Copper Recovery from Scrap Electrical Cables based on an Environmentally Sustainable Gravity Separation Technique

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ABSTRACT

The aim of this study is to recover copper from scrap cable wires through a sustainable gravity separation technique. Initially, the scrap wires were shredded in such a way, that the plastic on them was completely removed. The shredded mixture of the copper and plastic pieces was poured on a shaking table, where separation of copper and plastic was caused. The copper was collected in the concentrate zone and the plastic pieces were collected in the tailings zone. The study also examines the influence of the shaking table inclination at 1º, 3º, and 5º, and that of the wash water flow rate, ranging from 9 to 34.70 ml/sec, on the stratification of the copper plastic mixture. It was found that increasing both the shaking table inclination and the wash water flow rate improved copper recovery. However, at the maximum angle of 5º and wash water flow rate of 34.70 ml/sec, the recovered copper grade decreased due to the plastic pieces' contamination. The most favorable results were obtained at the shaking table inclination of 3º and wash water flow rate of 20.50 ml/sec, which resulted in a copper concentrate with a copper recovery of 93.5% and a copper grade of 98%. Additionally, it was found that wash water can be recycled, which, in a commercial setting, could save up to 590 L of fresh water per 8 hours.

Keywords-copper; water recycling; electric cables; electronic waste; shaking table; shredding; stratification

I. INTRODUCTION

The environmental concerns regarding proper waste management have globally become more and more intense. The increase in electronic waste due to the expansion of the electronic device industries is one of them [1-3]. Furthermore, the growth of electrical and electronic sector has intensified the global demand for metals, despite the fact that ore grades are decreasing, mineralogy is getting more complex, and environmental concerns are becoming more acute [1, 4].

Scrap cables/wires are unwanted or discarded electrical cables/wires, which come from a variety of sources, such as old electronic appliances, construction sites, and demolition projects. These electrical cables are made up of a conductor, usually a copper wire and a plastic insulation cover [4]. Copper is the most valuable component of the cable that can be recycled and recovered from the electrical cables. Being the third most common metal in the world by mass, following aluminum and iron, pure copper is 100% recyclable forever without causing any damage to property or modification/without any damage or modifications being caused to its properties [4, 5]

Copper is a reddish metallic element and is found naturally in minerals, such as cuprite, malachite, azurite, chalcopyrite and bornite. It is a valuable metal and has a variety of practical applications in electrical and electronic equipment, such as motors, mobile phones, solar panels, computers and electric cables etc. The copper production and usage have significantly increased due to the rapid development of the power and information technology industries [5]. Over the past few decades, global copper mining has significantly grown, with Chile having accounted for most of this production with 5.6 million tons from 2018 to 2021 and 5.3 million tons from 2022 and beyond. China is the largest copper user and accounts for approximately 12 million tons of the total copper demand worldwide [4, 6, 7]. Furthermore, along with the extraction and processing from mineral ores for copper production, copper is among the most recycled metals globally and its recovery from scrap electrical cables and electronic devices is increasingly important. Recycling scrap copper is a sustainable alternative to the primary copper production, reducing energy consumption and environmental pollution [7].

The development of the mineral processing and recycling techniques led to the creation of several advanced separation technologies. These technologies are based on the differences in physical and chemical properties and have been applied to separate metals and non-metals from electrical cables and electronic waste. Numerous studies have reviewed the progress and potential of these techniques for the recovery of metals and non-metals from electrical cables and electronic waste [7, 8]. These technologies include the application of physical separation, such as gravity separation methods [4, 7, 9], magnetic separation [10], and froth flotation methods [11, 12]. Several research studies have attempted to enhance the physical methods of electrical and electronic waste separation. Two such methods that have got more attention are the froth flotation, which bases its separation on the difference in hydrophobicity of materials, and the gravity separation, particularly shaking table, which works on the principle of difference in material density. Advanced technologies, such as Flotation cells [13] and the Reflux flotation cell, have been introduced for the segregation of solid particle species, mainly dealing with the size range of 1-50 microns [14]. Applying these technologies for the recovery of scrap copper wires would make this process more expensive, especially regarding copper wires in the size range of 2-3 mm, which can be easily recovered through gravity separation processes [4].

The gravity separation techniques are relatively low cost and easy to adapt [4]. However, there is a significant amount of fresh water which is being wasted [15, 16] while recovering copper either from a mineral ore or scrap electronic waste due to inadequate wastewater treatment and recycling processes, especially in the under developed countries [17]. After being utilized in flotation and as wash water in shaking table, fresh water contains contaminants and is a potential threat to the surrounding water sources.

In many countries, a significant amount of copper is wasted in the form of scrap and discarded cables, thus wasting a valuable metal and also causing environmental pollution. In Pakistan, especially in the Peshawar area, a large amount of scrap electrical cables are available that can be a valuable source of pure copper recovery. There are also many scrap cable dealers, but there are no clear specific data available regarding this matter. However, a survey was made to visit ten workshops of scrap electrical cable dealers, where it was found that on average a dealer purchases or sells approximately 400 kg of scrap electrical cables containing copper per day. These cables are burned in order to remove the plastic part and recover the copper. Nevertheless, this method is inefficient, time consuming and, a source of environmental pollution.

The current paper focuses on a systematic study of the shaking table utilization for separating copper from plastic and developing a process for water recycling and reuse. The effect of the inclination angle and wash water flow rate on the copper recovery and copper grade percentage was investigated. Furthermore, a water treatment system was developed for recycling and reusing the used wash water.

II. METHODOLOGY

A survey was conducted by visiting 10 workshops of scrap electrical cable dealers in Peshawar city. Scrap cables were collected from the dealers and shredded in a shredder at a size ranging from 2 to 3 mm, as depicted in Figure 1.

Fig. 1. (a) Scrap electrical cables, (b-c) shredder, (d) shredded scrap.

The shredder consisted of a 10 HP motor and large blades made of strong alloy to cut the scrap material into small pieces. The feed, scrap electrical cables, was put into the shredder from the top for cutting and reduced to 2-3 mm in size ensuring that the plastic material did not remain attached to the copper shredded wires. The final product comprising plastic and copper was picked up from the bottom of the shredder.

The shredded product was used to carry out experiments on the shaking table, as portrayed in Figure 2. Its measurements were 3.25 ft. in length, 1.62 ft. in width with partial riffles along the table of 4 mm high on the feed side that decrease towards the concentrate edge. Six water supplies were present for the wash water, and one for the feed box. The water flow rate ranged from 0 to 34.70 ml/sec. The shaking table inclination was adjusted to 1º, 2º, 3º, 4º, and 5º. Also, it had a multi-sectional product chute with four discharge outlets.

Fig. 2. Shaking table.

The separation of the feed occurred on the basis of the difference in the densities of the copper wires and plastic, as can be seen in Figure 3.

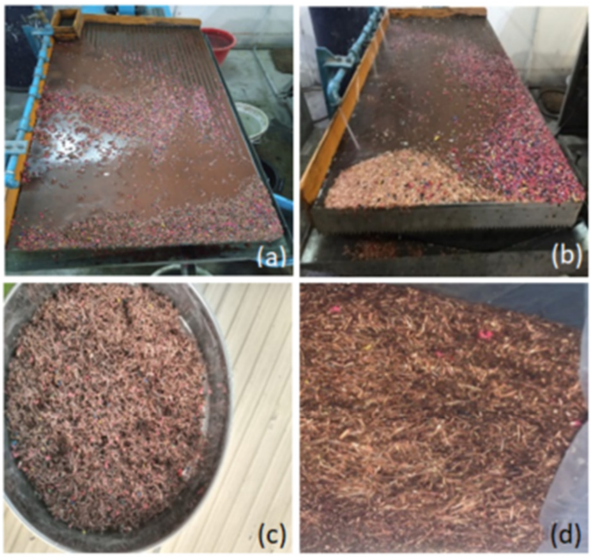

Fig. 3. (a) Shaking table at a higher wash water flow rate, (b) shaking table at a lower wash water flow rate demonstrating adequate separation, (c) copper wire concentrate with plastic pieces, (d) copper wire concentrate with minimum plastic pieces.

The backward and forward motion of the shaking table and the kinetic energy of the wash water running over the table caused stratification behind the riffles of the table. The dense copper shredded wires were settled at the bottom behind the riffles, whereas the low density plastic particles were accumulated above them. The shaking action of the table and wash water flow rate pushed the plastic particles towards the tailing zone, termed as float, while the copper wires were transported towards the concentrate zone, called sink.

A total of 15 experimental tests were performed on the shaking table. The recovery of copper was measured by simply weighing the amount of copper wires obtained in the sink, as displayed in Table I. The copper grade percentage was estimated by calculating the density of the recovered copper. The product with more plastic material had low density, hence the grade was poor.

TABLE I. EXPERIMENTAL CONDITIONS AND RESULTS

Feed (gm)	Angle of inclination	Wash water flow rate (ml/sec)	Concentrate copper (gm)	Time (min)
2000	1º	9	852	28.34
2000	3º	9	877	26.23
2000	5º	9	900	24.12
2000	1º	16.50	882	22.34
2000	3º	16.50	907	20.18
2000	5º	16.50	919	18.34
2000	1º	20.50	902	19.29
2000	3º	20.50	935	16.43
2000	5º	20.50	934	14.35
2000	1º	26.50	912	16.56
2000	3º	26.50	943	14.34
2000	5º	26.50	947	11.49
2000	1º	34.70	915	14.47
2000	3º	34.70	947	11.25
2000	5º	34.70	955	08.45

III. RESULTS AND DISSCUSSION

The feed on the shaking table was kept constant at 2000 gm containing shredded copper wires and plastic pieces. The wash water flow rates of 9, 16.5, 20.50, 26.50, and 34.70 ml/sec were used, while the shaking table inclination was studied at 1º, 3º, and 5º. Figure 4 illustrates the copper recovery versus the wash water flow rate for three shaking table inclinations. The results show that the recovery of copper increased with an increasing wash water flow rate while keeping the shaking table inclination at 1º. The recovery of copper after separation at the wash water flow rates of 9, 16.50, 20.50, 26.50, and 34.70 was 852, 882, 902, 912, and 915 gm, respectively. The kinetic energy given by the wash water flow and the shaking phenomena of the table caused copper and plastic to separate, with copper being the denser particle transported towards the concentrate zone (sink), whereas the plastic is relatively the lighter component moved towards the tailings zone. A similar trend of increased copper recovery was observed for the shaking table inclinations of 3º and 5º. When the wash water flow rate was 9 ml/sec, copper recovery at 1º, 3º, and 5º was 852, 877, and 900 gm, respectively. At a higher wash water flow rate of 26.50 ml/sec, copper recovery significantly increased to 943 and 947 gm at 3º and 5º shaking table inclinations, respectively.

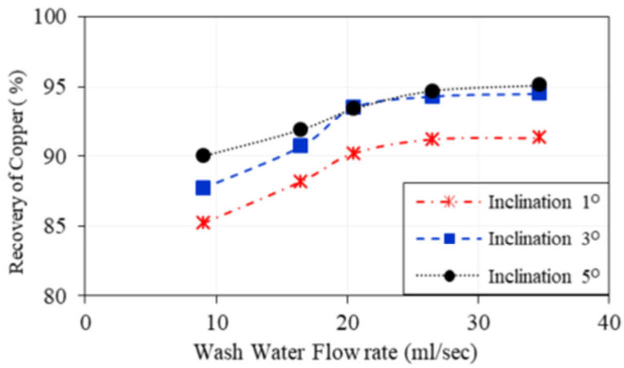

Fig. 4. Recovery of copper versus wash water flow rate.

It was also observed that as the wash water flow rate increased to a value of 34.70 ml/sec, the recovery of copper relatively decreased in each case. This was due to the fact that the high flow rate caused shredded copper wires to transport towards the float, while some of the plastic pieces transported towards the sink.

Figure 5 demonstrates the copper grade percentage versus the wash water flow rate for shaking table inclinations of 1º, 3º, and 5º. For inclination 1º, it was observed that initially the grade of copper improved with an increasing wash water flow rate, but at 26.5 ml/sec and higher values it started decreasing. That was due to the fact that at a higher wash water flow rate the separation did not take place adequately as the light weight plastic pieces transported towards the sink due to a higher kinetic energy of the wash water. The maximum copper grade was 82% at 20.5 ml/sec, and subsequently decreased further by increasing the wash water flow rate. A similar trend was observed when the separation process was carried out on the shaking table at an inclination of 3º. The copper grade increased to a maximum value of 98% at a wash water flow rate of 20.5 ml/sec, after which it decreased to 93 and 85% at 26.5 and 34.7 ml/sec, respectively. At inclination of 5º, the recovered copper grade first increased up to 92% at 16.5 ml/sec, however, it significantly decreased to 84, 77 and 73% with increasing wash water flow rates of 20.5, 26.5, and 34.7 ml/sec, respectively. Higher wash water flow rates and a higher inclination caused large amount of plastic material to transport towards the sink. Moreover, some copper also transported towards the float due to a higher wash water flow rate.

Overall, a higher copper grade percentage was obtained at an inclination of 3º, since at this inclination, the maximum of the copper wires was transported towards the sink while the plastic pieces were transported towards the float. The angle provided a slope that facilitated adequate stratification compared to the inclination of 5º in which due to a higher slope the plastic pieces transported towards the sink.

Additionally, an important observation was the time estimation for each experimental test to be completed, as can be seen in Table I, in order to calculate the amount of water consumed for each test according the flow rate.

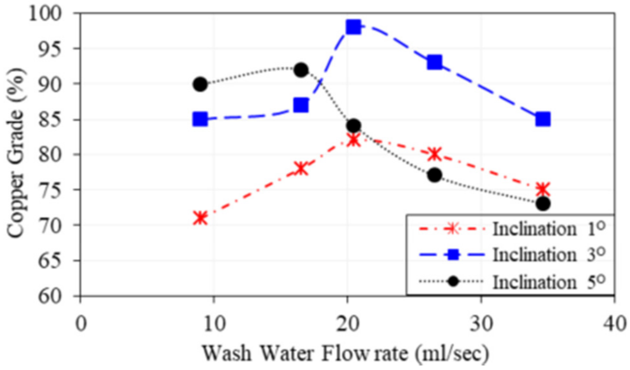

Fig. 5. Copper grade versus wash water flow rate.

Figure 6 illustrates the amount of water consumed in each experimental test at shaking table inclinations of 1°, 3°, and 5°. It was observed that the amount of water consumed for the first set of experimental tests at the shaking table inclination of 1° was the most, ranging from 15.30 to 30.12 L. The maximum time taken by an experimental test was 28 min 34 sec when the flow rate was kept at 9.1 ml/s. However, the experimental tests performed at the shaking table inclination of 5° relatively consumed the least amount of water, ranging from 13 to 17.59 L. So, the minimum time taken in an experimental test was 8 min 45 sec in which the wash water flow rate was kept at 34.73 ml/sec and the shaking table angle was 5°. Furthermore, the water consumption for the experimental tests carried out at the shaking table inclination of 3° was in the middle range, i.e. 14.16 to 19.25 L, compared to the water consumed at the shaking table inclinations of 1° and 5°. The minimum amount of water consumed at the shaking table inclination of 3° was 14.16 L at a wash water flow rate of 9 ml/sec, and the maximum amount of water consumed was 19.25 L at a wash water flow rate of 34.70 ml/sec.

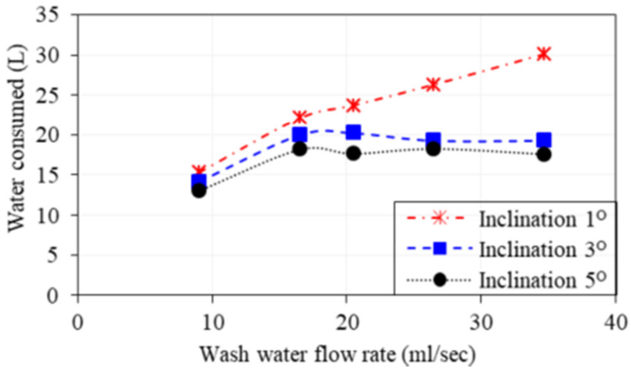

Fig. 6. Wash water consumed.

The water consumption for each experimental test was calculated. It was found that if the case of shaking table inclination of 3° and wash water flow rate of 20.5 ml/sec is taken as a basis, a total amount of 20.2 L of fresh water was consumed to stratify 2 kg feed in 16.43 minutes. If this process operates for 8 hours, approximately, a total amount of 58 kg of scrap cables will be stratified that will consume almost 590 L of fresh water. This number would increase to 5900 L for ten workshops. Furthermore, if large size shaking tables are used in the workshops to stratify 400 kg of scrap copper from plastic per day, the amount of fresh water usage would increase to a substantial amount. Any act towards recycling the used water would save a large amount of water. Therefore, based on the current lab scale studies, and literature review, a simple yet effective water recycling and reuse process has been developed in order to minimize the fresh water usage in the processes of copper recovery from scrap cables.

After the separation of copper and plastic, the wash water from the sink chute and from the three chutes of the floated zone was routed to pass through a filtration unit and was collected in a storage tank. The filtration unit consisted of three layers of gravel and one layer of sand of particle sizes of 1 and 0.1 mm, respectively. Initially, few water samples were collected from the chute outlets and tested for possible contaminants. It was found that the amount of Total Suspended Solids (TSS) in the wash water was 290 mg/L. The wash water was then passed through the filtration unit and it was analyzed again. The TSS value reduced to 220 mg/L. The wash water was mainly contaminated due to soil and silt on the surface of the scrap cables, which were easily removed by passing through a simple filtration unit. The treated water was reused to carry out the experimental test on the shaking table without using fresh water.

This study proposes a continuous process for a commercial unit for the recovery of copper from scrap cables, as illustrated in Figure 7. It consists of a shredder to reduce the size of the scrap cables. After shredding, the feed is transported to a shaking table with the help of a conveyer belt. The separation of copper and plastic occurs due the back and forth motion of the shaking table and wash water flow rate. The size of the shaking table can be designed according to the needs of the plant. After separation, copper is collected in the sink whereas plastic pieces in the tailing zone (float). The wash water from the sink and tailing zone is passed through a filtration unit and collected in a water storage tank. The water from the storage tank is then recycled to the shacking table with the help of a centrifugal pump for further separation of the copper and plastic materials.

Considering a shaking table of the same dimensions with that used in the experiments, the amount of water to be consumed during an eight hour shift at the rate of 20.5 ml/sec and at an inclination of 3°, to stratify copper wires and plastic pieces is 590.4 L. So the washing water that will be needed must have a rate of 74 L/h. The dimensions of the filtration unit to filter 74 L/h of used wash water are shown in Table II.

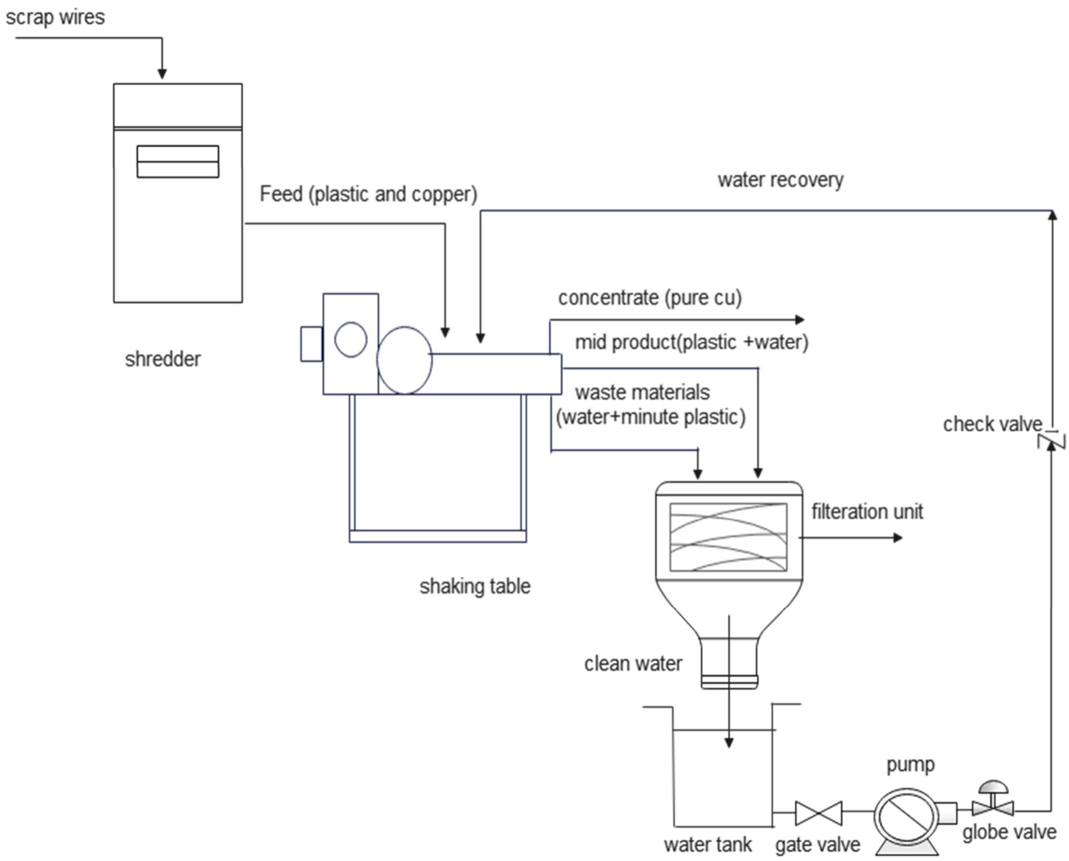

Fig. 7. Process flow diagram for a commercial scale copper recovery system.

TABLE II. DIMENSIONS OF THE FILTRATION UNIT

Description	Dimensions (ft)
Width of the filtration unit	1.64
Length of the filtration unit	2
Top gravel layer	0.5
Middle sand layer	1
Bottom gravel layer	0.5
Filtration cone	0.5
Water accumulation zone at the top of the filter media to hold water	0.5
Total height	3

IV. CONCLUSION

This study investigates the recovery of copper from scrap cable wires through a gravity separation technique. A total number of 15 experiments were performed using a shaking table as a gravity separation device. The shredded mixture of copper and plastic pieces, 2-3 mm, was poured to a shaking table where the back and forth motion of the shaking table and wash water flowing through the table surface caused the separation of copper and plastic. Since copper was the heaviest component, it was transported towards the concentrate zone. While, the light weight plastic pieces were transported towards the tailings zone, termed as the float. The experiments were performed on the shaking table at inclinations of 1º, 3º, and 5º and at a wash water flow rate ranging from 9 to 34.70 ml/sec. The optimum results were obtained at an inclination of 3º and a wash water flow rate of 20.50 ml/sec in which the recovery of copper was 93.5% and the copper grade percentage was 98%. Additionally, it was found that the recycling and reuse of wash water could save a significant amount of fresh water, which is vital for a sustainable future of such processes. It was estimated that an amount of 590 L of fresh water could be saved per 8 hours of the process in commercial settings.

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