WRAP MDD018/023 WEEE separation techniques

Allmineral 'Allflux' Upflow Separator trial report

This report describes a trial conducted with Allmineral on their small scale 'Allflux' upflow separator rig in Germany.

The aim of the project was to trial innovative techniques to tackle some of the more difficult separations encountered by primary and secondary WEEE processors. Recovering fine copper from mixed WEEE is a notoriously difficult separation and several techniques have been tested during this project to attempt to find a solution to the problem. Fine copper is left in WEEE plastic by eddy current separation units because the copper wires and other small metal items are too thin to be able to generate the eddy currents that make the separation happen.

Four samples were tested during the trial:

- Copper-rich plastic granulated with a 5mm screen;
- Copper-rich plastic hammer milled to 95% below 5mm;
- -2mm sieved fractions of the hammer milled copper-rich plastic; and
- +2mm sieved fractions of the hammer milled copper-rich plastic.

The results of the trial were conclusive:

- A separation of the granulated material was not possible because the copper wires became tangled in the separator and blocked the system;
- A reasonably good copper separation was achieved with hammer milled material; however it also blocked the system. The heavy fraction contained 75% copper and 91% of the copper was recovered from the feed;
- The -2mm fraction separated very well with a copper recovery of 94%. The heavy fraction contained 95% copper with virtually no copper in the middle and lights fractions; and
- The +2mm fraction separated initially but also blocked after a while. The heavy fraction only contained 36% copper with 61% copper recovery.

The hammer milled material worked better than the granulated material because the particles are rounded by the hammer mill, which means they have less drag when they settle in water than the thin copper strands which are present in the granulated material.

An economic assessment of the technique calculated a payback time of approximately 15 months, assuming a processing capacity of 2 tonnes per hour.

In conclusion the Allflux trial produced promising technical results which would meet the metal re-processor specifications and an economic assessment has shown to have an acceptable payback time. Therefore the technique could be considered for use in recovering copper from copper-plastic mixtures produced by WEEE recyclers, provided the material is hammer milled before processing.

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1.0 Information from trial

Trial host: Allmineral Aufbereitungstechnik GmbH & Co. KG, test conducted at facility at Finnentrop-Fretter, Germany.

Trial equipment: Allmineral 'Allflux/Miniflux' upflow separator

Trial date: 20th March 2009

1.1 Description of trial equipment

The full scale upflow separator is known as the 'Allflux', whilst the smaller test model, used in these trials, is the 'Miniflux'.

The principle of a fluidised bed is utilised by both models to achieve a separation. The advantage of the unit is that it can classify, separate, thicken and de-slime and do this at a high throughout. The original use for the technique was in the sand, ore, coal, heavy mineral sands and slag processing industries. It has not previously been trialled for plastics or WEEE recycling.

The test model, the 'Miniflux', is a 1/8th section of a full size (1m diameter) Allflux separator with a Perspex side to allow for viewing of the separation process.

The Allflux can process a wide range of feed concentrations, with a throughput rate of up to 2,000 m^3/hr and handle particles up to 4mm in size. The Miniflux can also process particles up to 4mm in size but with a throughput of up to 300kg/hr.

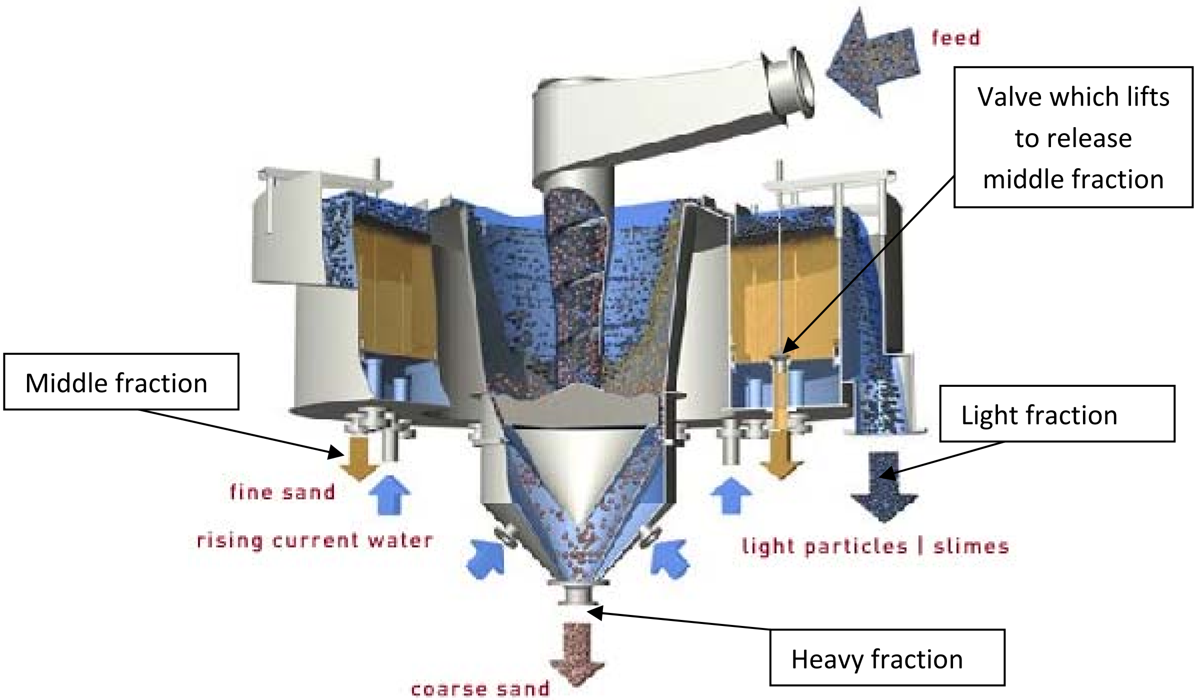

Figure 1: Diagram of a full scale Allflux (courtesy of Allmineral)

Figure 1 shows a diagram of an Allflux. The system has two separation stages. The inner section separates the heavy material from the middle/light material, whilst the outer section separates the middle and light materials from each other. The device produces three product fractions; heavy, middle and light.

Feed material is suspended in water in a separate vessel. It flows into the top of the machine and down the central core. At the bottom the material encounters an upflow of water. The velocity of the up flowing water is set so that the lighter particles fluidise and are carried upwards whilst the heavy particles are able to settle downwards. During operation the water flow rate is adjusted in order to find the optimal setting for the separation. The heavy particles exit at the bottom of the machine.

The lighter material flows up and over into the outer section of the machine where it encounters another upflow of water. The water velocity in the outer separation section is less than in the inner separation section. The lightest material is fluidised but the middle fraction sinks, as its settling velocity is greater than the water velocity. The light material is carried over the weir and is collected. The middle fraction meanwhile collects in the bottom of the outer section and a valve periodically opens to allow the material to flow out of the bottom of the machine. The upward water flow rate in the outer separation chamber depends on the size and density of the particles to be separated.

The machine can be supplied without the outer separation section if it is only required to separate two products (heavy and light).

The upflow separator has potential to separate fine metals from plastic and glass derived from small WEEE with relatively low operating cost and high throughput.

1.2 Photograph of trial equipment

Figure 2: Top view of the Miniflux separator showing the two separating sections

1.3 Trial objective

The objective of the trial was to test the suitability of the Allflux separator 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 trial objective was the same for all of the samples tested.

1.4 Sample material

The initial trial samples, which were both copper containing heavy plastics from WEEE, were pre-processed in two different formats:

1. Copper-rich plastic size reduced in a granulator with a 5mm screen; and
2. Copper-rich plastic size reduced in a hammer mill to 95% less than 5mm.

The hammer milled material was then sieved at 2mm to produce two further samples for testing because previous trials for this project indicated that tighter size fractions may give better separations.

3. -2mm sieved hammer milled material; and
4. +2mm sieved hammer milled material.

1.5 Trial methodology

Each sample was processed in the Miniflux separator. During the tests samples of the light, middle and heavy fractions were collected, bagged and labelled ready for post trial analysis. The Allmineral engineer used his judgement to select the machine settings for the different materials.

Based on the results from the first trial on the hammer milled material the decision was made to sieve a sample of the material at 2mm and process the two sieved fractions.

Post trial analysis of all the samples involved conducting a sink float test in a heavy media solution (sodium polytungstate solution) to separate the copper from the rest of the sample.

This method was chosen as the material particle size was very small making it too difficult to hand sort.

The same method was used for all the samples tested. A representative sample, of at least 20g, from each fraction was taken using a small sampling spear. The sample was then dried, weighed and added to the sodium tungstate solution, which had been made up to a density of 1.7g/cm^3. The samples were allowed to settle, resulting in a floating and a sinking fraction. The two fractions were carefully removed from the container, thoroughly washed to remove any traces of the heavy media solution, dried and weighed. The copper content of each fraction was then determined.

Finally the product separation efficiency, Q, was calculated. The separation efficiency is the probability of correctly recovering the copper to the desired product stream (i.e. the heavy fraction). The secondary streams (the middle and light fractions) are of little interest in this trial so long as their copper content is very low. This is because the copper is the only useful material present in the feed and the majority of it should be collected in the heavy fraction. The plastics present are a mixture of PVC, acetyl and other polymers for which there are limited processing markets. Separating these materials from each other is also challenging. The separation effort is not justified by the value of the materials that could be produced.

2.0 Trial 1 - Granulated material

2.1 Feed material

The feed material for trial 1 was the copper-rich plastic which had been granulated with a 5mm screen.

Figure 3: Trial 1 feed material

2.2 Results

The trial was not successful and had to be stopped because the material blocked the system very quickly. The copper wires knitted together in the entry ports. Too much of the heavy plastics settled into the heavy fraction and much of the fine copper was fluidised by the up flowing water.

2.3 Analysis of product samples

No product samples were collected as the trial was not completed as planned.

2.4 Discussion of results

The feed material was clearly not suitable for processing in the upflow separator as the particle size was too large. This caused the blockages and prevented the separation from occurring.

2.5 Conclusions from trial

For the material granulated with the 5mm screen the trial did not work. It is thought that it may have possibly worked if the material was granulated finer, to below at least 3mm. However using a granulator to reduce the size of material of this type with a screen smaller then 5mm is very expensive, because of the high blade wear rate and low throughput.

3.0 Trial 2 - Milled material

3.1 Feed material

The feed material for trial 2 was the copper-rich plastic which had been hammer milled to at least 95% less than 5mm, shown in Figure 4. The copper content of the material was measured, by the techniques described in section 1.5, at 12%.

Figure 4: Trial 2 feed material

3.2 Results

As with trial 1, after a short period of operation the hammer milled material blocked the system. It appeared that the larger plastic and copper particles in the feed became entangled in the first separation zone. However a reasonable copper separation was achieved and product samples were collected for analysis.

3.3 Photograph of product samples

Figure 5: Trial 2 product, middle fraction

Figure 6: Trial 2 product, light fraction

3.4 Analysis of product samples

A sieve analysis of the heavy fraction was conducted; the fractions +4mm, 2-4mm, 1-2mm, 0.5-1mm, 0.25-0.5mm and 0.125-0.25mm are shown in Figure 7. A seventh fraction -0.125mm was also collected. The copper content for each sieve fraction was determined by hand sorting or the sink float technique described earlier.

Figure 7: Trial 2 heavy fraction sieved into 6 fractions

Figure 8 shows the results of the sieve analysis. The total weight of each sieve fraction is shown along with the corresponding weight of copper in that fraction. The 1-2mm fraction had the highest fraction weight, but the 0.5-1mm fraction contained the most copper by weight.

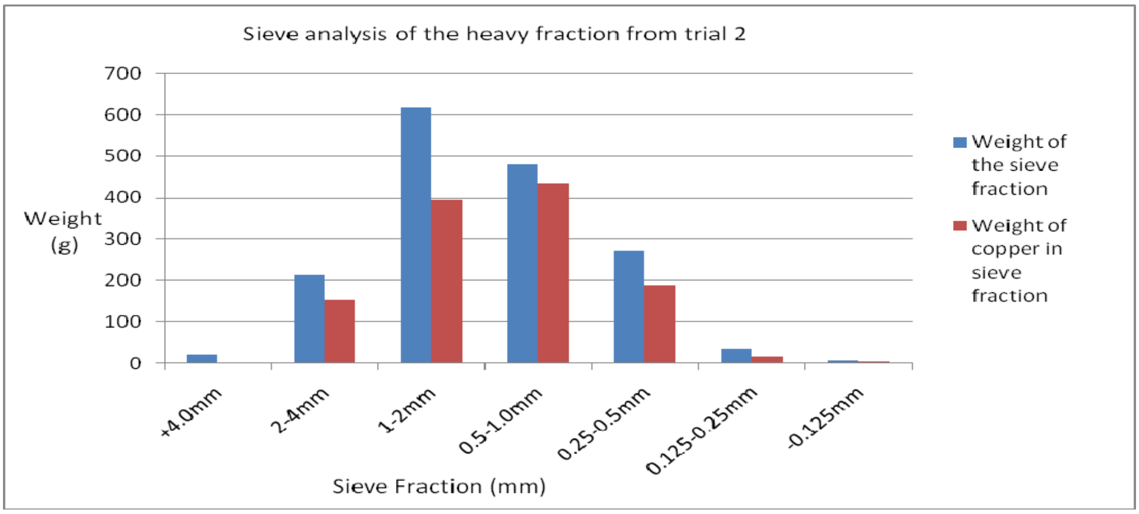

Figure 8: Graph of sieve analysis of heavy fraction from trial 2

Samples of the feed, light and middle product fractions were also analysed using the sink float method described in section 1.5. The results are shown in Table 1.

Trial	Sample		Float Fraction	Sink Fraction		Copper content of sample
	Fraction	Dry weight	Dry weight	Dry weight	Copper weight	
		g	g	g	g	%
2 (Hammer milled)	Feed	24.1	19.3	3.7	2.8	11.6%
	Light	10.9	9.2	1.1	0.2	2.0%
	Middle	22.9	21.1	1.4	0	0%

Table 1: Results of analytical testing on trial 2 samples

The heavy fraction had been sieved into sub-fractions which resulted in there being no overall sample available for analysis. However, from the copper contents of the individual sieve fractions the total copper content of the heavy fraction was determined.

Due to the blockages which occurred during the trial the complete middle and light fractions were not collected, only samples were taken. Therefore it is not possible to conduct a complete mass balance for the trial. However the key component of interest, the copper, can still be assessed as the feed and all three product samples were analysed. Table 2 shows the separation efficiency for the trial.

Fraction	Total Weight (kg)	% copper in fraction	Copper Weight (kg)
Feed	11.60	11.6%	1.35
Heavy	1.64	75%	1.23
		Q (Separation efficiency)	91%

Table 2: Separation efficiency for trial 2

3.5 Discussion of results

Even though the system blocked with material the trial was quite successful.

The heavy fraction was 14.2% of the feed amount and the compositional analysis determined that the copper content was 75%.

The separation efficiency, which is the probability of the copper being correctly sorted into the heavy fraction, is 91%. Taking into account the blockages, the separation efficiency is still high.

The middle fraction contained a very small amount of copper, 2%, whilst the light fraction contained no copper, so the loss of copper into the middle and light streams was low.

The sieve analysis of the heavy fraction showed that the copper concentrated predominantly into the 0.5-2.0mm fractions, with the 0.5-1.0mm fraction containing the most copper both by percentage and weight.

Based on the visual analysis of the sieved heavy fraction the decision was made to sieve the hammer milled material at 2mm. It was expected that copper would concentrate in the -2mm fraction. The sieving produced 53kg of -2mm material and 20kg of +2mm material. These samples were then tested in the Allflux and are reported in trials 3 and 4.

3.6 Conclusions from trial

The trial on the hammer milled material was a partial success. The material separated but also blocked the system. The blockages were because some of the particles were larger than the recommended particle size for processing in the separator. The heavy fraction still had a copper concentration of 75% and 91% of the copper was recovered from the feed.

It appears that the particle size of the material should be smaller, below 3mm, for the separation to be more successful.

4.0 Trial 3 - Hammer milled material sieve fraction (<2mm)

4.1 Feed material

The feed material for the third trial was the -2mm fraction of the sieved hammer milled material.

Figure 9: Trial 3 feed material, -2mm copper rich plastic

Analysis of the feed material, by the sink float method described in section 1.5, determined the copper content to be 15%.

4.2 Results

The separation went very well and there were no blockages in the system during the trial. Three product fractions were produced and analysed.

4.3 Photographs of product samples

Figure 10: Trial 3 product, heavy fraction

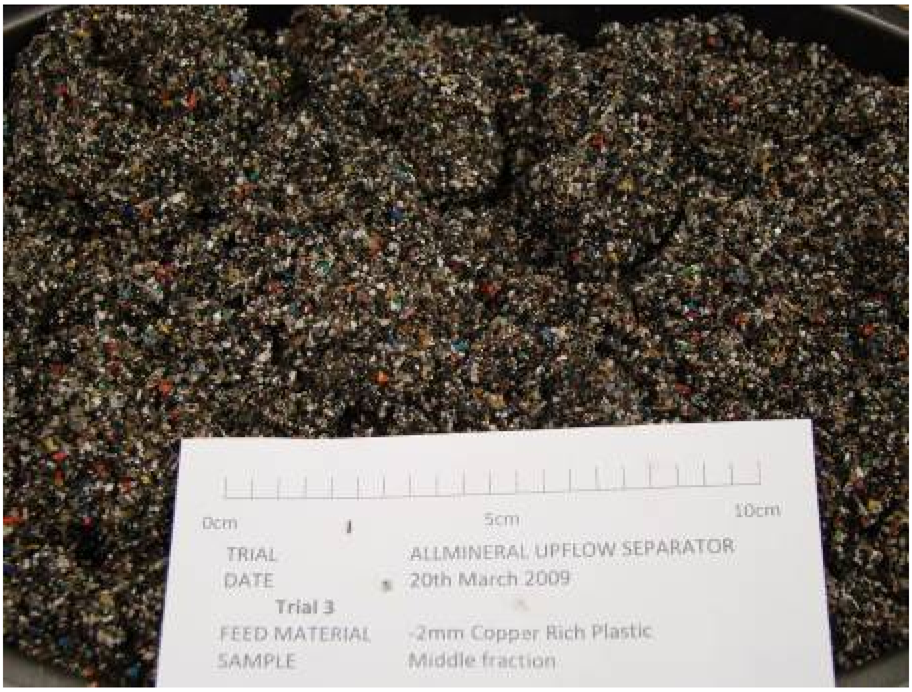

Figure 11: Trial 3 product, middle fraction

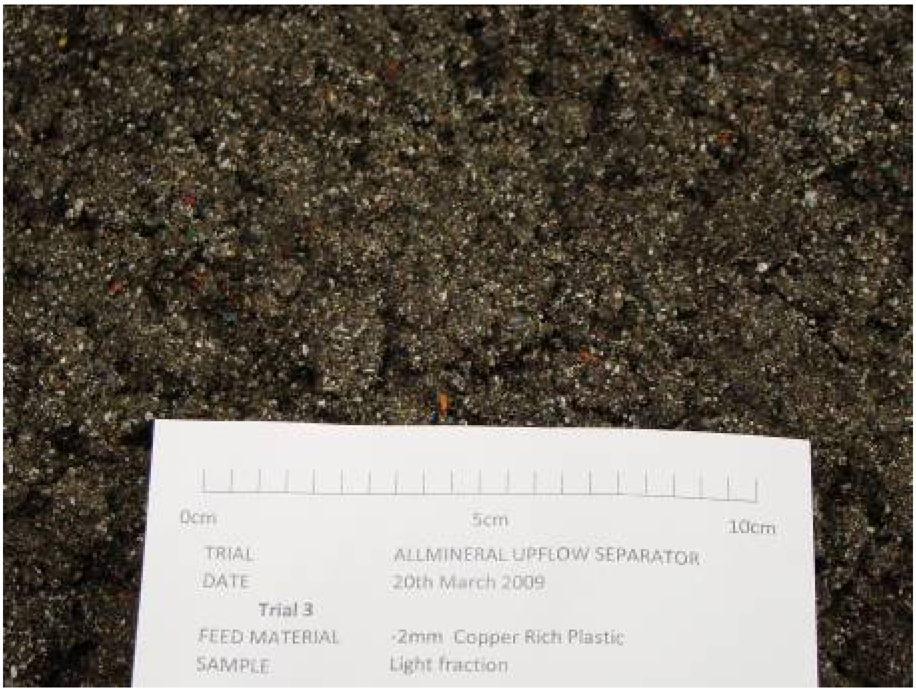

Figure 12: Trial 3 product, light fraction

A visual assessment of the three product fractions indicated that there was virtually no copper in the lights and middle fractions and the heavy fraction consisted of approximately 95% copper.

4.4 Analysis of product samples

The feed and three product samples were analysed, using the sink float technique described in section 1.5, to determine the copper content. Table 3 shows the results of the analysis of the three samples. Figure 13 shows the mass balance for the separation.

Trial	Sample		Float Fraction	Sink Fraction		% Copper in sample
	Fraction	Dry weight	Dry weight	Dry weight	Copper content	
		g	g	g	%	%
3 (-2mm hammer milled)	Feed	20.3	15.9	4.0	75%	14.8%
	Heavy	36.3	1.3	34.4	100%	94.8%
	Middle	11.7	10.5	0.6	50%	2.6%
	Light	8.7	7.9	0.5	0%	0%

Table 3: Results of analytical testing on trial 3 samples

Feed	-2mm fraction	
	kg	%
Dry Weight	37.3	100%
Plastic	31.8	85.2%
Copper	5.52	14.8%

Throughput for the test unit 90 kg/hr
Throughput scaled to a full unit 720kg/hr

Trial 3
Allmineral
Upflow
Separator

Light fraction			
		Composition of fraction	Recovery from feed
	kg		
Dry weight	21.06	100%	56%
Mixed Plastic	21.06	100.0%	66%
Copper	0.00	0.0%	0%

Middle fraction			
Total weight including water	13.47	kg	
Subtract 20% water content			
Dry Basis	kg	Composition of fraction	Recovery from feed
Dry weight	10.78	100%	29%
Mixed Plastic	10.50	97.4%	33%
Copper	0.28	2.6%	5%

Heavy fraction			
	kg		
Total weight including water	5.75		
Subtract 5% water content			
Dry Basis	kg	Composition of fraction	Recovery from feed
Dry weight	5.46	100%	15%
Mixed Plastic	0.28	5.2%	1%
Copper	5.18	94.8%	94%

Q (Separation efficiency) 93.8%

Figure 13: Results of trial 3

4.5 Discussion of results

Figure 13 shows the mass balance for trial 3. The weight of the light fraction was not directly measured during the trial. In Figure 13 the weight of the lights is inferred from the feed weight and the weights of the other two fractions, after taking into account the water content of the product materials. Consequently the actual loss of material during the trial cannot be calculated. However no significant loss of material was observed during the trial because the trial system was well-contained.

The heavy fraction was 14.6% of the feed amount. The compositional analysis determined that the copper content of this fraction was 94.8%.

The separation efficiency, which is the probability of the copper being correctly sorted into the heavy fraction, is 94%. This is high compared to the separation efficiencies measured during the majority of the other copper separation trials in this project.

The middle fraction contained a very small amount of copper, 2.6%, whilst the light fraction contained no copper. So the loss of copper into the middle and light streams was low.

The measured copper content for the feed was 14.8%. This is close to the back-calculated value of 14.6% which indicates the reliability of the analytical technique.

The throughput for the unit was measured at 37kg in 25 minutes which equates to approximately 90kg/hr. As the test unit is a $1/8^{th}$ of a full size unit this results in a scaled up throughput of 720 kg/hr for a 1m diameter Allflux. Allmineral is confident that an optimised full size unit should be able to process significantly higher volumes.

4.6 Conclusions from trial

The trial with -2mm sieved hammer milled material was a success. 94% of the copper was recovered from the feed, at a purity of 95%. This meets the specification of 5% or below combustibles and hence the material should be of interest to metal processors.

The Allmineral Allflux upflow separator has good potential for use in separating fine copper from WEEE fractions. The key is to ensure that the particle size of the material is below about 2mm. It appears that the performance of the separation is improved if the material is size reduced by hammer milling rather than by granulation, probably because the metal particles tend to be 'balled up' by the action of the hammer mill. This means that they will settle at a faster and more consistent rate than the fine metal strands produced by a granulator.

5.0 Trial 4 - Milled material (>2mm)

5.1 Feed material

The feed material for trial 4 was the +2mm fraction of the sieved hammer milled material. All of the material produced by the sieving operation was processed during the trial. The copper content of the feed material was measured by the sink float method at 5.5%.

Figure 14: Trial 4 feed material, +2mm copper rich plastic

5.2 Results

As described in section 1.1 the Allflux unit has two separating sections: the inner (heavy from middle/lights) and the outer (middle from lights). During the trial the separation in the inner section went very well but the separation in the middle-lights section was problematic. Again this was due to material blockages. The plastic chips struggled to exit through the bottom valve into the middle fraction collection part and eventually the material blocked the valve completely. To enable the separation in the heavy section to continue the middle-lights separation was ignored and the plastic chips were allowed to accumulate in the outer separation chamber. Once the chamber was full the trial was stopped and samples of the products were collected.

5.3 Photograph of product samples

Figure 15: Trial 4 product, heavy fraction

Figure 16: Trial 4 product, middle fraction

Figure 17: Trial 4 product, light fraction

5.4 Analysis of product samples

The feed and product samples from trial 4 were all analysed, by the sink float method, to determine the copper content. Table 4 shows the results of the analysis.

Trial	Sample		Float Fraction	Sink Fraction		% Copper in sample
	Fraction	Dry weight	Dry weight	Dry weight	Copper content	
		g	g	g	%	%
4 (+2mm hammer milled)	Feed	19.9	17.9	2.2	50%	5.5%
	Heavy	26.4	16.6	9.4	100%	35.6%
	Middle	15.8	14.6	0.8	70%	3.5%
	Light	10.6	9.7	0.3	0%	0%

Table 4: Results of analytical testing on trial 4 samples

Because of the blockages encountered during the trial, the full light and middle fractions were not collected, only samples were taken. This means a mass balance for the trial cannot be completed but the copper content of all the samples has been assessed.

Fraction	Total Weight (kg)	% copper in fraction	Copper Weight (kg)
Feed	19.6	5.5%	1.08
Heavy	2.1	35.6%	0.75
		Q (separation efficiency)	69%

Table 5: Separation efficiency for trial 4

5.5 Discussion of results

The measured copper content for the feed was 5.5%, which is close to the initial expectations.

The heavy fraction was 10.7% of the feed quantity. The compositional analysis determined that the copper content was only 35.6%, which is significantly lower than in the previous trials.

A check of the copper analysis yields the following results. The -2mm sieved hammer milled material had a measured copper content of 14.8%, whilst the +2mm material had a measured copper content of 5.5%. Back calculating the copper content of the original hammer milled material gives a result of 11.6%, which matches with the value measured by the analytical technique. This verifies the reliability and accuracy of the measurement technique.

The separation efficiency, which is the probability of the copper being correctly sorted into the heavy fraction, is 69%. This is not very high and less than some of the separation efficiencies measured during other copper separation trials in this project. During the trial it did not appear that the blockage in the second separation chamber was affecting the quality of the separation in the first chamber and it could be the reason behind the lower separation efficiency. It appeared that the lower separation efficiency was due to interference between the larger copper and plastic particles in the first separation section.

The copper content of the middle fraction was measured at 3.5%, whilst the light fraction contained no copper so the loss of copper into the middle and light streams was low.

The copper concentration of the feed was only 5.5% which is much lower than the other two trials.

5.6 Conclusions from trial

The trial with the +2mm hammer milled material was not a complete success due to the blockage. The heavy fraction had a copper content of only 36% and the separation efficiency was 69%. The trial objective was not met with this material; however the potential for creating a high purity copper fraction was seen during the trial. Allmineral felt that the separator design could be adjusted to allow for the successful separation of the +2mm hammer milled material.

6.0 Economic assessment

The results from the Miniflux trial show that this separation technique has the potential to create a product which meets the desired specification of less than 5% combustible material from copper smelters. Based on the promising technical performance the economic potential was assessed using a payback calculation.

The Allflux separator can be built without the outer separation chamber in which the lights and middles are separated from each other. The separation performed in the outer section ultimately has no commercial benefit because the mixed heavy plastics are worth very little once the copper fraction has been removed.

The trials demonstrated that the feed material must be size reduced to at least 3-4mm. Therefore size reduction prior to the Allflux is required, ideally by a hammer mill. After the Allflux the material must be dewatered. Figure 18 shows a flow diagram for the full separation system that is modelled in this economic analysis.

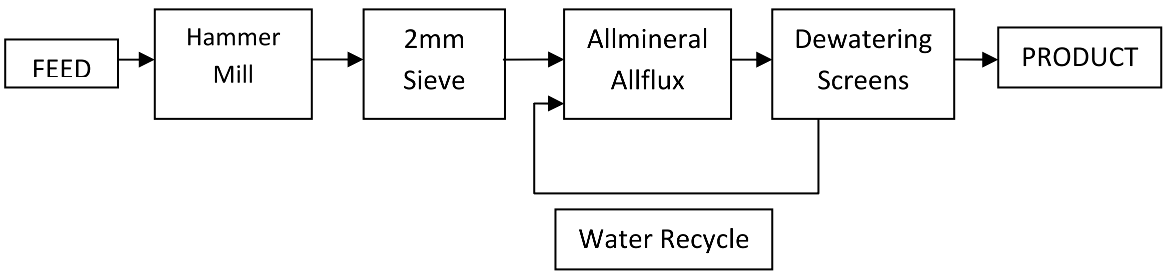

Figure 18: Process flow diagram for separation process using an Allflux

The payback calculation includes the equipment costs and installation of a hammer mill, 2mm sieve and dewatering screens along with the Allflux separator itself.

Table 6 shows a breakdown of the capital cost for the various pieces of equipment required, along with the installation factor.

Equipment	Cost (£)	Installation factor (%)
Hammer Mill	180,000	50
Allflux Separator	45,000	100
Sieves (2mm x 1, dewatering x 2)	45,000	100

Total	450,000	

Table 6: Capital cost breakdown

Two scenarios exist with regard to what happens to the +2mm fraction generated by the sieving step after the hammer mill. Either:

- The sieve size after the hammer mill could be increased to 2.5mm and the +2.5mm fraction could be discarded without further processing because the copper content of this fraction is relatively small; or

- The +2mm fraction could be re-circulated round the hammer mill to be sized reduced further and then processed in the Allflux.

Both these options have been modelled in the economic assessment as scenario 1 and 2 respectively.

Pay back calculation

	Trial Equipment	Allmineral Allflux Upflow Separator	
		Scenario 1	Scenario 2
		process only the -2.5mm in Allflux	recycle +2mm fraction through mill and process in Allflux
Capacity	te/hr	2	2
Cost of equipment	£	450000	450000
Basis of operation	hr/yr	3000	3000
Overall Equipment Effectiveness OEE	%	70%	70%
Plant Input	te/yr	4200	4200
Operating Costs			
Water			
Quantity	kg/hr	150	200
Cost (assuming £2/te)	£/hr	0.3	0.4
Power			
Quantity - Upflow Separator	kW	20	20
Quantity - Hammer mill	kW	200	260
Cost (assuming 10p/kW hr)	£/hr	22	28
Water and Power costs	£/te of feed	11.15	14.2
Water and Power costs	£/yr	46830	59640
Wear costs for hammer mill	£/te feed	6	8
	£/yr	25200	33600
Labour costs (assuming £15/hr)		45000	45000
Annual process licence costs		0	0
Total Operating Costs		117030	138240
Revenue		Assume 11% of copper is recovered	Assume 12% of copper is recovered
Product extracted	te/yr	462	504
Value of product	£/te	1000	1000
	£/yr	462000	504000
Margin	£/yr	344970	365760
Payback time	months	15.7	14.8

Table 7: Payback Calculation

For both scenarios the calculation assumes a capacity of 2 tonnes per hour, using only the inner separating section, and a total installed cost for all the equipment of £420,000.

The plant is assumed to operate 12 hours per day, 5 days a week, 50 weeks a year, giving a total of 3,000 hours of operation per year.

The payback calculation assumes a overall equipment effectiveness (OEE) of 70%, where the OEE is defined as follows:

$$OEE = \text{capacity rate} \times \text{quality rate} \times \text{availability}$$

$$\text{capacity rate} = \frac{\text{actual throughput}}{\text{rated throughput}}$$

$$\text{quality rate} = \%\ \text{of on specification product}$$

$$\text{availability} = \frac{\text{actual run hours}}{\text{available run hours}}$$

The overall plant throughput will be 4,200 tonnes per year.

Operational costs:

The feed material is currently sent to landfill and once the copper has been recovered the residual material will still be sent to landfill, so there is no net cost or benefit from disposal of the residue fraction.

It is assumed that 10% fresh water is lost per tonne of material sent to landfill with a water cost of £2/te.

The power cost is assumed to be 10p/kW hr.

The calculation assumes that the system will require one operator at a total job cost of £45,000 per year.

Revenue, margin and payback time:

For scenario 1, where the oversized sieve fraction is discarded, the revenue estimate assumes that 11% of the copper is extracted from the feed. This produces 462 tonnes of copper per year. The value of this material will fluctuate but is assumed to be approximately £1,000 per tonne. The revenue is £462,000, with a margin of £344,970 which gives a payback time of 16 months.

In scenario 2, where the oversized sieve fraction is recycled through the hammer mill, it is assumed that 12% of the copper is recovered from the feed. 504 tonnes of high purity copper is produced which gives a revenue of £504,000 and a margin of £365,760. The payback time is 15 months.

The difference between the two scenarios is very little and the shorter payback time is when the oversized fraction is recycled through the hammer mill.

7.0 Overall final conclusion of trial

Overall the trial on the Allflux separator was a success producing conclusive results.

The granulated material was not suitable for processing as it blocked the system very quickly.

The hammer milled material, in its original form, initially worked but then blocked the system. The analysis of the samples indicated that the heavy fraction contained 75% copper with a separation efficiency of 91% which is good considering the blockages that was encountered during the trial.

The -2mm sieved hammer milled material produced the best results of the four samples trialled. The heavy fraction contained 95% copper which is just within the specification requirements of copper smelters and the separation efficiency was 94%.

The +2mm sieved material worked, but did eventually block the system. The results showed a copper concentration of 36% in the heavy fraction, with a separation efficiency of 69%. Further trials and testing would be required to find the correct settings to prevent blockages from occurring.

Based on the successful technical results an assessment of the economic potential of the system was conducted. The ancillary and supporting equipment required for the machine to operate successfully was taken into account for the economic assessment. Two possible process scenarios exist and both were assessed. If the screen after the hammer mill is increased to 2.5mm and the +2.5mm fraction is discarded the payback time is 16 months. If a 2mm screen is used and the +2mm fraction is recycled back through the hammer mill and then processed in the Allflux the payback time is slightly shorter at 15 months.

The Allflux separator can be supplied without the middlings/lights separator. This arrangement would be more suitable for processing copper-plastic mixtures from WEEE. Based on the trial results the Allmineral engineer estimated that a full scale unit with this configuration should be able to separate up to 12te/hr of feed material.

In conclusion, an Allflux separator can be used to recover copper from copper-plastic mixtures produced during WEEE recycling, if the particle size of the material is below 3mm. The copper products from the trial on the hammer milled material met the specification required by metal processors. The separator itself is a high throughput low operating cost device. However the feed material must be size reduced in a hammer mill, with high power and wear costs, in order to make it suitable for processing.

Overall the economics of the separation look good, even when the capital and operating costs of the feed preparation process are taken into account.