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CORONA–ELECTROSTATIC SEPARATION: AN EFFICIENT TECHNIQUE FOR THE RECOVERY OF METALS AND PLASTICS FROM INDUSTRIAL WASTES

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Abstract Better management of secondary resources, such as copper, aluminium and plastics from electric wire and cable waste requires improved methods of processing of reusable materials. This paper presents three typical examples of recycling technologies, each of them using the capability of electric fields to sort metallic and insulating materials from granular mixture. The efficiency of corona–electrostatic separation as a basic operation of a recycling flowsheet has been demonstrated for feedrates not exceeding 200 kg/hour. At the same time, it has been proved that electroseparation can represent a complement to conventional air–gravity separation of metals and insulators from industrial wastes. The in–plant tests provided useful information for a customs–design of corona–electrostatic separators.

INTRODUCTION

Large quantities of valuable materials can be recovered from rejected electric or electronic products. In Romania, electric wire and cable wastes represent the most important secondary resource of copper and plastics for electrotechnical industry.

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Copper–bearing wastes have been continuously recycled since it was realized that to use scrap to produce copper requires only 3 to 40 per cent of energy that is required to produce copper from an ore [1]. As pointed out by Kaplan and Ness [1], the copper–bearing wastes account presently in the U.S.A. to almost 50 per cent of all raw copper materials, and secondary aluminium represents about 25 per cent of total aluminium production.

The recycling of the manufacturer and consumer plastics wastes has attracted significant attention in recent years only, since the increased concern about the environmental protection has led to more restrictive disposal regulations [2, 3]. Although many technical problems that once prevented the implementation of the recycling of plastics waste have been overcome, the quantities of recovered materials have not grown as quickly as expected. Alter [4] notes that secondary materials have always been marginal sources of supply for manufacturers, and the secondary materials from refuse represent marginal sources of the last resort because the post–consumer wastes are usually contaminated and non–homogeneous.

The aim of this paper is to demonstrate that the corona–electrostatic separation methods can, for some industrial wastes, such as electric wire and cable scrap, gain a better position in the resources market. Metal–insulation electroseparation represents an economically viable technique, as it ensures higher grades of recycled plastics and better removal efficiency of the metallics, compared to conventional methods of waste treatment.

CONVENTIONAL PROCESSING OF ELECTRIC WIRE AND CABLE WASTE

There are two main sources of cable waste (Fig. 1): manufacturers and consumers, i.e. plants where electric wire is either confected or compounded into final products. These "pre–application" wastes [5], clean and homogeneous, are easier to process than "post–application" wastes (generated during renewing and maintenance activities) which are mixtures of different sorts of metals, plastics and rubber, contaminated with dust, oil, grease etc.

The primary role of all waste–processing units ("in–plant" recycling workshops, specialized waste waste processors, urban refuse collectors) is to collect,

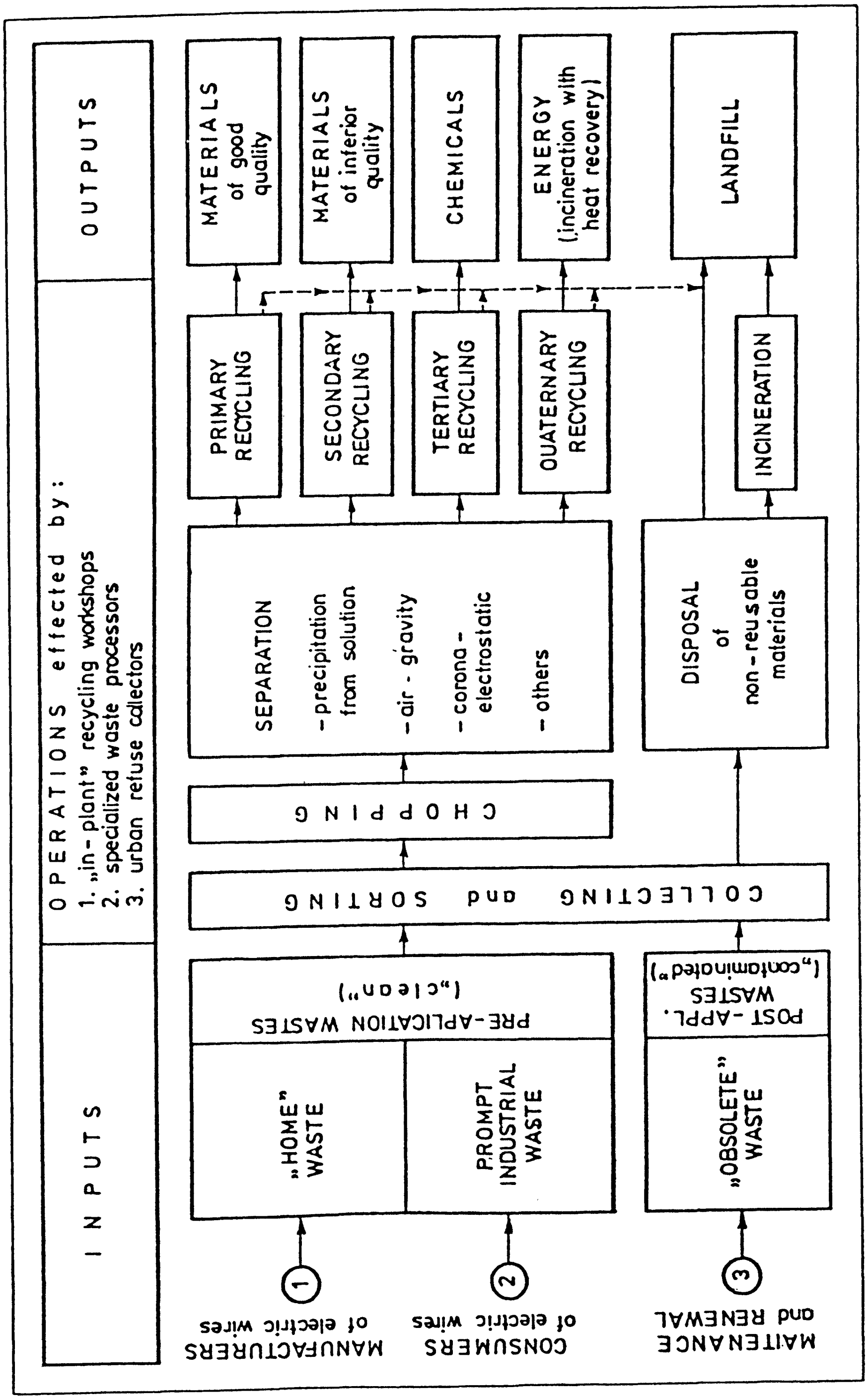

Fig.1. Block diagram of electric wire and cable waste processing

accumulate, sort, grade, prepare (i.e. by shearing, chopping and separating), market and distribute scrap.

Leidner [6] classifies various plastic recycling technologies into four main categories:

primary –	when the waste is processed into the same of similar types of products from which they have been generated
secondary –	when the recycled materials have less–demanding properties
tertiary –	when chemicals and fuels are recovered
quarternary –	when only energy is recovered from the waste.

Because very little contamination can be tolerated in the primary recycling of plastics, only a small proportion of the pre–application waste (single–resin, thermoplastic wastes) and virtually none of the post–application waste can be used to manufacture products that have characteristics similar to the original ones (such a wire insulation).

Most conventional metal–insulation separation techniques can provide only secondary recycling of plastics. The processing methods are based on multi–stage chopping of electric wire waste, after cutting up the cable bales, with an alligator shear [1, 7, 8].

Magnetic separation of ferrous contaminants follows the first and, sometimes, the second stage of chopping. Since the specific weight and shape of the metallic granules differ from the characteristics of non–conductive particles, both the coarse and intermediate size fractions can be processed by either precipitation from solution or by air–gravity separation. The first method uses expensive and toxic substances and is accompanied by absorption of liquid in the insulating particles whose dielectric characteristics deteriorate.

Higher energy consumption is involved in pneumatic techniques which are characterized by poor removal efficiency; at the same time the recovered insulation contains too a large percentage of metal to be used for electrotechnical purposes [9]. Any of the above methods leads to four fractions [1]: (I) clean metal, (II) liberated metal with some insulation contamination, (III) unliberated wire and (IV) clean insulation. Where and how can one integrate metal–insulation electroseparation in this waste recycling flowchart?

PRINCIPLES OF CORONA–ELECTROSTATIC SEPARATION

There is a large variety of electroseparation methods which are based either on electrophoresis or dielectrophoresis – processes involving charged and uncharged particles, respectively [10, 11]. It appears, taking into account an agreement between our experimental results and the data published by Knoll et al. [11], that the most adequate methods of metal–insulation electroseparation are those that make use of ion bombardment for the charging of the particles to be sorted. Carpco Inc. has been the first company to report a successful PVC–copper electroseparation using a roll–type separator [12].

The electric field of ELSMOD modular electroseparator (Fig. 2) conceived by the authors [13] is generated by several active electrodes connected to a dc high–voltage supply and a grounded rotating roll electrode. The granular material is fed onto the roll electrode and charged by a corona electrode placed above the roll electrode.

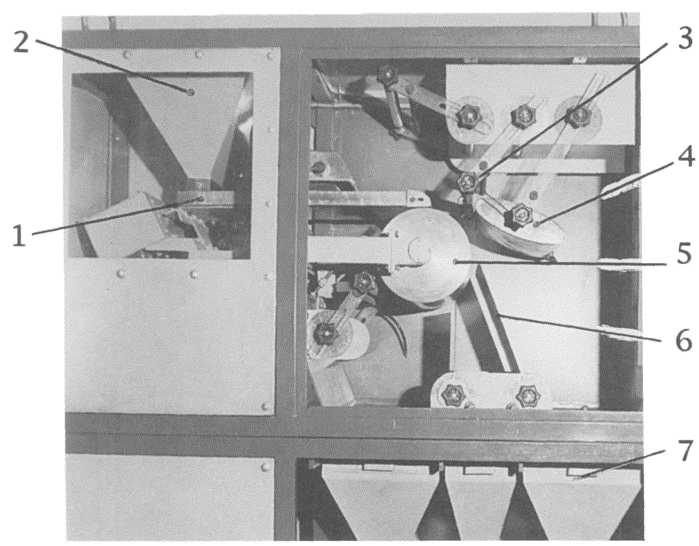

Fig. 2 The main components of ELSMOD roll–type electroseparator: 1–electromagnetic vibrating feeder + electrical heater, 2–hopper, 3–active corona electrode, 4–electrostatic electrode, 5–grounded rotating roll electrode, 6–splitters, 7–collector.

The corona electrodes energized at voltages beyond discharge limits represent powerful sources of unipolar ions (Fig. 3). While both conductors and non–conductors become charged by ion bombardment, only non–conductive particles are able to preserve their charges.

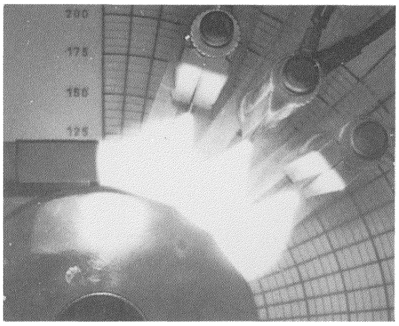

Fig.3 Corona discharge from three electrodes in a roll–type electroseparator

THe conductive particles discharge rapidly to the grounded surface of the rotating roll and are thrown from it with a projectile motion. The charged non–conductive particles are pinned by the electric image force to the surface of the grounded electrode an move with it. Slow exponential discharging law explains strong adhesion of non–conducting particles to the surface of the roll and justifies the necessity of using a wiper electrode to make the task of the brush easier.

An extended field is generated when the electrostatic electrode occupies the position of the second active electrode in Fig. 2 [14]. The electrostatic field does not influence the non–conductive material but it charges the conductive granules. The latter are attracted to the electrostatic electrode. Detailed presentations of theoretical problems involved in corona–electrostatic separation can be found in the works of Meinander [15], Iuga [16], Morar et al. [17] and Dascalescu et al. [9]. Extensive laboratory work is needed before optimum parameters of an electroseparation process can be determined and industrial application can be considered.

METAL–INSULATION SEPARATION TESTS

Preliminary experiments were effected either on ILES–1 [9] or ELSMOD separators, the latter being provided with two high–voltage generators: SIT 75 (dc, negative polarity, 0 to 75 kV_{peak}), which energized the active electrodes, and SIT 50 (ac, 50 Hz, 0 to 50 kV_{peak}) which supplied the wiper electrode.

Metal–insulation separation tests were carried out on samples of industrial waste containing 62.% Cu and 37.5% PVC, the size of granules being less than 5 mm (Fig. 4). The granular material was supplied by Electromures Co., Tirgu–Mures, Romania.

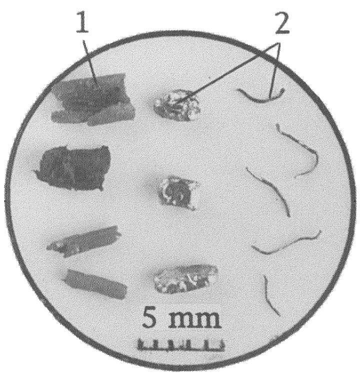

Fig.4 Shape and size of insulating and metallic particles contained in a sample of chopped electric wire waste. 1–PVC, 2–copper.

Experiments indicated that copper–PVC separation is possible in electrostatic, corona and corona–electrostatic fields (Fig. 5).

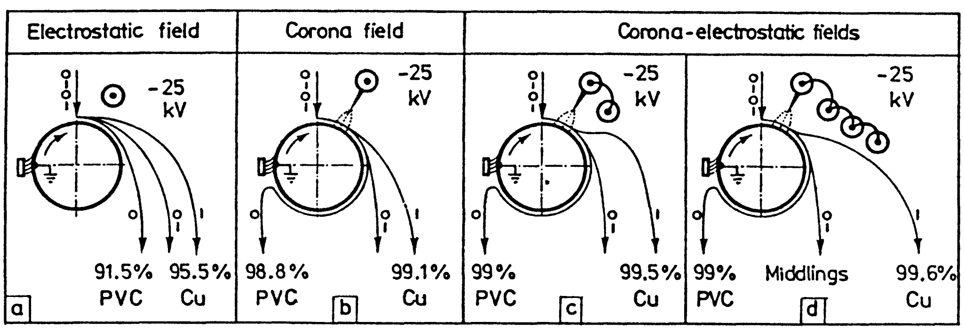

Fig. 5. The influence of the electric field on Cu–PVC separation. Feed: 62.5% Cu, 37.5% PVC, roll diameter 150 mm, roll speed: 100 rpm.

The nature of the field has a great influence on electroseparation trajectories and on the grade of copper and PVC concentrates. The best results were obtained in corona–electrostatic field (Fig. 5 c,d). The first group of experiments thus indicated the opportunity of using both the pinning effect of the corona electrode and the attraction forces developed by the electrostatic electrode on metallic particles.

As for the extension of the corona field zone (one or two needle–type electrodes) and of the electrostatic field zone (one, two or three tube electrodes), the second group of experiments demonstrated the superiority of configuration shown in Fig. 5, d. One corona electrode seems to be sufficient because a larger discharge field zone determines a reasonable contamination of PVC concentrate with copper granules. Three tube electrodes are preferable, as the extended electrostatic field ensures concentrates of higher grades. An electrostatic electrode of ellipsoidal cross–section replaces the three tubes in industrial applications [14].

RECOVERY FLOWSHEETS BASED ON ELECTROSEPARATION

Most waste–processing units operate with small amounts of wire and cable residues. Whenever the processed quantity of material is less than 200 kg per hour, electroseparation represents a more effective recovery method than any other separation technique. Therefore, an electroseparation circuit for treating 100 to 120 kg/h was developed for the Recovery and Recycling Co., Cluj, Romania and was put into operation in Ploiesti, Romania, in 1988.

One or two electroseparation stages are sufficient to recover a high–grade metal (either copper or aluminium), at acceptable removal efficiency (95 per cent) from used, partially sorted wire and cables, most of them arising from renewal and maintenance activities. Almost 90 per cent of aluminium in a 44,2 per cent Al, 55.8 per cent PVC chopped wire waste was recycled at the grade of up to 98.5 per cent Al, employing a single electroseparation stage (Fig. 6). The concentration of aluminium in the PVC concentrate could be reduced by the second, cleaning stage using the same electroseparation method.

Several important Romanian manufacturers of electrical and electronic equipment intend to use the same flowsheet to recover their own 'in–plant"–generated cable waste.

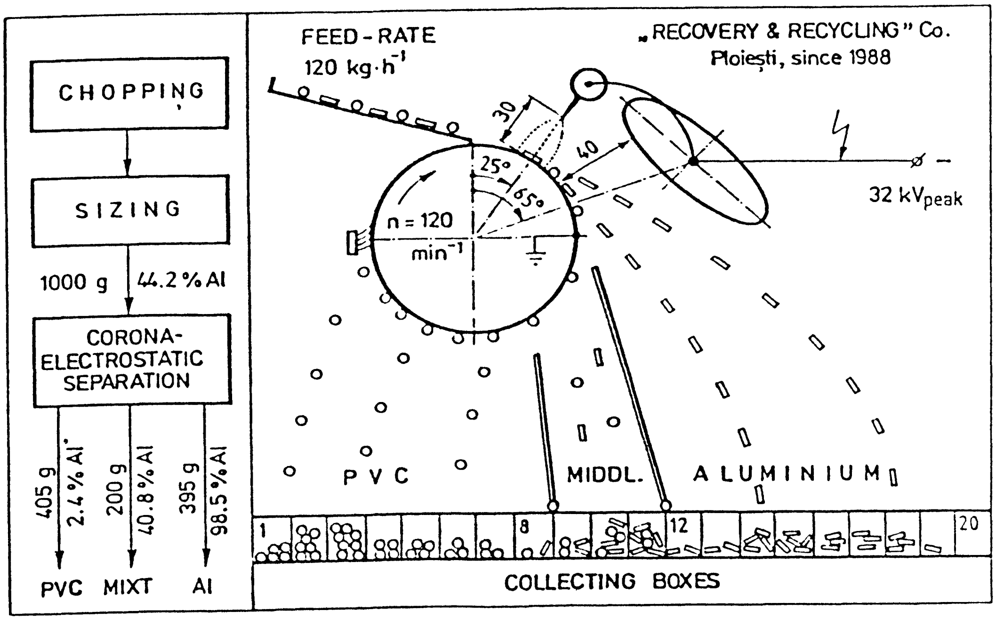

Fig. 6 Experimental Al–PVC corona–electroseparation results and operating parameters

ELECTROSEPARATION AS AN AUXILIARY SΓAGE OF CONVENTIONAL RECOVERY FLOWSHEETS

Presently, electroseparation cannot compete in terms of productivity with conventional air–gravity separation techniques. Corona–electrostatic separation is, however, able to complement classic flowsheets since it ensures the recovery of fine metallics from stranded wire and of reusable plastics (PVC, polyethylene, nylon etc.), free of metallics [11].

A typical flowsheet was set up by I. Csorvasy and C. Bularca at Electromures Co., Tirgu–Mures, a leading Romanian manufacturer of electric wire and cables. Two insulation–metal electroseparators (ELSIM–1 and ELSIM–2 [18]) have been added to the existing air–gravity circuit. The air–gravity reject product which represents less than one third of the total processed material, and consists of almost 5 per cent metallics, has been subjected to electroseparation (Fig. 7). Thus, the metal has been almost entirely recovered (the middlings were introduced again into the air–gravity separator) and the plastics concentrate obtained after the electroseparation (at the recovery > 90 per cent, and containing less than 0.1 per cent of fine metallics) is suitable for secondary recycling.

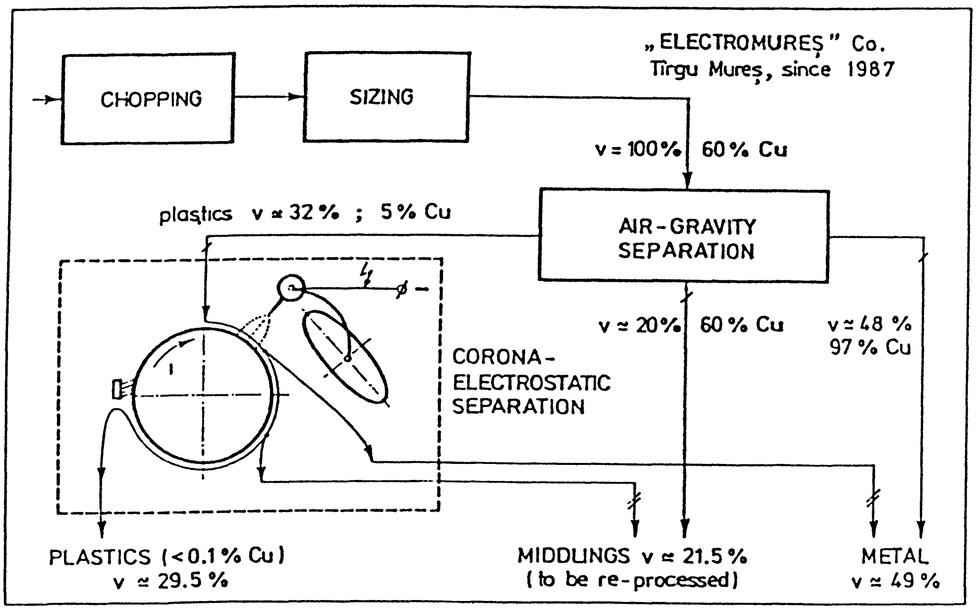

Fig. 7 Production plant flowsheet for obtaining reusable insulation free of metallics by electroseparating the plastics product from an air–gravity separator

Another recovery flowsheet (Fig. 8) could be used for the middlings from air–gravity separation. After corona–electrostatic stage, the metallic concentrate would contain less than 1 per cent of impurities.

The final middlings which have to be chopped again before re–entering the air–gravity separator, represent only 8 per cent of the processed quantity of material, as compared to more than 20 per cent in the other flowsheets. Thus, the quantity of excessive fines generated and lost when fine liberated wire (contained in the middlings) is re–granulated, has been reduced. This scheme, in conjunction with a large air–gravity circuit, is to be applied at Cable and Electroinsulating Materials Co., Bucharest, Romania, in order to increase the recovery of fine metallics.

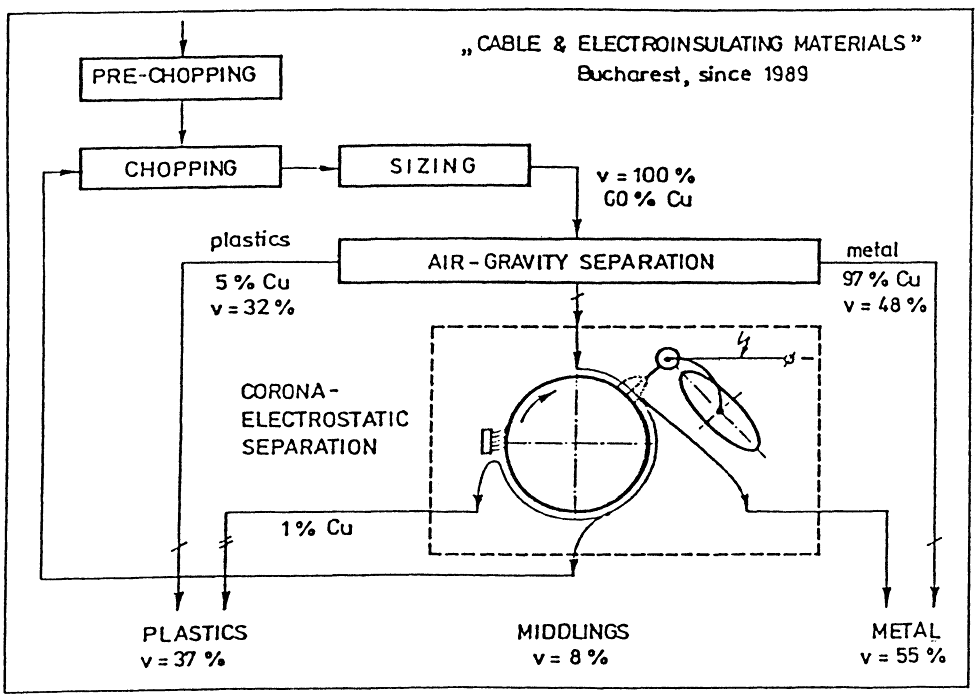

Fig. 8 A proposed production flowsheet for quasi–complete recovery of plastics and metallics from wire and cable waste, by electroseparating the middlings product from an air–gravity–separator.

DISCUSSION AND CONCLUSIONS

The research and development work carried out at the High–Intensity Electric Fields Research Laboratory of the Technical University of Cluj–Napoca [9, 17, 18] aimed at clearing up the main steps between the theory and the applications of corona–electrostatic separation:

(1) the feasibility analysis based on materials properties and on a simplified mathematical model

(2) laboratory tests to determine the correct type and size of electroseparators, and their optimum operating conditions

(3) design of industrial flowsheets.

Undoubtedly, each application may lead to a different optimum flowsheet and this paper presents three typical examples of recycling techniques that use high–intensity electric fields. The efficiency of electroseparation as the basic operation of a recycling flowsheet, when the throughput of wire and cable waste is less than 200 kg/h has been demonstrated. At the same time, it has been shown that electroseparation can represent a complement to the conventional air–gravity separation of metal and insulation from chopped waste.

The in–plant experiments have generated useful design information. As a consequence of fruitful co–operation between researches and the manufacturer (the Equipment Division of Electromures Co.), the latest model of ELSIM–2 insulation–metal electroseparator (Fig. 9) is capable of processing more than 100 kg per hour per meter length of wire and cable waste. Improved performance has been attained by using the original patent–pending corona and electrostatic electrodes, together with a new positioning system for electrode carriers.

In spite of great differences in electric conductivities between metallic and insulating particles, the industrial application of electroseparation techniques is accompanied by numerous difficulties. For instance, during the pilot–plant operation of the electroseparation process at Electromures Co., significant variations of the plastics grade and the efficiency of metal removal from one day to another were observed and the commissioning of the recycling plant in Tirgu Mures was in jeopardy. Besides an increased proportion of unliberated wire contained in the feed, and considerable amount of dust accumulated on the electrodes, resulting in the collapse of the electric field, unsatisfactory results

results were primarily caused by the fact that the material to be separated had not been properly stored (some of the bags with chopped wire waste had been exposed to rain).

Although the granulators were adjusted to provide metallic particles liberated from insulation, the electrodes were cleaned and no operating conditions were modified as compared to experiments that had been performed with dry material, electroseparation was no longer possible.

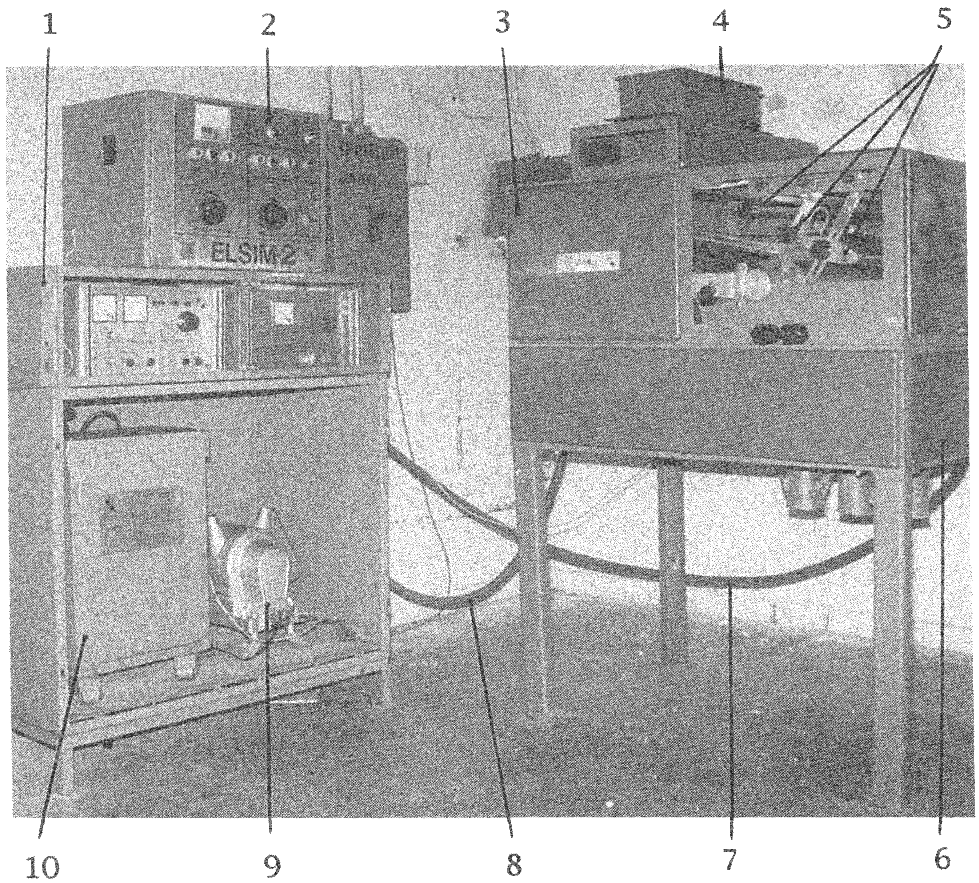

Fig. 9 Industrial insulation–metal electroseparator. 1–control panel of high–voltage supplies, 2–general control panel, 3–electroseparation unit, 4–feed hopper, 5–high–voltage electrode system, 6–collector, 7–high–voltage cable, 8–control cable, 9–ac high–voltage supply (25 kV_{peak}, 5 mA, 50 Hz), 10–dc high–voltage supply (50 kV_{peak}, 5 mA)

As a result of reduced surface electrical resistivity the PVC granules were rapidly losing their electric charge and the electric image force no longer acted on them. As soon as the material was heated up and the surface moisture reduced [19] the electroseparation improved and the operation of the recycling plant at Tirgu Mures could have started in time. It was proposed that a specifically designed electric heater be added to the corona–electrostatic recycling line in order to prevent such a problem, and to increase the quality of products.

Technical literature [11, 20 – 24] suggests a possibility of using electroseparation in a variety of other recycling processes, involving electronic scrap,, metals, glass, paper, plastics from municipal refuse. Industrial applications of such techniques [25] are still limited because of high processing costs and low quality of products. Further research must focus on these technical issues while the management has to solve the problems of collecting the waste and marketing the products.

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