WRAP MDD018/23 WEEE separation techniques

Dry Jigging (University of Nottingham) trial report

Abstract

Pneumatic separation techniques (for example air tables) were in fairly widespread use in the coal industry in the early to middle part of the 20th Century. Since then the techniques have fallen out of use, primarily because the moisture content of the feeds were progressively higher making the technique highly inefficient. From an operational point of view such units had high capacities, of up to about 50-100 tonnes per hour per metre width. However with a drive to explore new methods of dry processing in the minerals industry there is an increasing level of interest on pneumatic separation processes. At the University of Nottingham a re-appraisal of pneumatic jigging has led to the development of an experimental batch-scale jig that was used in this trial work.

Trials were performed to assess the potential of pneumatic jigging as a means to generate a metal/copper-rich product from Waste Electrical and Electronic Equipment (WEEE) using a batch-scale experimental jig. The results were promising in that copper-rich products could be generated from the WEEE samples at a copper concentration level of around 44 to 54%.

The work contained in this report indicates that pneumatic dry jigging shows potential for recovery of valuable materials from a WEEE stream. However, this is based on a batch based experimental jig and to be of commercial relevance further work would be required to design and develop a continuous pneumatic jig.

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1.0 Information from Trial

Trial host: University of Nottingham, United Kingdom

Trial equipment: Batch scale experimental pneumatic jig

Trial date: 9th March 2009 to 31st March 2009

1.1 Description of trial equipment

The experimental pneumatic jig was specially designed for batch scale operation and consists of four major components:

- Separation chamber;
- Air supply unit (blower);
- Air control units (the inverter and the butterfly valves); and
- Programmable Logic Controller (PLC).

The main system component is the jig chamber where the actual separation takes place. It is a 160mm x 160mm x 500mm square profile column made of perspex to enable observation of the materials during the separation process. It has an open top which is often covered with a mesh-like lid that helps to control upward splashing of the materials during the separation process. The lower part of the separation chamber is fitted with a removable bottom screen that consists of apertures that will retain the smallest particles of feed material placed upon it yet will let sufficient airflow through.

During operation, the separation of feed materials is initiated by the flow of air, from an air supply unit (the blower), that runs into the separation chamber. The blower is a 4.0 kW centrifugal fan with the capacity to generate a continuous airflow up to a maximum fan speed of about 3,000 rpm (equivalent to a superficial velocity of 50cm/s on a calibrated scale). It has a single outlet that is coupled to a Y-shaped metal tube that connects the blower to the bottom section of the separation chamber. The flow of air into the separation chamber is regulated and controlled through the combined actions of a variable speed control unit (inverter) and two pneumatic butterfly valves.

The two pneumatic butterfly valves are time-controlled to open and close in alternating patterns; it is this alternating pattern of the valves that enables proper regulation of the pulse frequencies, thus giving the device the jigging effect. A micro-programmable logic control unit (connected to the pneumatic valves) is used to regulate the opening and closing time of the pneumatic valves. This is shown in Figures 1 and 2 below.

1.2 Photograph of trial equipment

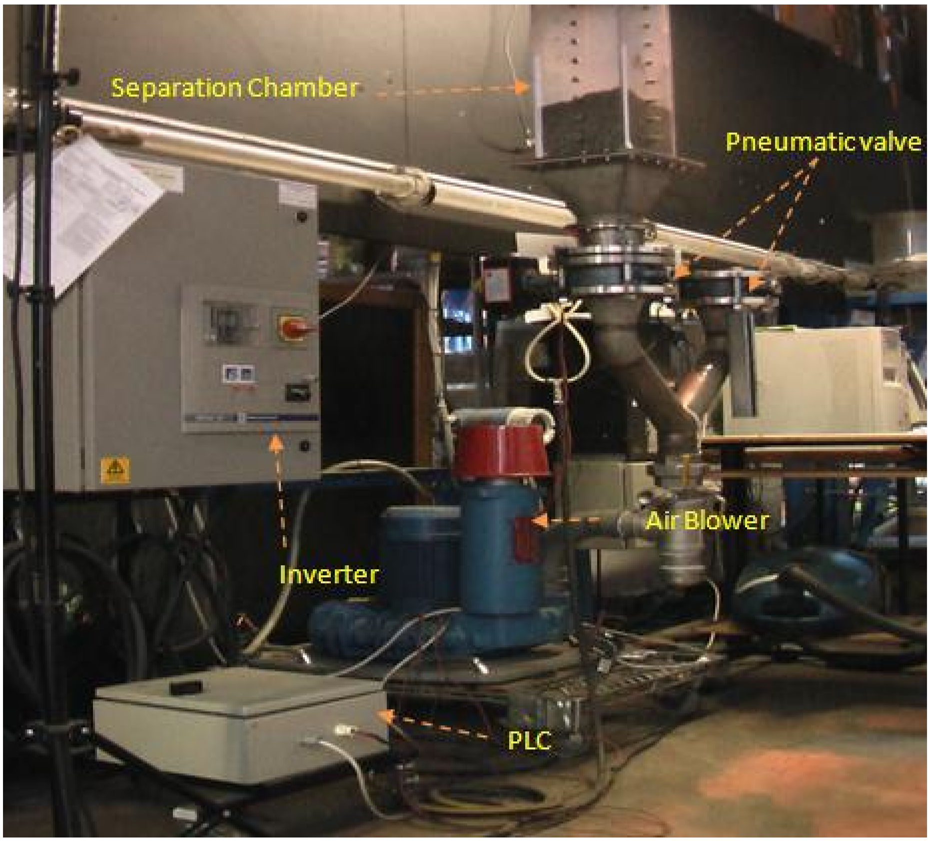

Fig. 1: Batch scale experimental pneumatic jig

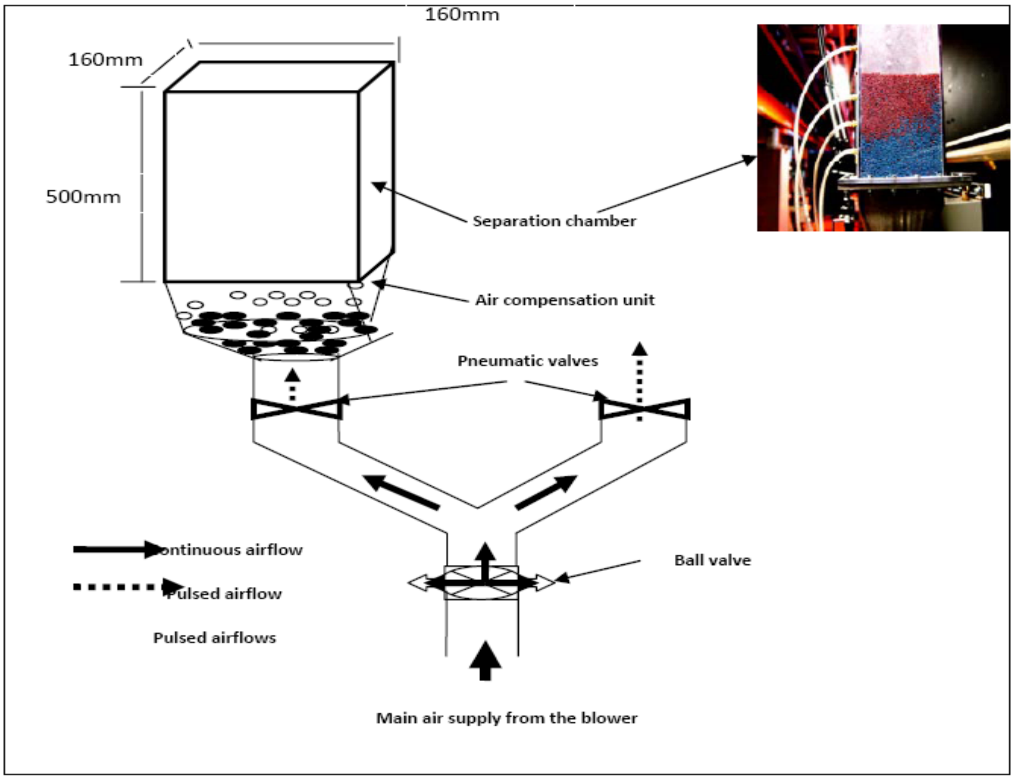

Fig. 2: Schematic of the pneumatic dry jig and separation chamber

1.3 Trial objectives

The objective of the trial was to test the suitability of pneumatic dry jigging for processing materials derived from WEEE, with the specific aim of separating fine copper particles from copper-rich plastic mixtures. In commercial processing the materials will have already passed through conventional metal separation stages and the copper will have not been successfully recovered in a purity which is of interest to metal processors.

The combustible content of the copper fraction must be below 5% by weight to make it attractive to the majority of copper smelters in Europe. This is because conventional cupola furnaces are not designed to handle and clean significant gas flows from the melt. If the copper fraction contains too much plastic and other combustible material then this will burn in the furnace and create more gas than the furnace can cope with. There are very few specialist non-ferrous metal processors in Europe with the sophisticated gas cleaning systems required to cope with high plastic content. These processors target precious metals in non-ferrous scrap. The high value of the precious metals helps to justify the increased gas cleaning costs. The fine non-ferrous fraction from small WEEE tends to have a rather low precious metal content and is therefore of little interest to these specialist recyclers.

The objectives of this trial were:

- To produce a copper fraction from WEEE containing less than 5% combustible material; and

- To produce individual fractions of stone/glass, metal and plastics or the metal distributed across stone/glass and plastics fractions.

1.4 Sample material

Three samples of various size fractions were supplied to the University of Nottingham by Axion Recycling, derived from WEEE (see Table 1).

Material	Size	Sample	Composition
WEEE	<2.36 mm	1	Plastic (70%), copper/metal (1-5%), PVC coated wires (~5%), rubber (~10%), glass, stone, wood and circuit boards
	2.36 – 5.0mm	2	
	~12 mm	3	

Table 1: Detail of WEEE Samples

Initially all the samples were riffled (a uniform sampling technique) down to produce a range of representative samples for subsequent testing as shown in Figure 3.

Fig. 3: Riffled Samples

Some preliminary separation work was conducted using the jig to assess how amenable the samples were to treatment and processing. These results indicated that Samples 1 and 2 produced layers of stratified particles, but stratification did not occur to any great degree for Sample 3. Therefore, the trial focused on Samples 1 and 2 for treatment in the batch jig.

1.5 Trial procedure

For each run material was placed into the chamber and the airflow velocity and pulse frequency were set from a pre-determined range for the trial. The jig was operated for a 300 second period, at the end of which the various stratified layers were removed and subjected to both qualitative (visual inspection) and quantitative (Loss-on-Ignition (LOI) and heavy liquid analysis) analysis. By conducting LOI it was possible to assess the quantity of combustible (and non-combustible) material present in the materials. Heavy liquid analysis was conducted using sodium polytungstate at two densities (2.2 and 2.8 g/cm^3) to give some indication of the quality of the products from the jig. Material that had a density less than 2.2 g/cm^3 would predominantly be wood, plastics and rubber; glass and stone would be the major components in the 2.2 to 2.8 g/cm^3 density range and at densities greater than 2.8 g/cm^3 copper and other metals would be in the majority. It should be noted that the above density classification only hold for fully liberated materials.

2.0 Trial 1 (Axion sample 1)

2.1 Specific trial objective

The objective of this trial was to produce a copper-rich fraction containing about 5% combustible material or less. The presence of glass and stone was not considered to be problematic in subsequent processing.

2.2 Feed material

Material used in this trial (sample 1) had a particle size of less than 2.36mm. It comprised plastic, copper, Poly Vinyl Chloride (PVC) coated wires, rubber, small quantities of glass, stone, wood and circuit board fragments.

2.3 Results and analysis

The results of this trial covered the effect of both pulse frequency and air flow velocity on subsequent separation.

Three experiments were conducted varying the pulse frequencies (75, 86 and 120 cycles/min) whilst maintaining a constant airflow velocity of 25cm/s over a jigging period of 300 seconds. A further experiment was conducted at an air flow velocity of 18 cm/s whilst maintaining a constant pulse frequency of 86 cycles/min, over a similar jigging period of 300 seconds.

Three layers of particles were produced after the separation process. The top layer consisted of small wooden particles and dust, the middle layer contained predominantly plastic products and the bottom layer comprised of higher density stones/glass and metals (see Figures 4 and 5).

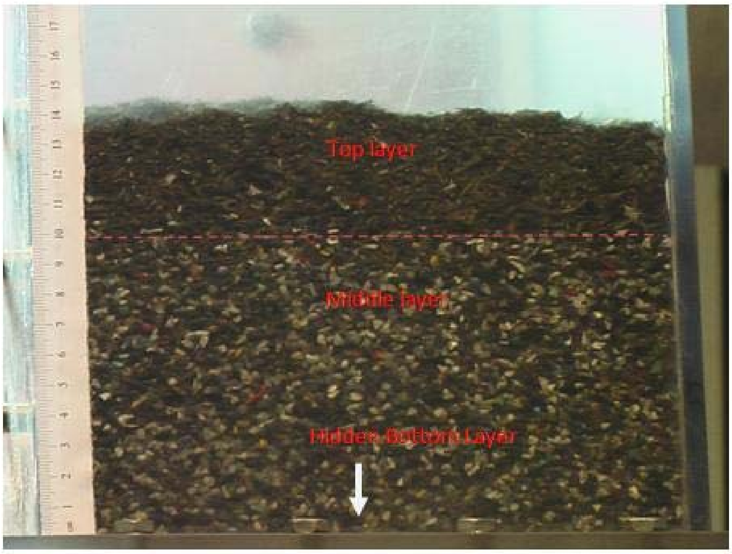

Fig. 4: Side view of jig showing the three layers after separation

The three layers were identified visually, removed from the top using suction, their masses recorded and, each subjected to analysis. This was conducted for all four test runs under different operating conditions and is presented in Table 2.

2.4 Photograph of result samples

Fig. 5: Sample 1 – top layer

Fig. 6: Sample 1 – middle layer

Fig. 7: Sample 1 – bottom layer (copper/metal rich fraction)

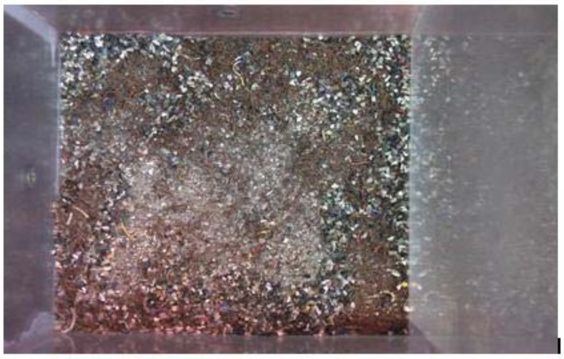

Fig. 8: Top view of jig compartment showing the bottom layer after the upper layers have been removed

Sample	Pulse Frequency (cycles/min)	Airflow Velocity (cm/s)	% Mass Distribution Across Layers			
			Top	Middle	Bottom	Total
1a	75	25	17	63	20	100
1b	86	25	20	52	28	100
1c	120	25	15	63	22	100
1d	86	18	18	66	16	100

Table 2: Mass distribution across product layers

Since the bottom layers were considered to be the valuable phases containing the majority of the metals (copper) they were subjected to heavy liquid analysis to ascertain the approximate percentage of metals, plastics, stone and glass present. The results are presented in Table 3.

Sample	Pulse Frequency (cycles/min)	Airflow Velocity (cm/s)	% Concentration of Various Components in Bottom Layers			
			Plastics/Rubber (Density: 2.2 floats)	Stone/Glass (Density: 2.2 – 2.8)	Metals/Copper (Density: 2.8 sinks)	Total
1a	75	25	7	46	47	100
1b	86	25	5	43	52	100
1c	120	25	6	50	44	100
1d	86	18	8	45	47	100

Table 3: % concentration of components in bottom layer

Since it had the highest metals/copper content, Sample 1b was chosen for further analysis. This consisted of taking the three fractions from the heavy liquid analysis of the bottom layer sample and determining the amount of combustible material present in each through a LOI analysis. The results are presented in Table 4.

Sample	% Combustibles in Various Fractions			
	Plastics/Rubber (Density: 2.2 floats)	Stone/Glass (Density: 2.2 – 2.8)	Metals/Copper (Density: 2.8 sinks)	Total for bottom layer (Calculated)
1b	68	9	11	13

Table 4: % combustibles in bottom layer

The relatively higher combustible value of the metal/copper fraction (11%) in comparison to the stone/glass fraction (9%) was thought to be due, predominantly, to the very small sample weight available for analysis.

The total combustible value (13%) in the bottom layer is calculated from the summed relative weights of the combustible material in each density fraction divided by the total weight of the fraction. Using the three individual combustible values determined on the density fractions (Table 4) multiplied by the mass of the fractions, which in this case was the same as the concentration values for the heavy liquid data in Table 3. These were then summed and divided by the total weight.

That is for sample 1b;

$$((5 \times 68) + (43 \times 9) + (52 \times 11)) / 100 = 13\%$$

2.5 Discussion of results

Across the test conditions the jig produced a mass recovery between 16 and 28% of the desired product (metal/copper-rich fraction) as shown in Table 2. The concentration of metal/copper in the product fraction was fairly consistent at around 44 to 52% (as measured by heavy liquid analysis) with the concentration of stone and glass between 43 to 50%. There was little variation in the concentration of low density material in the bottom layer, which was around 5 to 8%. Since this material comprised rubber and plastics it would have made the highest contribution to the combustibles. Further examination of this material through LOI analysis indicates that the combustible level in the bottom layer was around 13% (see Table 4). The jig came reasonably close to achieving the desired objective of a product with less than 5% combustibles. Considering this was an experimental jig, operated in batch mode with only a single pass, achieving a product with a combustible value less than 5% in a continuous process would be feasible.

2.6 Conclusions from trial

The key conclusions from the trial are:

- A desired (bottom layer) product was obtained at a mass recovery of 16 to 28% over the various operating conditions;
- Based on heavy liquid analysis the product comprised the follow;
    - ~5-8% plastics/rubber/wood (density: 2.2 g/cm^3 floats);
    - ~43-50% stone/glass (density: 2.2 – 2.8 g/cm^3);
    - ~44-52% metal/copper (density: 2.8 g/cm^3 sinks);
- Through LOI analysis the combustible value of the product was calculated to be 13%; and
- Separation was effective over a range of conditions including air flow velocities (18 – 25 cm/s) and pulse frequencies (75 – 120 cycles/min) at a treatment time of 300 seconds.

3.0 Trial 2 (Axion sample 2)

3.1 Specific trial objective

The objective of this trial was to produce a copper-rich fraction containing less than about 5% combustible material. The presence of glass and stone was not considered to be problematic in subsequent processing.

3.2 Feed material

Material used in this trial (sample 2) was derived from WEEE and had a particle size between 2.36 and 5.0 mm. It comprised plastic, copper, PVC coated wires, rubber, small quantities of glass, stone, wood and circuit boards.

3.3 Results and analysis

The results of this trial covered the effect of both pulse frequency and air flow velocity on subsequent separation.

Three experiments were conducted varying the pulse frequencies (75, 86 and 120 cycles/min) whilst maintaining a constant airflow velocity of 25cm/s, over a jigging period of 300 seconds. A further experiment was conducted at an air flow velocity of 18 cm/s whilst maintaining a constant pulse frequency of 86 cycles/min over the same jigging period of 300 seconds.

The process produced three layers of stratified particles; lower density plastics in the top layer, denser plastics in the middle layer and a small amount of copper, metal and glass in the bottom layer (see Figures 10, 11 and 12).

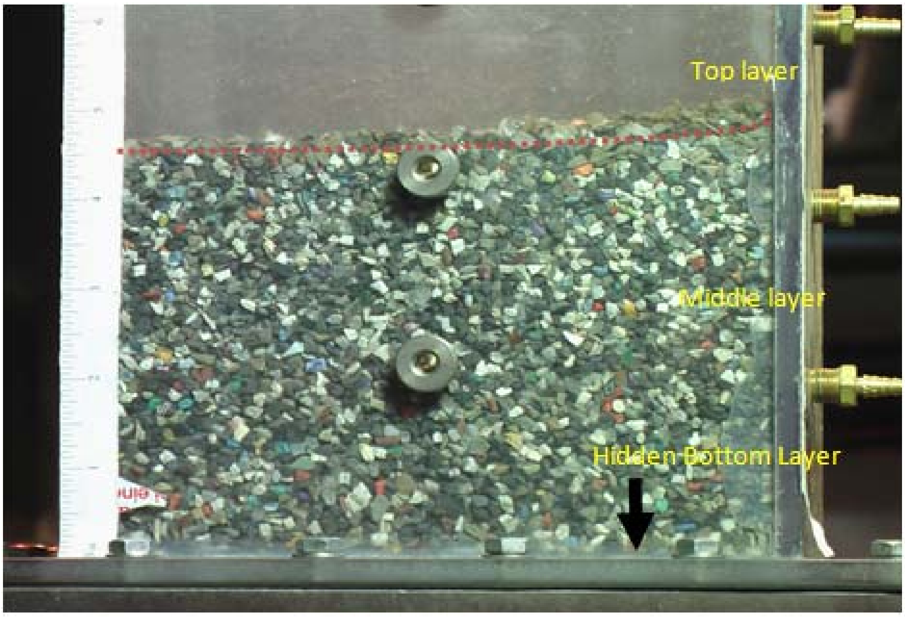

Fig. 9: Side view of jig showing the three layers after separation

The three layers were identified visually, removed from above using suction, their masses recorded and each was subjected to analysis. This was conducted for all four test runs under different operating conditions and the mass distribution is presented in Table 5.

3.4 Photograph of result samples

Fig. 10: Top layer

Fig. 11: Middle Layer

Fig. 12: Bottom layer (small amount of copper/metal)

Fig. 13: Top view of jig compartment showing the bottom layer after the upper layers have been removed

Sample	Pulse Frequency (cycles/min)	Airflow Velocity (cm/s)	% Mass Distribution Across Layers			
			Top	Middle	Bottom	Total
2a	75	25	4	86	10	100
2b	86	25	5	83	12	100
2c	120	25	4	86	10	100
2d	86	18	4	86	10	100

Table 5: Mass distribution across product layers

Since the bottom layers were considered to be the valuable phases containing the majority of the metals (copper), they were subjected to heavy liquid analysis to ascertain the approximate percentage of metals, plastics, stone and glass present. The composition analysis results are presented in Table 6.

Sample	Pulse Frequency (cycles/min)	Airflow Velocity (cm/s)	% Concentration of Various Components in Bottom Layers			
			Plastics/Rubber (Density: 2.2 floats)	Stone/Glass (Density: 2.2 – 2.8)	Metals/Copper (Density: 2.8 sinks)	Total
2a	75	25	56	34	10	100
2b	86	25	50	35	15	100
2c	120	25	54	33	13	100
2d	86	18	64	29	7	100

Table 6: % concentration of components in bottom layer

Since it had the highest metals/copper content, sample 2b was chosen for further analysis. This consisted of taking the three fractions from the heavy liquid analysis of the bottom layer sample and determining the amount of combustible material present in each through a LOI analysis. The results are presented in Table 7.

Sample	% Combustibles in Various Fractions			
	Plastics/Rubber (Density: 2.2 floats)	Stone/Glass (Density: 2.2 – 2.8)	Metals/Copper (Density: 2.8 sinks)	Total for bottom layer (Calculated)
2b	74	1	3	38

Table 7: % Combustibles in bottom layer

The low values for the metal/copper fraction (3%) and the stone/glass fraction (1%) should be viewed with caution as only very small sample weights were available for analysis.

The total combustibles in the bottom layer were calculated using sample 2b data. Using the three individual combustible values determined on the density fractions (Table 7) multiplied by the mass of the fractions, which in this case was the same as the concentration values for the heavy liquid data in Table 6. These were then summed and divided by the total weight.

That is for sample 2b;

((50 x 74) + (35 x 1) + (15 x 3)) / 100 = 38%

3.5 Discussion of results

Sample 2 gave similar results to sample 1 in that concentration of the higher density components into a bottom layer was achieved. The main difference being lower mass recovery, i.e. 10 to 12% for sample 2 in comparison to 16 to 28% for sample 1 (*cf.* Tables 2 and 5). The concentration of metal/copper in the product fraction was relatively consistent at around 7 to 15% (as measured by heavy liquid analysis) and it was significantly lower than that obtained with sample 1 at 43 to 50% (*cf.* Tables 3 and 6). Less higher density material in sample 1, in comparison to sample 2, resulted in the formation of a “thinner” bottom layer making it difficult to extract the material for assessment. The combustible values of the bottom layer presented in Table 7 support this hypothesis, with an overall level of 38% for sample 2 in comparison to a value of 13% for sample 1. Although the indications were strong that this material was amenable to dry jigging a larger stock of higher density material was required for assessment and re-treatment to actually prove this point.

3.6 Conclusions from trial

The conclusions from this second trial were:

- A (bottom layer) product was obtained at a mass recovery of 10 to 12% over the various operating conditions;

- Based on heavy liquid analysis the product comprised the follow;

    - ~50-64% plastics/rubber/wood (density: 2.2 g/cm^3 floats);
    - ~29-35% stone/glass (density: 2.2 – 2.8 g/cm^3);
    - ~7-15% metal/copper (density: 2.8 g/cm^3 sinks);

- Through LOI analysis the combustible value of the product was calculated to be 38%; and

- Further enhancement of this material was considered possible if multiple batches were treated to produce a larger stock for re-treatment. For this reason a third trial on sample 2 was designed and is detailed below as Trial 3.

4.0 Trial 3 (Axion sample 2 – retreat)

4.1 Specific trial objective

The objective of this trial was to treat multiple lots of Axion sample 2, producing a pre-concentrated feed for further treatment with the ultimate aim of generating a copper-rich fraction containing less than about 5% combustible material. The presence of glass and stone was not considered to be problematic in subsequent processing.

4.2 Feed material

Material used in this trial (sample 2) was derived from WEEE and had a particle size between 2.36 and 5.0 mm. It comprised plastic, copper, PVC coated wires, rubber, small quantities of glass, stone, wood and circuit boards.

4.3 Results and analysis

Ten identical sub-samples of sample 2 were treated individually in the jig at a pulse frequency of 86 cycles/min and an air flow velocity of 25cm/s, over a jigging period of 300 seconds.

In this case, of the three layers of stratified particles, the bottom layer was kept whilst the other two were rejected. The bottom layers from all ten tests were the combined to form a new feed stock for further treatment. This new feed was treated using the same operating conditions over a period of 300 seconds. In this case two layers of stratified particles were identified visually (bottom and top layer), each was removed from above using suction and their masses recorded (see Table 8). The top layer contained predominantly plastics and rubber whilst the bottom layer comprised metal, copper, stone and glass (see Figures 14 and 15).

Sample	Pulse Frequency (cycles/min)	Airflow Velocity (cm/s)	% Mass Distribution Across Layers		
			Top	Bottom	Total
Retreat	86	25	57	43	100

Table 8: Mass distribution across product layer

The bottom layer was subjected to a heavy liquid analysis to ascertain the concentrations of stone/glass and copper/metal present. The results are presented in Table 9.

Sample	Pulse Frequency (cycles/min)	Airflow Velocity (cm/s)	% Concentration of Various Components in Bottom Layers			
			Plastics/Rubber (Density: 2.2 floats)	Stone/Glass (Density: 2.2 – 2.8)	Metals/Copper (Density: 2.8 sinks)	Total
Retreat	86	25	11	35	54	100

Table 9: % concentration of components in bottom layer

That is for sample 2b;

((50 x 74) + (35 x 1) + (15 x 3)) / 100 = 38%

4.4 Photograph of result samples

Fig. 14: Top layer

Fig. 15: Bottom layer

4.5 Discussion of results

As identified in Trial 2 above, the mass recovery to the bottom layer was around 10% (see Table 5) making it difficult to extract this “thin” layer from the jig without contaminating it with lower density material (i.e., plastics/rubber). This is highlighted in Table 6 where the concentration of low density material was between 50 to 64% in this bottom layer with an accompanying combustible value of 38% (see Table 7). To overcome this issue, ten samples were treated individually and all the bottom layers combined to form a new feed which was then processed under the same operating conditions. The results in Table 9 clearly show the advantage of the multiple treatment approach with the concentration of low density material (plastics/rubber) in the bottom fraction being reduced to 11% in comparison to 50 to 64% (*cf.* Tables 6 and 9). In addition the concentration of copper/metals (2.8 g/cm^3 sinks material) increased from between 7 to 15% to 54% (*cf.* Tables 6 and 9). This trial has highlighted the ability of dry jigging, through multiple process steps, to achieve the desired recovery outcome.

4.6 Conclusions from trial

The main conclusions from this trial are:

- Retreatment of multiple samples of Axion sample 2 successfully reduced the plastics/rubber content in the final product down to 11%;
- Based on heavy liquid analysis the product comprised the follow;
    - 11% plastics/rubber/wood (density: 2.2 g/cm^3 floats);
        - *[compares with 50-64% for a single pass];*
    - 35% stone/glass (density: 2.2 – 2.8 g/cm^3);
        - *[compares with 29-35% for a single pass];*
    - 54% metal/copper (density: 2.8 g/cm^3 sinks);
        - *[compares with 7-15% for a single pass].*

The total combustibles in the bottom layer was approximated (no data for this trial) using sample 2b combustibles data. Using the three individual combustible values determined on the density fractions (sample 2b Table 7) multiplied by the mass of the fractions from above. These were then summed and divided by the total weight.

That is for Trial 3 bottom layer;

$$((11 \times 74) + (35 \times 1) + (54 \times 3)) / 100 = 10\%$$

5.0 Overall conclusions

It has been demonstrated that pneumatic jigging can produce stratified layers of particulates from a number of the samples of WEEE supplied by Axion. The results indicated that:

- Separation was dependant on two variables operating over a fairly wide range – pulse frequency (75 – 120 cycles/min) and air flow velocity (18 – 35 cm/s);
- Treatment (including retreatment stages) of all three of the WEEE trials generated high density (copper/metal rich) products at a mass recovery of between 10 to 28% comprising;
    - ~5-11% plastics/rubber/wood (density: 2.2 g/cm^3 floats);
    - ~35-50% stone/glass (density: 2.2 – 2.8 g/cm^3);
    - ~44-54% metal/copper (density: 2.8 g/cm^3 sinks);

- The work contained in this report indicates that pneumatic jigging has potential as a means to recover valuable metal rich materials from WEEE streams. However the work was carried out on an experimental rig and that the practical and commercial use of pneumatic separation techniques in the coal and minerals industry is, currently, fairly sparse;

- From an operational point of view such pneumatic jigging units used in the coal and minerals industry had high capacities up to about 50-100 tonnes per hour per metre width. The main operating costs were the energy used for vibration, air supply and dust extraction;

- Since the test pneumatic jigging unit involved a dry process there would be no associated water recovery and treatment costs; and

- For pneumatic jigging to be of industrial and commercial relevance in recovery of metals/copper from WEEE streams, further work would be required to design and develop a continuous pneumatic jig.