AN ALGORITHM FOR METALLURGICAL WASTE MINIMIZATION

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ABSTRACT

The selection of the optimal process that satisfies both environmental and economic objectives simultaneously is rather difficult. Identifying the optimum from set of objectives is depending of the preferences of decision makers. Successful and widespread implementation of existing methodologies for pollution prevention and waste minimization has failed to provide significant benefits for applications in metallurgical processes.

One of the main reasons for this is the lack of a comprehensive approach that integrates and guides the application of the proper tool. The existing methodologies have been developed more general and for particular stages in the process and they require different detailed and accurate information which may not be available.

An algorithm developed for waste minimization from metallurgical processes is presented in this paper. The methodology incorporates both environmental and economics criteria into the metallurgical processes in order to select the best alternative for waste material flow minimization. The proposed algorithm and described criteria can be used in multi criteria decision making during alternatives evaluation both new and technological modernization of existing metallurgical installation.

Keywords: metallurgical waste, minimization, optimal process, algorithm.

INTRODUCTION

The wastes affect every part of the society with not only damaging the environment but also economically. Much attention has been paid in the past to reuse, recycling and waste management. We focus the problem of waste management on the waste minimization.

The necessity to safeguard our environment has been increasing ever since the industrial revolution. Advancement in technology has caused environmental deterioration that could lead to serious consequences. Therefore, it has become necessary to implement techniques that will prevent industrial pollution from causing a major ecological disaster. From engineering point of view one way of reducing environmental impact is by designing for sustainability [1, 16, 17].

Pollution prevention is an area of concern that has been addressed by several researchers. The waste minimization techniques that are practiced in the industry can be broadly classified into source reduction and recycling techniques. Waste generated that cannot be prevented should be recycled in an environmentally safety manner.
Waste that cannot be recycled should be treated in accordance with environmental standards and regulations and disposed of safely. The first step in a hierarchy of options for reducing pollution is a source reduction or reduction of waste generation. Process integration techniques may be used for pollution prevention by reducing generation of waste.

Waste generation in various metallurgical processes has to be analysed from the different sub-sources that may cause it. This includes understanding of the process, gathering, identifying and classifying the necessary information and knowledge to describe the crucial parts of the process. Organising and grouping the whole knowledge about the process provides an effective way of reducing gaps in the information needed to fully understand the process and identify the signs that point towards waste generation. This translates into an accurate way to identify the areas for the purpose of pollution prevention and to define the activities that have to be performed to implement it.

In order to overcome the difficulties found in the application of existing waste minimisation methodologies, we propose a methodology to assist in developing and optimizing of metallurgical processes. Instead of focusing on economic performance of the process, designers currently incorporate environmental concerns as design objectives at early stages of metallurgical process development in the context of environmental impact minimization. The environmental aspects are forcing metallurgical process designers to change their practices in process design and decision making. Process design methods and tools are required, which help to achieve environmental impact minimization at a desired economic performance. Many approaches are developed and available in the literature [7 - 11].

Several methodologies have been proposed in the field of waste minimisation to tackle the complexity of the problem. These approaches have been developed in the form of technical recommendations for renovation of existing plants or for the design of new plants [3, 6, 15].

The main issue is incorporating the environmental perspectives into the process design and optimization. In general, there are two main ways. The most common one is to treat environmental consideration as constraints on economic optimization, or to treat environmental incentives as main objectives in process selection and design but overlooking the economic feasibility. Another key problem for the latter approach is how to find a suitable environmental objective that can reflect the whole environmental impact of the process. Minimizing the waste generation, environmental penalties (global emission) [4], mass of pollutant of concern, total mass of waste [3], etc., are often adopted as environmental objective in the early stage especially in 1990s.

**METHODOLOGY**

To generalize the process model, a holistic concept of macro-structure is proposed for environmental impacts, energy and economic issues. The macro-structure separates a process into four functional parts including material transformation, energy utilization, negative environmental impacts, and economic benefits [12].

Two broad approaches have emerged in the literature, that are widely applied in synthesizing a process flowsheet in an attempt to identify strategies that are feasible to achieve waste minimization in industrial processes. The techniques are classified as qualitative and quantitative approaches [2]. This classification is significantly influenced by data and information features accessible in a given industrial process.

According to this objective the system decomposition, can be described from various points of view, including material transformation, energy utilization, negative impacts on the environment, and economical efficiency. The process can be divided into five modules regarding to material transformation:

- Material processing;
- Metallurgical aggregates (furnaces, converters, refining furnaces, etc.);
- Semi-product and recycling product handling;
- Final product;

The process can be divided into raw material consumption, energy consumption, waste generation, waste handling, waste treatment and waste discharge with respect to negative impacts. With regards to cost-benefits, the process can be divided into material costs, energy costs, operation depreciation costs, profits from the sale of products and expenses of waste management. [14, 18]. The goal to environmental concerns is to minimize both the use of natural resources and impacts on the environment. Every process can be regarded as a system, with small or large boundaries, for example just one stage of
a process, or larger, for example the whole multistage production [4, 8].

The main solid waste is generated slag in the extractive metallurgy. The amount of slag produced by smelting is mainly influenced by the impurities of the raw material, so that cleaner materials lead to reduced generation of these solids. Several techniques exist to reduce the amount of residues that are formed in the production processes. Important techniques are to reduce the amount of slag and to recover metals in the slag.

This study proposes a novel approach for evaluation for proposed technique alternatives in an attempt to find a compromise solution between the alternatives.

An algorithm is formulated by introducing identification of the process and preparing of material balances for each technological units. From the base of the performed extensive researches as regards to technological process including complete material and energy balances, the production process has to be evaluated as a system for waste minimization. During the assessment process, has to be investigated causes and technological operations, in which waste material flows are generated and also the measures to prevent or minimize if possible.

The main causes of the waste generation are categorized as follows:

- Poor materials;
- Type of technology;
- Type of main aggregates and equipments and their maintenance;
- Internal organization of production;
- Transport of mass flows;
- Contamination of the mass flows;
- Others.

Quantitatively or relative contribution of each of the above described categories is to be understood in regards to:

- Each elementary module (single technological operation) and total for the sub system and for the whole system;
- Any valuable component of raw and auxiliary materials;
- Any toxic component contained in the raw materials and / or auxiliary materials.

Conclusions of a detailed analysis should include the following aspects:

- The type on the main causes for generation of waste material flows;
- The main sources of solid, liquid and gaseous waste material flows localized technological operations and unit process design;
- The reasons for the transfer of a valuable component from the raw materials and / or auxiliary materials in a waste stream by localizing this transfer in current technological operations;
- The reasons for the passage of any toxic components of the raw materials and / or auxiliary materials in a waste stream localizing this transfer in current technological operations.

The information obtained is summarized tabular and quantitative data are based on measurements and expert estimates. On the basis of this information, are prepared technical and technological alternatives for minimization of generated waste material flow and content of toxic components in them. The most common alternatives are divided into two main groups [13] depending on their implementation:

- Alternatives for direct application, including: internal production organization, transport of major material flows, contamination of major material flows and more;
- Alternatives for long-term use (reconstruction and modernization), including measures for exchange of raw materials, technological changes and events in respect of the equipment used.

In order to select the optimum technical and technological alternative, the proposed alternatives should be compared with pre-established criteria. In this study are used four criteria for environmental assessment and cost-effectiveness of alternatives [4, 13]

The criteria can be summarized in the following categories:

- Quantitative minimization of the waste material flows;
- Minimizing the content of toxic components present in the waste material flow;
- Changing of the flowsheet;
- Costs for implementation of the alternative;
- Cost saving in caused by penalties and sanctions for violation of emission limit value for the pollutants;
- Costs due to loss of valuable components of waste material flows.

The goal to environmental concerns is to minimize both the use of natural resources and the impacts on the environment. The criteria [19] are:
\( \epsilon_1 \) – no-waste degree, expressed with valuable components in raw and auxiliary materials.
\( \epsilon_2 \) – no-waste degree, expressed with waste material flows.
\( \epsilon_3 \) – criteria for environment minimization of the waste.
\( \epsilon_4 \) – criteria for economic minimization of the waste.

\[
\epsilon_1 = \left( \frac{M_{p,0} + \Delta_p}{M_{in} + \sum \Delta_m} \right) \times 100
\]

\[
\epsilon_2 = \left( \frac{M_{sg} + \Delta_{sg} + M_{ww} + \Delta_{ww} + M_{ws} + \Delta_{ws}}{M_{in} + \sum \Delta_m} \right) \times 100
\]

\[
\epsilon_3 = \left( \frac{WG \sum_{j=1}^{m} M_{wg,j} + WW \sum_{j=1}^{m} M_{ww,j} + WS \sum_{j=1}^{m} M_{ws,j}}{\sum_{j=1}^{m} M_{wg,j} + \sum_{j=1}^{m} M_{ww,j} + \sum_{j=1}^{m} M_{ws,j}} \right) \times 100
\]

\[
\epsilon_4 = \frac{\sum_{v=1}^{N} M_{products,v} \cdot P_v}{\sum_{v=1}^{N} m_v \cdot P_v} \times 100
\]

where:

\( M_{p,v} \) – mass of the final products;
\( \Delta_{p,v} \) – error during measuring/calculation of the mass of the final products;
\( M_{in} \) – sum of all mass flow;
\( \sum \Delta_m \) – error during measuring/calculation of the masses of all input material flows.

\( M_{wg} \) – flow rate of the flow \( j_1 \) of technological and ventilation gases;
\( M_{ww} \) – flow rate of flow \( j_2 \) wastewaters;
\( M_{ws} \) – mass \( j_3 \) of industrial solid;
\( WG \) – i\textsubscript{1} toxic components in gaseous waste flow;
\( WW \) – i\textsubscript{2} toxic components in waste water flow;
\( WS \) – i\textsubscript{3} toxic components in solid wastes flow;

\( M_{product,v} \cdot P_v \) – cash equivalent of the total quantity of the valuable component \( v \) in the final products;
\( m_v \cdot P_v \) – total cost of the \( v\textsuperscript{th} \) valuable component in the raw materials.

Regarding to best available techniques, the proposed alternatives are compared with the corresponding vertical BAT Reference documents (BREF) document for certain industrial category and the required horizontal BREF documents relating to the cross-media effects. The final selection of the technique-technological alternative is based on multi-criteria optimization process of the obtained complex evaluation. An optimization model comprises an objective function, the decision (or adjustable) variables and the constraints. The block-scheme of the proposed algorithm is given below.

**CONCLUSIONS**

An algorithm for minimizing of the waste material flows from metallurgical installations is designed. It has been evolved with a significant number of features, which address the shortcomings of the previous frameworks developed in this area and thus leads to a sustainable solution.

A general methodology involving process modeling, generation of process alternatives was formulated. It was found that increase in continuous alternatives resulted in production of more product as well as waste in the anode copper production. This methodology is designed to enhance a process both economically as well as environmentally. Using this methodology, it is possible to generate a non-inferior curve which identifies the superior discrete alternative.

The successful application of these approaches relies on the appropriate identification, gathering and classification of the relevant information required by each case.

The optimal economic and waste efficient process alternative can be obtained by implementing the proposed methodology.

The effectiveness of the algorithm is not still authenticated by the quantitative case studies, however, the research is ongoing in that direction and the results will be reported soon.
START

Identification of the metallurgical process.

Establishment of a flowsheet of the process in regarding to main mass flow. The flow sheet must contain each sub-flows in/out form every technological units.

Preparing of materials and mass balances for each sub-process or technological unit.

Is the obtained information sufficient for implementation of algorithm.

Yes

Evaluation of the process as a waste minimization system

Selection of the materials present in the waste material flows for each sub-process or technological unit.

Identification what contributes to waste material flows generation

Finding of the parameters which affect the generation of waste materials flows

No

Perform of additional studies, analysis and experiments

Knowledge of process, boundaries, flowsheets, inputs, outputs, transformation side reactions

Brainstorming decision and expert analysis.

Summary table with all sources of waste material flows and causes for the occurrence.
Developing of criteria for evaluating, verification and validation of proposed alternatives.

Evaluation of the proposed alternatives using environment criteria developed.

Evaluation of the proposed alternatives using economics criteria developed.

Selection of the alternative with the best environment and economics benefits and preparing for economic evaluation.

Multi-criteria decision making for selection of alternative through optimal expertise.

Apply of the adopted alternative and collecting the information.

Post applying control and evaluation of the results. Collection of the results for assessments.

Alternatives for immediate application.
Alternatives for long-term application.
REFERENCES