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Process integration analysis and some economic-environmental implications for an innovative environmentally friendly recovery and pre-treatment of steel scrap

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HIGHLIGHTS

- A method combining preheating and surface rinsing of coated steel scrap is explained.
- The recovery of valuable raw material (e.g. Zinc) is one of the main objective.
- Energy and chlorine containing plastic waste such as PVC is used as a resource.
- A flowsheet simulation and optimization of the involved processes have been realized.
- The method has been analyzed also from an environmental and economic perspective.

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ABSTRACT

The use of Zinc-coated steel (e.g. galvanized steel) in melting cycles based on Electric Arc Furnaces can increase the production of harmful dust and hazardous air emissions. This article describes a novel process to simultaneously preheat and remove the coating from the scrap surface before the melting phase. The zinc in coating is removed in the gas phase by chloride containing syngas combustion and collected in a dedicated recovery system. Two possible innovative process routes are described, which involve plastic waste pre-treatment, shredded plastic gasification/pyrolysis, steel scrap preheating and zinc recovery processes. The routes have been modeled in an integrated flowsheet, in order to allow a comprehensive simulation and optimization of the pretreatment processes. The process optimization results in possible energy savings of over 300 MJ/t of preheated scrap charged in the Electric Arc Furnace for steel production. Moreover, a comparison among different scenarios according to economic and environmental criteria has been carried out.

1. Introduction

Steel scrap is a valuable raw material for the steel industry, especially for the electric steelmaking route: its recycling reduces the need for iron ore extraction, significantly reducing CO_2 emissions, energy and water consumption as well as air pollution [1]. In 2013 the percentage of the crude steel produced in the EU-27 through Electric Arc Furnace (EAF) is 39.8% with a production of about 66 Mt steel [2]. In order to increase its resistance to corrosion, steel is sometimes subjected to a galvanization process, resulting in the creation of a Zinc coating on its surface. At the end of its life cycle, when it is recycled as scrap into the EAF, galvanized steel is contaminated by Zinc and organics creating harmful or toxic elements that contaminate the EAF dust (EAFD) which is therefore considered as hazardous waste. Originally, the EAFD was landfilled as a waste from EAF process and no metals were recovered: in recent years, following regulations on waste management and an increasing cost for landfilled wastes due to a shortage of landfill areas, the percentage of dust put into landfill has been reduced [3]. An alternative to the landfill process is to further process the EAFD in order to recover and recycle metals. In the literature, there are some studies where the EAFD has been used for cement and concrete industry and, recently, EAFD has been

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Nomenclature

Abbreviations

AP	acidification potential
ASR	automotive shredder residues
BF/BOF	blast furnace and basic oxygen furnace
COSS	Continuous Optimized Shaft System
CO_2	carbon dioxide
EAF	Electric Arc Furnace
EAFD	Electric Arc Furnace Dust
EP	Eutrophication Potential
FAT	Freshwater Aquatic Ecotoxicity
GOB	Good Ordinary Brand
GWP	Global Warming Potential
HCl	hydrochloric acid
HU	Human Toxicity Potential
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LHV	Lower Heating Value
MAT	Marine Aquatic Ecotoxicity
PE	Polyethylene
PI	Process Integration
PlastSep	Plastics Pre-treatment process developed by Stena Metall A/S
POCP	Photochemical Ozone Creation Potential
PVC	Polyvinylchloride
SHG	Special High Grade
SLF	Shredder Light Fractions
TE	Terrestrial Ecotoxicity Potential
TSCRAP	Ton of Steel Scrap
VW-SiCon	Plastics Pre-treatment process developed by SiCon Gmbh

Symbols

C_O	operating cost
C_E	energy cost
C_{RM}	raw material Cost
C_{LB}	labor cost
C_{LD}	waste landfill cost
C_{INT}	interest cost
C_{INS}	insurance cost
C_{inv}	investment cost
C_{MAINT}	maintenance cost
C_s	savings and revenues
C_t	net total cost
r	discounting rate

Subscript

LS	liquid steel
n	time
t	ton
tot	total

evaluated as a filler material into a polymer matrix, in order to obtain a heavyweight sheet useful as acoustic insulation supplement in building envelopes [4,5]. By the way, currently, different pyro-metallurgical processes such as Waelz Kiln, Rotary Hearth (RH) or Shaft Furnace are the mostly applied technologies for the recycling of dusty steel mill residues. In [6], the Waelz Kiln and the RH have been compared by an exergy analysis, taking into consideration different operational modes of the processes and where the amount of Zn (wt%) in the treated dust, different product qualities for the RHF process and the inclusion of the Waelz Slag as a useful product were considered as the most important variables. The most common treatment process of EAFD today is the Waelz Kiln, which represents 80% of the global capacity in the EU-27 [7]. The significant inconvenience of the Waelz process is that the Fe content (and the valuable Ni) of the residues cannot be re-used in the steel industry. In the best case the Waelz slag is usable in road construction or cement production [8]. Pre-treatment of scrap prior to its melting in the EAF is another way to handle the problem with the coated scrap [9]. In literature several pre-treatment methods are reported, such as electrochemically aided caustic leaching, but few concepts have reached industrial scale [10]. In this article an innovative stand-alone method which combines scrap preheating and surface cleaning is presented. Its basic principle consists in removing Zinc from the steel scrap prior to the steel recovery process (through EAF or BF/BOF), so that the formation of Zinc ferrites in the EAF is avoided. The energy and chlorine containing plastic waste such as PVC and SLF is used as a resource. The plastic is converted to a chlorine containing syngas which is burnt in a dedicated preheating shaft. Such a concept has been suggested and developed firstly in Sweden at Swerea MEFOS. The pre-treated and cleaned scrap is charged hot into the steelmaking furnaces giving direct savings of energy [9] and improving the energy efficiency of the scrap melting process [11]. European manufacturing industries, e.g. the steel industries, are nowadays facing such issues in order to maintain their competitiveness in the international panorama [12]. In such context, in order to achieve a fundamental understanding and a total insight of the processes, especially in complex industrial plants such as those ones which are commonly found in the steel sector, thanks to its holistic approach to process design, retrofitting and operation, Process Integration (PI) can be very helpful by providing also a practical support to decision makers [13]. PI represents a family of methodologies in which several parts of processes or whole processes are combined in order to face complex tasks such as resource conservation, pollution prevention and waste management [14]. The International Energy Agency has adopted the following definition for the PI: "Process Integration is the common term used for the application of methodologies developed for system-oriented and integrated approaches to industrial process plant design for both new and retrofit applications. Such methodologies can be mathematical, thermodynamic and economic models, methods and techniques" [15,16]. El-Halwaigi in [17] explains the activities involved in PI: task identification (the goal to be reached should be an actionable task), targeting, generation of alternatives (process synthesis), selection of the alternatives (mathematical optimization techniques can be used for select the optimum alternatives) and, finally, the analysis of the selected alternatives. Process analysis, process techniques and optimization are in fact the three key elements to obtain a comprehensive PI. Systematic methods based on mathematical programming and pinch analysis have been applied over more than 40 years in order to achieve improved energy and water integration [18]. Also advanced optimization techniques, combining flow-sheeting models and artificial intelligence [12] are very helpful in order to achieve both reduction of total energy [19] and natural resources conservation [20].

In the steel industry, process integration techniques have been applied several times. For instance, a PI approach based on mathematical programming, i.e. mixed integer linear programming (MILP) has been applied to illustrate the investment strategies for a typical European integrated steel plant toward positive energy and environmental effects [21]. Lundkvist et al. [22] use the PI in order to investigate the possibilities for recovering the materials by developing a system optimization model of the steel