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METHODS AND TECHNIQUES USED IN RECYCLING PROJECTS FOR WASTE CONTAINING IRON

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Abstract: Waste management is a problem faced by many countries of the world and its storage is no longer a reliable solution, which is why many European Union states have decided to practice the export and import of the waste they have generated. An efficient management of ferrous waste does not provide for the export or import of waste as a saving solution, and this waste must be regarded by the states of the world as a resource generating added value. The Romanian steel industry currently operates at a quarter of what it represented in 1989; however, in Romania there are still huge amounts of waste containing stored iron. Therefore, it is imperative that the Romanian steel industry adopts a cyclical model for the reintroduction of most of the waste generated (slag, agglomerated, scrap metal waste) into the manufacturing process. The paper presents methods and techniques used in planning and conducting a research project on the recovery of waste from the steel industry and the level of impact that the implementation of the obtained results could have.

Keywords: research project, ferrous waste, recycling, steel industry

INTRODUCTION

Under Directive 2006/12/EC on waste, adopted on 12 December 2010, any substance or object which the holder intends to dispose of, discards or is forced to dispose of is considered to be waste. Those substances and materials that represent residues of production or consumption processes are not necessarily considered waste, which is why it is important to distinguish between the notions of 'residues' and 'waste'. "Production residues" are considered to be materials that are not intentionally produced in a production process, but which may or may not be considered waste [1].

Ferrous metal waste is wastes that have in their chemical composition a high content of iron (Fe). Correlation Table 1 shows the types of ferrous waste, which is made according to the statistical waste nomenclature established on the basis of substances and the European list of wastes established by Decision 2000/532/EC of the European Commission.

Table 1. Classification of ferrous waste [2]

Cod	Type of waste
06	metallic wastes
06.1	metal waste, ferrous
06.11	ferrous metal waste and scrap
0	non-hazardous
10 02 10	mill scales
10 12 06	discarded molds
12 01 01	ferrous metal filings and turnings
12 01 02	ferrous metal dust and particles
16 01 17	ferrous metal
17 04 05	iron and steel
19 01 02	ferrous materials removed from the bottom ash
19 10 01	iron and steel waste
19 12 02	ferrous metal

The Romanian steel industry is currently operating at almost a quarter of what it operated at the end of 1989. At the moment, the Romanian steel industry is facing problems related to capacity and lower prices, the demand for steel depending on the economic and financial situation of some key industrial areas, which hinders the economic performance of domestic steel plants. The pandemic has also made the situation in plants even more difficult, making steel demand even higher. About 90% of the country's total steel production goes to export.

Due to the fact that Romania has been a highly industrialized country, significant amounts of ferrous waste have been generated (waste with high iron content, especially from the steel industry), the evolution of the amounts of these types of waste is shown in the graph in Figure 1. The graph was based on a set of data downloads from the Eurostat site, according to which the amounts of ferrous waste in Romania exceeded the threshold of 1,600,000 tons in 2018, being the highest amount recorded since 2010.

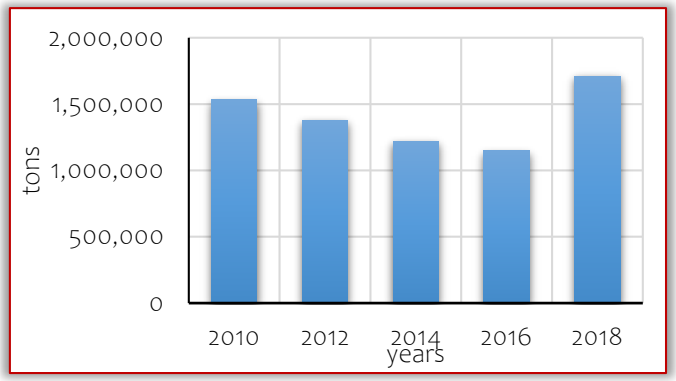

Figure 1. Evolution of ferrous waste quantities in Romania

In Romania, there are many historic waste deposits with iron content, to which are added landfills generated by the technological flows that currently operate. Most of the waste is not recycled, and the recovery rate of the waste is low. Such landfills are predominant in the western part of Romania (slag dump in Hunedoara, red sludge deposit in Oradea, tailings dump in Ghelari, Teliuc, etc.) and non-use

and lack of maintenance activities cause a high degree of pollution. According to statistics made at the 2020 level, ferrous waste exports (iron and steel) from the European Union amounted to approximately 17.4 million tons, representing more than half (53%) of total waste exports. In 2020, the main export destination of the Union was Turkey (70 % of the Union's iron and steel exports). The EU also focused on imports, with 4.1 million tons of ferrous metal waste imported in 2020, with a third (32%) coming from the UK [3].

At the level of 2020, according to statistics, the export of ferrous waste represented about half of total waste exports from the EU. The quantities of ferrous waste (iron and steel), according to figures 2 and 3, occupy the first place in the hierarchy of imports and exports of different types of waste from and into the EU, according to Eurostat statistics.

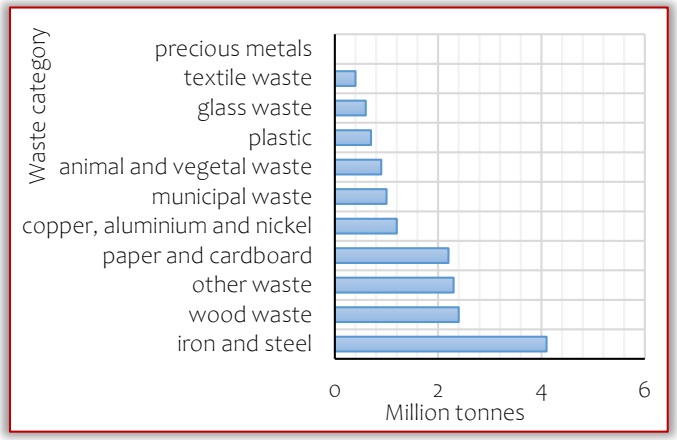

Figure 2. Statistical data on EU imports by waste category in 2020 [3]

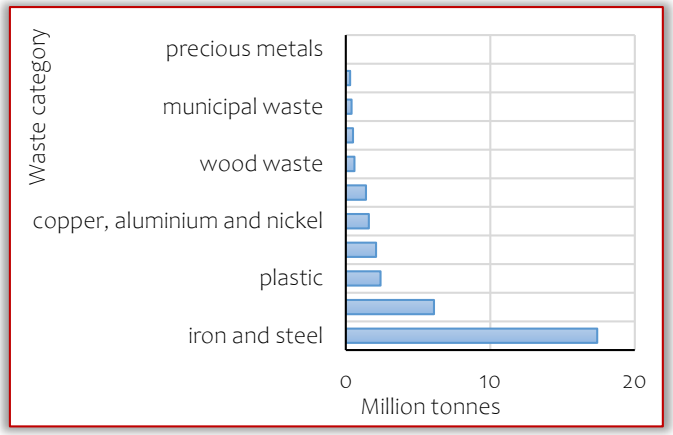

Figure 3. Statistical data on EU exports by waste category in 2020 [3]

In 2020, the main export destinations for "ferrous waste and scrap, iron and steel rebutting, iron or steel ingots" from Romania were: Turkey, Bulgaria, and Moldova. Ferrous waste and scrap, iron or steel scrap from Romania, in 2020, were imported by countries such as Bulgaria (with a share of 46%), Hungary (with a share of 24%) and Italy with a share of 11.4% (1.89 million USD) [4].

METHODOLOGIES

The methodology followed was to study, within a research approach, the applicability of specific management methods and techniques within the field of recovery / recycling of waste with iron content, following the identification of existing quantities of waste deposited in kind, located on the territory of Romania. Everything was done in order to study the way of waste management and to improve the management systems of waste generators (steel plants, metallurgical plants), carrying out the planning and development of a waste research project on waste.

Within the initiated research approach, a series of methods with high applicability in the field of industrial waste recovery were analyzed, identifying the causes that led to the generation of high quantities of waste, the strengths and weaknesses of the waste management process of these waste, the opportunities and threats that can arise in this field, respectively, the issuance of recommendations necessary to remedy or improve the situation encountered.

Management methods and techniques are those tools that are available to decision makers and are used to achieve the predicted objectives. The category of specific management methods and techniques is used when it is necessary to solve specific problems as efficiently as possible specific problems, in this case the problems and impediments that may arise within the research projects on the recovery of ferrous waste.

In the specialized literature, there are many management methods and techniques that have applicability in any field or some specific only to a certain field. Here are some methods and techniques that can be applied successfully in all research projects on the recovery of all types of waste, but in particular on the recovery of ferrous waste (small and powdery), the main subject of the paper.

THE METHOD OF DIAGNOSIS is characterized by the fact that it has a strong anticipatory character, its completion consists of the formulation of recommendations, and the essence of its application lies in the cause-effect analysis. The method results in corrective decisions on the malfunctions found. The application of the method in a waste recovery research project involves the steps listed in Table 2.

Table 2. Exemplification of the diagnostic method

1. Choosing the domain to be researched
≡ the field to be investigated shall take into account the recyclability of industrial waste, in particular of waste with a high iron content; ≡ in the area of Hunedoara County (Romania) there are many historical landfills, because historically the county was a mono-industrial area specialized in extractive industry and ferrous metallurgy.
2. Creating documentation on the investigated field
≡ it is necessary to carry out a study from the specialized literature on the typology of waste (types of waste deposited in the area: slurry from agglomeration-blast furnaces, steel dust, sideritic waste, slag), to make quantitative estimates of the waste obtained on streams that currently no longer work, as well as of the waste that is currently produced on technological streams; ≡ industrial waste landfills are located throughout Hunedoara County (e.g. in Teliuc there are sideritic waste deposits, in Hunedoara there is a slag dump, in Ghelari there is a dump of waste that contain iron, the waste are resulting from mining); ≡ waste from industry, in particular waste with a high iron content (slag, steel

dust) must be physically, chemically and mineralogical characterized for the purpose of establishing a concrete database and which will prove useful for further research to be undertaken;
≡during the investigation process of the chosen field, answers are sought regarding the intrinsic value of the waste and the specific elements it contains (e.g. high iron content, useful mineral element iron), which recommends it in order to be the subject to a recovery process or to design, develop a specific recycling process;
≡it imports the analysis of the form under which the useful element is found, following its study being able to choose the optimal form of extraction;
≡after the characterisation of the waste, one can proceed to the study of the recycling processes and processes or even the development of proposals, as a result of which the obtained products can be used in the steel industry or in other industries (e.g. identify the recycling solutions to steel dust for zinc recovery);
≡the documentation will be done from the specialized literature, but also on the spot by sampling and performing experimental analyzes.

3. Identifying the strengths and causes that led to their appearance

Strengths	Causes
≡highly industrialized area based on mining (iron ore, coal) and processing in the metallurgical and steel industry; ≡economics in full momentum since the years 50' – 60', the main flow of the Hunedoara metallurgical plant operating for almost 100 years; ≡worldwide there is an extremely high demand for products made of steel or cast iron (e.g. in the territory of Călan city, there was in the past a gray cast iron foundry whose elaboration used white cast iron as a raw material).	≡industrial waste is generated as a result of manufacturing processes, it is impossible to produce cast iron or steel without generating such waste (e.g. slag resulting from the steelmaking process, sideristic waste resulting from the process of enrichment of the iron ore concentrate present in the Ghelari area); ≡increasing the iron content in the ore through the process of magnetic concentration and using only that concentrate, the rest being considered sterile, this material being stored in nature, currently in the county there are three such tailings ponds.

4. Identifying the weaknesses and causes that generated them

Weaknesses	Causes
≡large quantities of industrial waste deposited and currently unused (sideritic waste, slag); ≡currently, the Hunedoara slag dump from Hunedoara, which is under concession, is being processed, but the processing speed, consumption is not very high; ≡lack of new ways in which the ferrous fraction of the slag (with a grain size below 10mm) can be used.	≡the correlation between legislation and rules on industrial waste management, so that waste producers benefit from the fact that they process their waste and no longer store it in kind; ≡the frequency of waste generation by the technological processes carried out, plus the historical landfills.

5. Issuing recommendations

≡identification of economic entities that are specialized in processing industrial waste, especially those with a high iron content (e.g. Ecoremat, Econet Romania);
≡in the context of sustainable development, future generations will have to use industrial waste, currently in storage, as secondary raw materials to be able to produce more, as natural resources will be depleted;
≡designing and developing a technology for the recovery of small and powdered ferrous waste (such waste exists in Hunedoara County);
≡the research, once materialized, will be used and implemented in other monoindustrial areas in Romania, such as Galați and Reșița.

Annually, across the world, nearly 630 million tons of steel waste are recycled, thus preventing the emission of almost 950 million tonnes of CO_2 emissions, making "a decisive contribution to climate protection" [5].
Some reports by the Joint Research Center of the European Commission attest to the existence of a market and demand for the use of iron and steel waste in Europe, respectively, as a raw material in steelworks and smelters related to the production of metals and metal products.

Table 3. SWOT analysis applied to research on the recovery of iron-containing waste in Romania

Strengths	Weaknesses
≡the existence of historic industrial waste landfills and the landfilling of the resulting waste in current streams; ≡the presence of useful elements in the waste, elements which can still be recovered, the waste thus turning into secondary raw materials; ≡the application of the principle of sustainability or sustainable development through the processing and recovery of waste with a high iron content and its reintroduction into the steel industry; ≡the existence of large quantities of waste that are currently not processed, used (e.g. steelworks dust); ≡when products are obtained based on the useful element of a type of waste, the products can be used in industry, this being a way of saving natural resources.	≡industrial landfills that are not recovered and maintained (most of the landfills in the Hunedoara County area) pollute the environment, damaging natural ecosystems; ≡the lack of interest of the entities that are managing such landfills, and implicitly of the generators, in the processing or recovery of that waste; ≡substantial investments are needed to develop and implement a recovery technology to cover the very high costs generated by that process; ≡not accessing European funds to create a recycling stream for landfill waste.
Opportunities	**Threats**
≡processing of industrial waste deposited in kind produces secondary raw materials that are cheaper than raw materials obtained from natural sources; ≡the research that will be undertaken locally will be able to be applied by other processors at national or even international level; ≡by processing and recovering industrial waste and reintroducing it into the economic circuit, the number of landfills will decrease considerably, the degree of pollution caused by these sources will also decreasing.	≡processing and recovery technologies can generate high costs that would generate a decrease in the interest of processors or investors; ≡the finding by the beneficiaries of the recycling process of the need to make some changes in the production flow, changes due to the implementation of the respective process or technology of recycling/ recovery; ≡obtaining low yields on the production side makes the technological process more difficult.

SWOT ANALYSIS is a specific management technique that each company can use to assess its internal environment,

identifying strengths and weaknesses, and its external environment, identifying opportunities and threats from outside. The SWOT model can be applied not only to any managerial process but also to a concept, which is not directly related to the internal and external environment of a company. The SWOT model applied to the recovery process of industrial waste, particularly waste with a high iron content, is shown in Table 3.

According to the representatives of the International Recycling Bureau (BIR), the only global federation of the recycling industry, this industry is facing enormous challenges, with representatives of the organization trying in recent years to convince the executive branch, the European Commission (EC), that it should no longer consider processed, clean waste with high metallic content as "waste" [6].

As is the case for those iron and steel waste generated that have a sufficient degree of purity and which comply with the standards applicable to the category to which it belongs, namely the specifications required by the metallurgical industry. According to the legislation in force, both ferrous and non-ferrous waste in Europe can no longer be sold abroad, unless buyers are able to demonstrate that their waste processing standards comply with those of the countries of origin and do not generate additional pollution, as proposed by the EC [6].

Therefore, in the first month of 2020, China redefined important scrap metal as recyclable material, and since then there has been a massive acquisition of the highest quality scrap metal.

THE METHOD OF MORPHOLOGICAL RESEARCH is based on the decomposition of a complex objective into structural parts, whose evolution in the future will be independently researched, thus obtaining data on their future improvement, taking into account the forecasts of the technique and technology in the field in question. The steps and way of exemplification of the method in the field of recycling waste containing iron are presented in Table 4.

Table 4. Exemplification of the method of morphology research

1. Specifying the problem and identifying the main parameters involved in solving it
≡ the problem lies in the identification or development of processes for the recovery of industrial waste containing iron;
≡ the parameters to be identified are regarding the type of waste (ferrous or nonferrous waste), the chemical composition (high iron content or high value of other elements such as silicon, manganese, carbon), the physical composition, the mineralogical structure, and also the form in which the respective waste or class of waste is found (waste to pieces, small waste, powdery waste).
2. Careful analysis of the parameters and setting the values that each parameter can take
≡ after identification of the parameters mentioned in Step 1, the waste is thoroughly analyzed in terms of its chemical composition, mineralogy structure, and physical form under which it is found it;
≡ in view of the above characteristics, an attempt is made to find and develop those processes which can be successfully applied;
≡ for example, if it is found that the dimensions of the waste and, respectively, of the waste under analysis, are large, the recovery process by pelletization cannot be applied (pelleting is applied to powdery waste);
≡ if the waste is presented in an irregular (sharp) form following microscopic analysis, its recovery may be problematic. However, it was found, in some research conducted within the Faculty of Engineering Hunedoara (Politehnica University Timisoara), that in the case of producing briquettes from waste of 5-10mm granulation, low values were recorded for the cracking resistance of the briquettes, the breaking/cracking appearing where the large pieces of the ferrous waste were used [7,8].
≡ the physical form under which the waste is found can cause the physical occurrence of phenomena, inappropriate events (e.g. briquette breakage, appearance of structural defects: air gaps).
3. Choosing the optimal solution, taking into account the conditions and possibilities that exist at a time
≡ in the framework of the research, to remedy the inconvenience that arose, regarding the cracking of the briquettes in the places where there were larger pieces of a particular ferrous waste, it was opted to crush them in a ball mill. After the use of this type of ferrous waste in the production of briquettes, the resistance to cracking and crushing of the samples made [9,10]; The waste used in the investigation is the result of the continuous pouring process and is called scale.
≡ sometimes, with relatively minimal efforts, nonconformities in products resulting from the application of recovery/recycling processes can be corrected.

The criteria for determining the conditions under which certain types of scrap metal are no longer considered waste, established under Directive 2008/98/EC of the European Parliament and of the Council, are set out in Regulation (EU) No. 333/2011 of the Council of the European Union. The criteria for determining the conditions under which iron and steel waste are no longer considered waste are closely linked to the activity of transferring it from the producer to another holder, the conditions to be met by the waste are set out in Regulation (EU) No. 333/2011 of the Council of the European Union adopted on 31 March 2011, on the establishment of criteria for determining the conditions under which certain types of scrap metal are no longer considered as waste, are the following:

- ≡ waste used as input of raw materials for the recovery operation contains iron or recoverable steel and should not contain hazardous waste, filings, fluids, pressure vessels;
- ≡ waste used as raw materials for the recovery operation has been properly treated for final use as input to steelworks and foundries;
- ≡ the iron and steel waste resulting from the recovery operation must meet the following criteria: the amount of tailings must be ≤ 2% by weight, do not contain excess iron oxide, do not contain oil, oily emulsions, lubricants or fats, toxic / radioactive/ hazardous substances.

The reports of the Joint Research Center of the European Commission have shown that the proposed criteria for waste used as inputs of raw materials in the recovery operation, for treatment processes and techniques, as well

as for scrap metal resulting from the recovery operation meet those objectives and should lead to the production of iron waste, steel without hazardous properties, and with as few nonmetallic compounds as possible.

By applying the methods and techniques presented above within any type of research project, especially those projects concerning the recycling of waste containing iron, it is possible to identify, forecast and remedy the inconveniences that have occurred (the morphological method) and an exhaustive knowledge of the entire process (SWOT analysis, diagnostic method), can be identified, forecasted, and remedied, thus generated extraordinary results. The examples of the methods presented, including the implementation of the aspects and solutions identified following the application of the methods, are currently in the planning phase and will be put into practice in the near future.

RESULTS

According to recent data, all activities carried out on the recycling of iron-containing waste reduce energy consumption by 33% and CO_2 emissions by up to 32%. According to the statement of the statistics adviser of the Ferrous Division of THE BIR on 4 November 2021, adding ferrous waste back to the foundry sector would generate annual savings in CO_2 emissions that would amount to more than 1 billion tons. At the international level, as a result of the previous data, the waste with iron content generated by the steel industry is reintroduced into the production streams, it is desired to implement this concept in Romania, first locally (Hunedoara County) and then at national level.

According to the latest Eurostat data, the EU is one of the largest exporters of ferrous waste in the world. The 27 member states exported 17.45 million tons of waste to non-EU countries, in 2020. Over time, Romania has completed international collaboration projects on the implementation of an integrated waste system with Germany. Regarding the ferrous content, Romania does not have significant projects to collaborate with other countries, as landfills are still significant. A concrete example of this kind is found in Hunedoara County, where the recovery works for the deposited slag are completed in a proportion of 62%, while in Tulcea County, the recovery works have been completed up to 66%.

The problem of the aspects identified and detailed after the application of the methods could help to carry out a critical analysis generating a much clearer and more precise situation of the entire industrial waste management system, also highlighted the correlation with the legislation in force and with the regulations and directives of the Commission of the European Union.

The results obtained on the territory of Romania represent an applicative model also in the case of other states that face large amounts of industrial waste. Certain ferrous deserts generated on the territory of Romania that comply with the conditions of REGULATION (EU) No.333/2011 of the Council of the European Union are frequently exported to neighboring countries (Bulgaria, Moldova).

CONCLUSIONS

In the context of sustainable development, efficient use of resources, reuse, and recycling of steel and small and powdery ferrous waste is very important for the metallurgical industry. Currently, all raw materials must be used to their fullest capacity, ensuring zero waste in steelmaking. Each coproduct resulting during steelmaking, in the context of the circular economy, must be used in new products, this approach minimizes the amount of waste deposited, reduces emissions, and preserves raw materials. The recovery of waste regardless of the industrial branch, respectively, its expansion, leads to the minimization of the consumption of natural resources, the development of business opportunities, the optimization of costs, and the creation of new jobs.

It would be beneficial for Romania to process its waste generated from the steel industry by reintroducing it into the economic circuit. Romania could conclude collaboration projects with recycling institutions and centers located in the country or abroad, provided that this approach is supported and boosted by the country's leadership.

At the international level, many countries have decided to focus on the field of industrial waste recovery with the aim of increasing steel production. An example of this is Turkey, which in recent years has been heavily importing ferrous scrap (scrap iron), which has subsequently been recovered as part of the steel manufacturing process.

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