PVC	0	0%
Polyamides	1	1%
POM	0	0%
PMMA	0	0%
Polybutadiene	4	4%
OTHERS/UNIDENTIFIED	5	5%
	100	

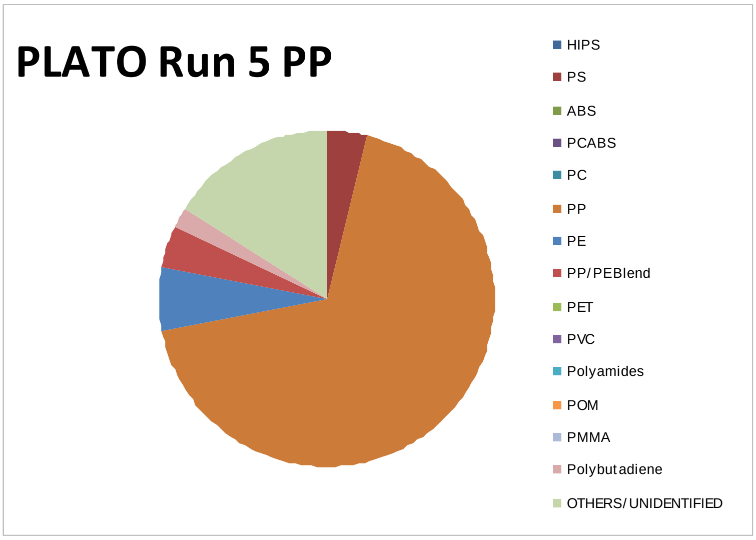
It can be seen that the material identified as PE from the input material has increased from 20% to 53% in the output cleaned flake measurement.

Similar tests were carried out on the PE flexible films and the two samples of sorted rigid plastic – PP & PET.

The input PE film sample was measured as 98% PE material in a 100 flake test. Which indicates a high purity.

The PET sample of flakes was measured at 96% PET (on a 50 flake test only), with 3 of the flakes (6%) being 'unidentified' and one being seen as PE material type.

For the PP 50 flake sample test, on material that had been sorted using the Titech equipment, the result was more mixed, with 68% of tested flakes being positively identified as PP, 10% of flakes ID as PE or PE/PP blend and 16% seen as 'other' or 'unidentified' material. (per the pie chart below:-)



Compounding Tests

As a means to evaluate the potential market value and 'processing potential' of the cleaned flake materials following the various upstream trials, it was decided to carry out simple compounding of the raw flakes on a laboratory scale twin-screw extruder. The ability of the flake to be uniformly melted and to extrude as a continuous strand gives an initial indication of its potential use by recyclers in the production of pelletised plastic recyclate.

The following three materials were successfully converted into a small quantity of extruded pellets:-

2102 – H	Sorted, dry-cleaned PE Film flakes	Successfully made compound
2102 – Run 5	Dry cleaned, PP flakes	Successfully made compound
2102 – Run 6	Dry clkeaned PET flakes	Successfully Made compound

For the PE film material it was possible to produce a good looking pellet and some test plaques were injection moulded from these to demonstrate the materials possible application. We also measured the melt flow index MFI to get a result of 7.8 grams/10 mins at 200 deg.C, 5 kg weight.

Fig 14 – Pellet made from PE film flakes and test plaques.

The PP pellet made from the dry cleaned PP flakes is shown below, in this case the injection moulded plaque was made directly from the flakes (without an extrusion step). This material has an MFI 0f 15 gram/10min at 200 deg.C / 5kg.

Fig 15 – Pellet and plaque from PP material

The PET flake was given a simple aspiration to remove the light pieces of label film and then made into the pellet shown below. There was some trial and error in finding the correct operating temperatures to make this extrude satisfactorily, but this was mainly due to a lack of experience with this material at the Axion laboratory. It was not possible to measure the MFI for this sample.

Fig 16 – Pellet from dry-cleaned, aspirated PET flakes.

Even those these simple extrusion compounding tests are a long way from ideal conditions and with no 'target specification' for the material properties, they do indicate that it is possible to produce a viable recyclate from the mixed plastics infeed.

9.0 Statistical Assessment and Reliability of Results

Mass balance results were achieved with careful control of all input and output material flows. The sample weights were measured on top-pan scales with accuracy of 0.1 kilogramme. All test results were recorded by two people and the simple mass balance sheets check for consistency. The process was left to run empty after each trial batch in order to check that no further material was help up inside the process.

Therefore it can be stated that the quoted mass balance results are accurate for the purposes of the trial.

Comment on the variability of sampling mixed plastics is made in the previous section, regarding the use of 100 flake IR samples for polymer identification.

10.0 Economics (capital costs, operating costs)

10.1 Estimate of Capital Costs

Pla.To have provided the following budget cost estimates for the equipment based upon a nominal 1 tonne/hour and 3 tonne/hour throughput, processing a rigid flake material (with lower levels of paper/dirt than seen during this trial).

The dry cleaner MR55-80 having a main motor with a rated power of 55 kW and a rotor diameter of 800 mm will process 1 tonne/hr of rigid flake. The price for the dry cleaner alone is €54,000 Euro. The whole system including pneumatic system, piping, dust filter, cables and switch cabinet is €112,000 Euro. For erection and commissioning another 10% of the equipment costs has to be added. For the removal of lightweight foreign objects post-cleaning (e.g. label films) an aspirator system should be added. The price for an aspirator is €14,900 Euro.

To comfortably handle a throughput of 3000 kg/hr the biggest machine offered by Pla.To is required:- model number MR110-120. The price for this machine as a stand-alone unit is €93,500. The complete system including an aspirator is €184,500 ex works.

Delivery costs for the UK are about €3,000 Euros.

The following table summarises the capital costs based upon an exchange rate of 1.35 Euro:£.

<u>Capital Cost Estimate</u>		Throughput:- Model:-	1 tonne/hr MR55	3 tonne/hr MR110
Basis			**GBP £**	**GBP £**
Budget Quote	Dry cleaning system ex works		82,963	
Budget Quote	with aspirator		11,037	136,700
		Total	**94,000**	**136,700**
Installation	based on 10%		9,400	13,670
Delivery to UK			2,222	2,222
	Installed Cost		**103,400**	**150,370**

10.2 Estimated Operating Costs

The following process operating costs have been provided by Pla.To based upon recent experience of the equipment on similar infeed materials. This data can be verified by reference to existing UK operators of the dry-cleaning process on bottle flakes, but that is outside of the scope of this report.

Operating costs are based upon:- 3 shift operation – 5 days per week, giving 6,000 hours planned operation per annum.

Material used – rigid container flakes, medium level of dirt and contamination (i.e. circa 10% dirt level by mass; NOTE:- In this trial much higher paper & dirt levels were tested).

Power consumption – estimated at 70% of the total motor power rating on the plant. Main motor drive on the dry cleaners – 55 KWatt – 1 tonne / hour; 110 KWatt – 3 tonne/hour.

No other utilities needed – e.g. compressed air, or water.

Some allowance should be made for cost of waste disposal as a part of the operating costs.

<u>Spares parts used and costs</u>:-
Spare rotor wear-plates made out of fully hardened steel are about €45 Euros each. Estimated consumption of 10 wear-plates per year.

A spare mesh-screen for MR55-80 is €5,000 and for MR110-120 €6,600. It is estimated that the screen should be replaced once per year.

Estimated overall operating efficiency:- The availability of the system is approx. 90 to 98% depending on the quality and rigour of regular preventive maintenance practiced.
Weekly maintenance hours required:- A standard inspection without changing wear-plates on rotor or mesh-screen will require one person for 1 to 2 hours.

Process operator labour – Due to the fact that the system works automatically and the process is installed in-line, there is no need for a dedicated process operator. For general supervision purposes you can calculate 10% of one process operator.
Plus may need to allow for one staff member for infeed supply and fork lift truck handling.

The above data has been combined into a simple analysis of overall operating costs for the two different throughput levels and is shown in the tables below:-

Pla.To Dry Cleaner Process		-	**Operating Cost Estimates**		**MR 55**
Hours per shift	8				
Shifts per Day	3		**1 tonne / hour**		
Days per Year	250				
Annual Running Hours	6000			**£ UK Sterling**	**Euros**
	Cost as quoted	Hours basis for use	Unit cost per Hour	Estimated Cost /Year	Estimated Cost /Year
Spare Parts Used	4,037	6000	0.67	4,037	5,450
Maintenance Labour	4,000	6000	0.67	4,000	5,400
Electrical Power	53	KWatt	5.25	31,500	42,525
	-			-	-
	-			-	-
Waste Disposal	0.095	tonne/hr	4.8	28,500	38,475
Process operator cost	3,000	£/yr	1.50	9,000	12,150
Fork lift etc labour	20,000	£/yr	10.00	60,000	81,000
Total Operating Costs				**137,037**	**185,000**
Throughput					
Tonnes per hour	1.0	Input			
Operating efficiency	95%			UK £ / tonne	Euro / tonne
Tonnes per annum	5,700	Input		**26.71**	**36.06**
Output Tonnage	5,130				

Pla.To Dry Cleaner Process		-		**Operating Cost Estimates**	**MR 110**
Hours per shift	8				
Shifts per Day	3		**3 tonne/hr**	Throughput	
Days per Year	250				
Annual Running Hours	6000			**£ UK Sterling**	**Euros**
	Cost as quoted	Hours basis for use	Unit cost per Hour	Estimated Cost /Year	Estimated Cost /Year
Spare Parts Used	6,367	6000	1.06	6,367	8,595
Maintenance Labour	4,000	6000	0.67	4,000	5,400
Electrical Power	95	KWatt	9.45	56,700	76,545
	-			-	-
	-			-	-
Waste Disposal	0.285	tonne/hr	14.25	85,500	115,425
Process operator cost	3,000	£/yr	1.50	9,000	12,150
Fork lift etc labour	20,000	£/yr	10.00	60,000	81,000
Total Operating Costs				**221,567**	**299,115**
Throughput					
Tonnes per hour	3.0	Input			
Operating efficiency	95%			UK £ / tonne	Euro / tonne
Tonnes per annum	17,100	Input		**14.40**	**19.44**
Output Tonnage	15,390				

11.0 Conclusions

The following main conclusions are drawn from this trial:-

- The Pla.To Dry-Cleaning process offers an effective route for the removal of surface dirt and paper from flakes of both rigid and flexible plastics.
- For the very high level of wet-paper and dirt seen in the mixed, rigid plastic sample used in this trial, TWO passes through the unit were needed to reduce the contamination down to 3% by mass of the plastic flakes. During the two passes through the dry-cleaner around 50% of the original input mass was removed as dirt & paper waste (wet weighed).
- When processing 40mm flakes of post-consumer, flexible films around 10% of the input mass was removed as dirt/fibres. There was also a significant drying effect in the process, which accounted for a further ~10% reduction in mass.
- Smaller sample batches of sorted PP and PET rigid flakes were successfully cleaned in the process. There was a higher level of dirt and paper removed from the PP flakes (~40%) than from the PET flakes (13%).
- Dry-cleaned samples of the rigid PP, PET and the flexible PE flakes were successfully compounded into recycled plastic pellets on a laboratory scale extruder. This demonstrates that dry-cleaned flake material represents a potential end-product for direct sale into certain polymer markets.
- Throughputs of 3 – 4 tonnes per hour are quoted for the largest Pla.To machine based upon real operating experience of equipment used commercially on PET and HDPE bottle flakes. Dirt contamination levels of around 10-15% are typical in these applications. The higher levels of contamination expected with mixed rigid food container plastic could lead to lower throughputs than this, due to the increased cleaning requirement.
- Throughputs on flexible films will be lower due to the much higher surface area to mass ratio. Around 1 tonne per hour is the best rate that could be expected on this type of infeed with 10-20% input dirt levels.
- Operating costs per tonne of infeed material compare favourably with equivalent wet washing processes. In this report, an estimate of £14.40 GBP per tonne has been made for dry-cleaning of sorted rigid flakes with a 10% level of dirt/paper at input at 3 tonnes/hr.
- Capital costs for a complete system to handle 3 tonnes/hr of flaked rigid plastic (from an upstream granulation stage) have been estimated at £150,000 GBP installed in UK.
- The absence of any process wash-water with its associated high capital and effluent treatment costs, makes the Pla.To dry-cleaning process a very attractive option when considering process equipment for the task of cleaning mixed post-consumer plastic waste. The simplicity of the operation means that it could be considered as a 'bolt-on' technology to existing plastic sorting plants.

Keith Freegard

Axion Recycling Ltd

Appendix

>> appendices<<

www.wrap.org.uk/relevant link

Waste & Resources
Action Programme

The Old Academy
21 Horse Fair
Banbury, Oxon
OX16 0AH

Tel: 01295 819 900
Fax: 01295 819 911
E-mail: info@wrap.org.uk

Helpline freephone
0808 100 2040

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