

PURIFICATION OF POST-CONSUMER STEEL SCRAP

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Abstract

Post-consumer steel scrap is often hand picked for contaminants such as copper to meet specifications of steelmakers. If the hand sorting capacity exceeds 20 tons scrap/h the efficiency generally becomes problematic, leaving 50% of the copper contaminants in the steel product. In response, new technologies are emerging that facilitate hand sorting of these types of scrap. Advantages are increased revenues, expanded plant capacity and higher and more consistent steel product quality. Proposed is a shape-sensitive magnetic separator that pre-sorts scrap into two products. One product is a bulky thin-walled steel fraction of high purity and the other a volumetrically small flow of relatively heavy parts including the contaminants. The concentrated contaminant product is amenable for effective sorting by hand pickers or for sensor sorting, but could also be sold directly to specialized sorters that extract the copper. Detailed results for the magnetic sorter are reported for mid-sized IBA scrap.

Keywords: Steel scrap; Recycling; Hand picking; Sensor sorting; Magnetic sorter

Introduction

In 2010, 1.4 billion metric tons of steel produced worldwide consumed about 0.5 billion metric tons of steel scrap¹. Despite this impressive volume of recycled scrap in absolute numbers, the relative contribution of scrap to the production of new steel (about 37%) was actually historically low in 2007 as a result of the steep increase of new steel production in the fast-growing Far East economies. Figures for Germany² show a 45% contribution of scrap to new steel, suggesting that a higher input of scrap is possible in stabilized economies. From the perspective of ecology, using more scrap is a positive development. The Fraunhofer Institute³ reports 0.68 tons of CO₂ emissions for a ton of recycled steel versus 1.54 tons of CO₂ for a ton of primary produced steel. Yet, there are also problems with maximizing the recycling of steel. About 10%, or 50 million tons, of the steel scrap that becomes available worldwide annually is post-consumer scrap that is contaminated with elements such as copper, tin, zinc, chromium, nickel, molybdenum, phosphorus and sulphur. This is scrap resulting from End-of-Life Vehicles (ELV), Waste from Electric and Electronic Equipment (WEEE) and Municipal Solid Waste (MSW) Incineration Bottom Ash (IBA) (see Table 1).

Table 1: EU Statistics of post-consumer scrap.

Type of steel scrap	EU production Mtons/y	Typical capacities* tons/h	Typical contaminants/levels
WEEE	2	1-5	2.3% Cu
IBA	1	2-40	0.7% Cu, Phosphor, 0.1% S, sand, 0.2% coarse stone, 0.1% cloth/plastic
ELV	8-11	30-200	0,7% Cu, rubber, stainless, cast Al
Total	11-14		

*Input steel scrap for hand sorting operations

Contaminating elements like copper and tin affect the mechanical strength and resistance to corrosion of the steel product⁴, whereas phosphor and sulphur pose problems during smelting. Depending on the type of smelter (electric arc furnace or blast furnace) and the required steel quality (from rebar to cold rolled steel), maximum contaminant concentrations in the scrap vary (e.g. for Cu: between 0.04% and 0.4%). Unfortunately, some elements also build up in the steel matrix, increasing the need for scrap purification with each life cycle in countries that recycle lots of scrap.

Widely implemented solutions for reducing the contamination levels of post-consumer scrap are mechanical processing and hand picking. Combinations of screening, shredding and magnetic separation are able to concentrate copper, stainless steel, cast aluminium, stone, dirt and cloth into fine fractions that may be either non-magnetic or weakly magnetic. Hand-sorting primarily serves to reduce the content of relatively large pieces of stone and cloth, and recover the valuable fraction of copper-containing parts from the scrap, consisting mainly of electrical motors, transformers and electric wires. A basic evaluation of the existing purification technologies shows that there is still a lot to gain, both in terms of process costs and in terms of value recovery. Shredding the steel scrap to liberate the contaminants so that they can be separated from the scrap by magnets is a relatively expensive technique (25 €/ton of scrap) and also not fully effective. The cost of hand-sorting is lower, typically 5 €/ton of scrap, but the efficiency of contaminant removal depends strongly on the throughput. For example, for a flow of WEEE scrap of 5 tons/h a well-managed hand-sorting team can recover 90% of the copper content, but at 20 tons/h the efficiency will have dropped to less than 50%. This means that for a typical copper contents in IBA and automotive scrap of between 0.4% and 0.7% between 12 € to 17 € of copper scrap value is left in each ton of scrap, while the remaining copper presents a problem for the quality of the steel scrap itself. Other problems of hand-sorting are that the efficiency of contaminant removal is fluctuating as it is difficult to control, while some contaminants, such as stainless steel or cast aluminium, are not duly recognized

by hand-pickers. A final issue is that the legislation of some countries explicitly discourages the use of hand-pickers, promoting the use of mechanical separators.

Here Figure 1: Figure 1: Side view (left) and front view (right) of the shape-sensitive magnetic separator of Resteel.

Automatic upgrading of steel scrap

From a technical point of view an obvious alternative to hand sorting is sensor sorting. Sensor systems may be based on a single principle or a combination, and are thus able to identify contaminant particles in the scrap with a comparable or even higher precision as a human sorter. The invariable advantage is that a sensor system can replace a number of hand sorters, delivers a more consistent performance and is capable of performing quality inspection. Therefore, the use of sensors solves the problems of quality control, inconsistent product purity, contaminants that are difficult to distinguish from steel by the naked eye and legislation. However, the problem of process costs and limited capacity remain. Sensor sorting is relatively expensive and it is extremely difficult to automatically remove contaminant particles from steel scrap at high throughputs.

To solve the problems of cost and capacity the technology in Fig. 1, called clean scrap machine (CSM), was developed by Delft University of Technology⁴. It essentially eliminates steel scrap particles with a flat or longitudinal shape from the scrap stream using a shape-sensitive magnetic field. To this end a magnet is introduced into the pulley of a conveyor belt with field lines that are almost parallel to the curved part of the belt surface where the scrap particles follow different trajectories, in accordance to the difference between magnetic and centrifugal forces (Fig. 2). Flat and longitudinal steel particles (Fig. 3) are strongly attracted by such a magnetic field, even when the field intensity is relatively weak. Oppositely, more compact steel particles and non-magnetic materials, such as stones and cloth (Fig. 4) are more weakly attracted or not at all. Electrical motors, transformers, copper wires, stones, cloth, stainless, cast aluminium and rubber parts with steel inserts all belong to the latter category, and are therefore released from the belt at an early point. The flat and elongated steel pieces move with the belt and are separated from the rest of the scrap. The shape-sensitivity of the CSM magnetic field may be understood qualitatively from the following force balance for particles marginally following the belt surface at the point of separation (Fig. 2),

$$F_{\text{centrifugal}} = F_{\text{magnet}} \quad (1)$$

Here Figure 2: Figure 2: Side view of the pulley, magnet and magnetic field of the CSM technology.

Here Figure 3: Flat and longitudinal steel particles reporting to the clean scrap product.

Here Figure 4: Compact steel parts and contaminants reporting to the contaminant concentrate.

Here Figure 5: Demagnetizing factor for ferromagnetic parts of simple shapes, as a function of the ratio of the largest dimension to the smallest dimension.

Evaluating both sides of Eq. (1) for a steel particle of mass m and volume V , moving with the velocity v of the conveyor at radius R around the magnet, we get:

$$\frac{V}{D_z} H_z \left| \frac{\partial B_z}{\partial x} \right| = \frac{mv^2}{R} \quad (2)$$

In this equation H_z and $B_z = \mu_0 H_z$ are the magnetic field strength and magnetic flux density, respectively, and D_z is the demagnetizing (shape) factor of the steel part⁶. The magnetic induction of the CSM magnet at the particle position on the belt surface is $B_0 \approx 0.08$ Tesla, and its gradient is given by:

$$\left| \frac{\partial B_z}{\partial x} \right| = \frac{2B_0}{R} \quad (3)$$

This equation shows that the critical demagnetizing factor of the steel particle for which the centrifugal force just matches the magnet force is (ρ is the density of steel):

$$D_z = \frac{2B_0^2}{\mu_0 \rho v^2}, \quad \rho = m/V \quad (4)$$

Inserting the typical values $\rho = 8000 \text{ kg/m}^3$, $\mu_0 = 4\pi \cdot 10^{-7} \text{ Tesla m/A}$ and $v = 4 \text{ m/s}$, the critical value for the demagnetizing factor for a steel particle to remain attracted to the drum is about 0.09. Fig. 5 shows the demagnetizing factors for simple steel bars and flat pieces of varying dimension ratios. It is clear that approximately spherically shaped particles have a demagnetizing factor higher than 0.09, while bar-shaped and flat pieces have lower demagnetizing factors. Actual shapes of scrap particles are often more complex than bars and sheets and their motion at the point of separation depends on more factors than the magnetic-centrifugal force balance alone. Yet, low demagnetizing factors are normal for clean steel pieces in post-consumer scrap, while high demagnetizing factors are typical for magnetic contaminant parts.

Here Figure 6: Cumulative mass distribution of the measured demagnetizing factor for more than hundred clean steel particles and contaminated ferromagnetic scrap particles, randomly selected from IBA scrap.

Fig. 6 shows the statistics of the demagnetizing factor for particles from IBA scrap, indicating that 85% of the clean steel can be recovered in the clean scrap product while 90% of the copper-containing parts reports to the contaminant concentrate.

The amount of steel scrap that can be separated by CSM as a clean product (assuming 0.1% Cu metal content for the clean product) depends on the type of scrap, and varies between about 60% of the input for some automotive scrap and 85% for mid-size IBA scrap. The amount that is to be sorted by either hand picking or using sensors therefore reduces to 15% - 40% of the original input. However, since the clean scrap product contains the light and bulky flat and elongated pieces, the volume (Table 2), the belt coverage (Fig. 7) and the number of particles of the contaminant concentrate are reduced more strongly than suggested by the mass split. It is remarked that the volume, belt coverage and number of particles are critical for the throughput capacity of a sensor sorter or for hand sorting. In 2009, a Dutch upgrading plant for IBA scrap replaced its hand-sorting operation of 20 tons/h using a team of eight hand-pickers by a CSM running at 40 tons/h and a team of four hand-pickers to clean the contaminant concentrate of the CSM. In this approach the plant managed to eliminate a bottleneck and the cost of hand sorting per ton of scrap was reduced by a factor of four, while the number of contaminant parts to be hand-picked remained the same.

The wall thickness of the steel scrap is an important parameter in feeding the scrap to the smelt, both for electric arc furnaces and blast furnaces. Thick-walled, high bulk density scrap behaves differently in the smelt than thin-walled scrap and smelters therefore schedule the feeding according to wall thickness. Since the clean scrap product of the CSM consists largely of thin sheet and has a lower bulk density than the steel scrap produced from the contaminant concentrate by hand-sorting, an interesting option is to market the two scrap products separately.

Table 2: Statistics of example cases of CSM separations on post-consumer scrap.

Type of steel scrap	Clean scrap product			Contaminant concentrate		
	Mass %	Bulk density ton/m ³	Volume %	Mass %	Bulk density ton/m ³	Volume %
WEEE	73*	0.7	78	27	0.9	22
IBA	72*	0.9	85	28	2	15
ELV	75*	0.7	85	25	1.3	15

* Primary variable dependent on machine settings: range is 60% - 85%

Here Figure 7: Contaminant concentrate (a) and clean scrap product (b) for a batch of automotive scrap, spread out on a flat surface to show the improved presentation of the copper contaminant particles (the part to the right from the ruler in the Figure 7b) using hand sorting or sensor sorting.

Conclusions

There is a strong ecological drive to maximize the input of steel scrap in the production of new steel. Yet, in order to produce high quality steel the contaminant levels in post-consumer scrap must be reduced by either hand picking or by sensor sorting. At present, both of these options have a problem with cost and high throughput capacities of 20 tons/h or more. Proposed is a shape-sensitive magnetic sorting technique to remove the bulky but clean flat and rod-shaped parts from the scrap, prior to sorting out the contaminants. Results from a CSM-retrofitted Dutch processing site for IBA scrap showed an increase in capacity of the scrap treatment line from 20 tons/h to 40 tons/h and a factor four in reduction of hand sorting costs per ton scrap. A positive side effect of using shape-sensitive magnetic sorting is that two steel scrap products are produced of strongly different bulk densities, offering the possibility to optimize feeding of the clean scrap to the smelt.

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