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New Methods for Waste Minimization in an Integrated Steel Site

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Recycling of materials is of major interest in steel making for environmental reasons as well as economical. All process units produce by-products which are either recycled sold or put on landfill. The products have been selected into the categories slags, dusts and sludges.
This work evaluates new methods for recycling of by-products in an integrated steel site. The study estimates how much material can be recycled and in which order that would be the most beneficial with respect to costs, energy and deposits. Main focus has been on by-products produced in significant quantities and those difficult to use because of their physical or chemical nature.
The work show conflicting results and a pareto front was constructed comparing deposits with increased energy use and costs in the system. Chosen case studies have been tested in industrial scale and results from test periods have been used to compare modelling with process parameters. The results show that improved resource efficiency can be achieved by keeping the energy consumption constant or even receiving small energy credits. Major cost savings can be found if internal recirculation can replace raw material such as iron ore, coke and lime stone. Before the new methods will be implemented careful considerations will be made according to test results and predictions through modelling.

1. Introduction

The steel industry uses large amounts of resources as raw materials and generates considerable amounts of dusts, sludges and slags. Usually these dusts, sludges and slags contains significant amounts of valuable metals, energy carriers etc. with potential to be utilised via direct recycling or through reuse either in the steel industry or in other industries. Raw material consumption in an integrated steelworks, generally involve about 500 - 600 kg reducing agents (injection coal and coke), ca. 1,400 – 1,500 kg of iron ore pellets and 100 - 150 kg slag formers such as limestone and burnt lime for the production of one tone of produced steel slab. Figure 1 shows a schematic view of SSAB Luleå integrated steel work and its material flows including by-products.
Recycling of material within a steel plant is important for economic and environmental reasons. Costs can be reduced because of less raw material costs, decreased deposits and energy savings. By-products and wastes flows for the integrated steel plant, where dusts, scales, slags, sludges etc. are recycled from different sub-processes. As an example the larger fraction (5-55 mm) of Basic oxygen furnace slag (BOF slag) is recovered within the blast furnace (BF), while the fine fraction are used as internal construction material or goes to landfill. Fine grained scrap and dusts are processed within the briquette plant (cold agglomeration) before they are charged to the BF. Recyclable materials like desulphurisation slag, BOF iron/slag residuals and steel ladle slag (LS) are magnetically separated and distributed for different destinations. Materials that have no further use within the integrated steel plant are sold to be used in other applications. Some materials, e.g. materials with high alkali and/or zinc content, fine or wet fractions of dust, slag and sludge are put on landfill as last resort. Although methods of zinc stripping have been described Wichterle et al. (2010), no real applications have been demonstrated to be feasible so far. If higher contents of harmful elements can be allowed in the system with increased recycling, less deposit of material could be achieved.

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Process Integration (PI) and system analysis was used in the ongoing RFCS project “Efficient use of resources in steel plants through Process Integration (REFFIPLANT) to improve efficiency of resources (materials, water, energy) in integrated steelmaking. A case study with the objective to analyse possibilities for increased material efficiency was performed. Modelling and analysis were made to assess possibilities and impacts from recycling of some selected secondary materials at SSAB's steel plant in Luleå. Earlier work from REFFIPLANT has also been described by Wedholm et al. (2014) and Matino et al. (2014).

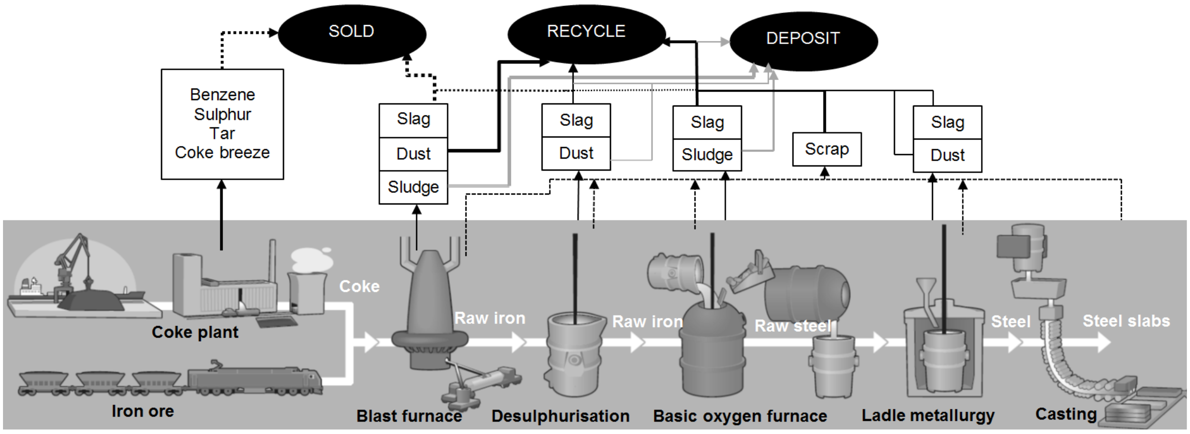


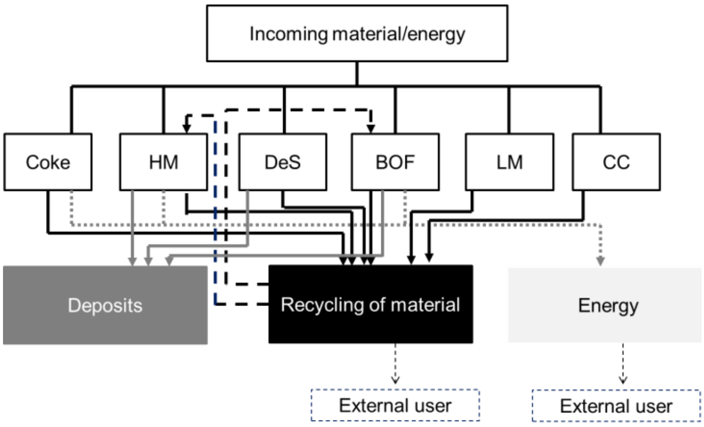
Figure 1: Schematic description of by-products and wastes flows at the SSAB EMEA in Luleå. The materials are sold, internal recycled or put on landfill

2. Material and methods

The fine grained BOF sludge of SSAB is today landfilled. As the sludge contains about 50 % Fe it would be worthwhile to use it as raw material in some process e.g. the BF. The possibility to use the BOF sludge as a raw material could be achieved if the sludge is dried and agglomerated either as pellet or briquette. Although the Zn content is rather low it could be a limitation for recycling to BF. Another material sent to landfill is steel ladle slag which could be used as slag former or as complementary binding agent in agglomerates. SSAB has no sinter plant so fine grained material as BF flue dust and fine scrap are recycled via cold bonded briquettes. The briquette plant has reached its maximum production volume but if the BF dust could be recycled via injection to the BF there would be some capacity to increase the total recycling since other material could be briquetted. These three by-product materials have been investigated in different scenarios to find most suitable combination in terms of material efficiency, energy efficiency, quality and costs. Examples of investigated and in some cases established routes for site internal recycling of materials at SSAB steel production plant in Luleå, are cold bonded briquetting or pelletizing, Sundqvist Ökvist (1999), recycling of desulphurisation scrap and BOF slag to the BF, Jansson and Sundqvist Ökvist (2004), as well as injection of BF flue dust in the BF, Robinson and Sundqvist Ökvist (2003), dust and sludge to BOF, Su et al. (2004).
The preliminary case studies involved simulation with the excel-based TOTMOD model. The method and developed model is based on the Microsoft® Office Excel spreadsheet model “Masmod” presented by Hooey et al. (2010). The developed model includes element distribution between slag and metal, and can be used for process simulation and analysis of various operating conditions as well as the influence of specific process parameters.
The optimisation method used in the modelling work for recycling of secondary materials at the SSAB steel production plant is mixed-integer linear programming (MILP) by using the Java-based software reMIND. This tool has been proved to be powerful when analysing improvements in energy and material efficiency, Larsson et al. (2006b) and economic and environmental evaluation, Larsson et al. (2006a). ReMIND has also been demonstrated in scrap based steelmaking and industrial heating systems Lingebrant et al. (2012) and Riesbeck et al. (2012). Figure 2 illustrates the structure of the developed reMIND model. The model is based on a global mass- and energy balance for the production chain and individual sub-balances for the main processes. Other mathematical modelling on integrated steel system with process integration approach has been made, Ghanbari et al. (2012) and Ghanbari and Saxén (2013).
The developed model makes it possible to perform total analysis assessing effects from changes in operations regarding the included processes. Analysis using reMIND can be made as multi-objective/multi-

criteria analysis and can be made with different time steps. A MILP problem consists of an objective function, variables and constraints. The objective function includes different variables which can be minimised or maximised depending on what is desired. Typical objectives are minimised landfill, cost, CO_2 and energy.

The developed system optimisation model was used to investigate recycling strategies for secondary materials to improve the in-plant material efficiency. The model consists of the steel production routes with the consumption of resources, generation of secondary materials and the material recycling possibilities. Optimisation is made regarding the different recycling options of dusts, sludges and slag, minimising the landfilled amounts, while constraining the energy consumption. The cplex software was used to find optimised solutions of the multi objective problems.



Abbreviations in Figure 2
Coke – reducing agent made in coke plant
HM - Hot metal made in blast furnace
DeS – desulphurisation of hot metal
BOF – basic oxygen furnace – production of liquid steel
LM – Ladle metallurgy – refining of steel
CC – Continuous casting

Figure 2: Illustration of nodes and flows in the reMIND software

3. Results

Results from 8 cases for material recirculation investigated at the SSAB Luleå plant were implemented in the superstructure of the reMIND software. Each case was implemented in the BF-node and optimised scenarios using linear solver cplex was performed. The cases implemented are shown in Table 1. In first scenarios optimisation was made on minimising deposits and energy. Constraints on deposits have been used.

Table 1: Results of the cases simulated in Excel Masmod which was implemented in the reMIND software

Cases (kg/t HM)	1. Reference	2. 50 % BOF sludge	3. 100 % BOF-sludge	4. 50 % SM-slag	5. 100 % SM-slag	6. BOF sludge, SM-slag	7. BOF sludge, SM –slag, incr. LD-slag	8. Dust injection
Pellets	1,302	1,303	1,295	1,310	1,308	1,293	1,288	1,311
Coke	323	322	322	323	323	322	322	322
PCI	131	131	131	131	131	131	131	131
LD-sludge	0	11	22	0	0	22	22	0
SM-slag	0	0	0	5	10	10	10	0
BF-dust inj.	0	0	0	0	0	0	0	11
Lime stone	18	14	10	16	14	0	0	18
BOF-slag	47	47	47	47	48	58	58	47

Case 1 to 8 was implemented in the blast furnace node. The optimisation was made to minimise energy with fixed constraints on maximum allowed deposits from the steel plant. The model allows all cases and a mix of cases for each maximum deposit. Figure 3 shows the most energy efficient mixture of cases when allowing a certain amount of deposits. On the y-axes the most energy efficient case mix under a certain deposit constraint is described. This means that from a theoretical point of view under some conditions a mix of cases would be the most energy efficient way to run the steel plant. The results show that only two cases (3 and 6) come into consideration when optimising on energy with deposit constraints. It can be seen that when allowing less and less deposits case 2 (Full BOF-sludge, Full SM slag) will increase in proportion to fulfil the requirements.

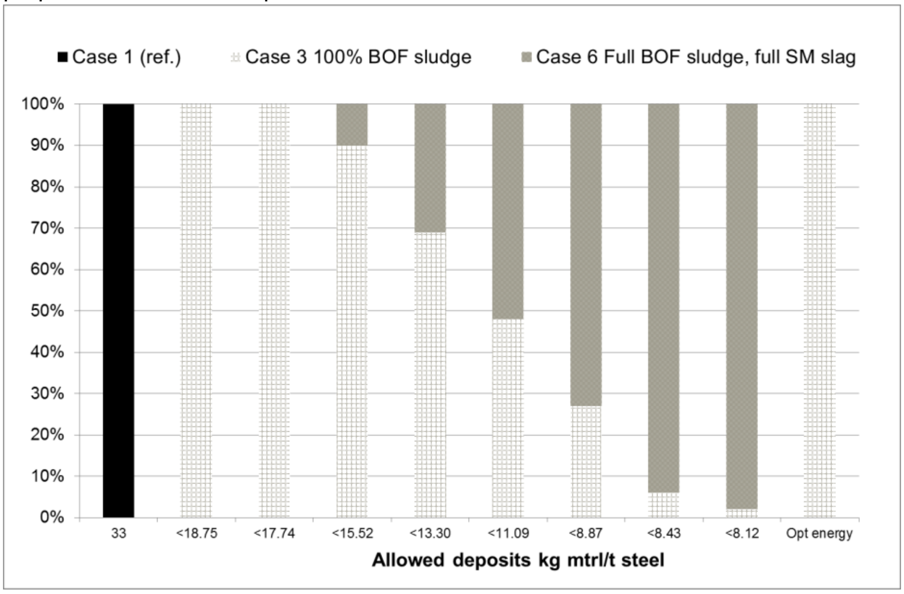


Figure 3: Mix of cases that are most efficient when minimizing energy with deposit constraints.

In Figure 4 a sequence scenario is seen when only one case at a time is allowed. The diagram shows total energy consumption (GJ/t HM) for each case. Case 3 is the most energy efficient case and uses 60 MJ/t HM or 0.33 % less energy than the reference case. Case 3 also recycle about 22 kg/t steel more material than the reference case which adds up to about 46 kt less deposit material per year.

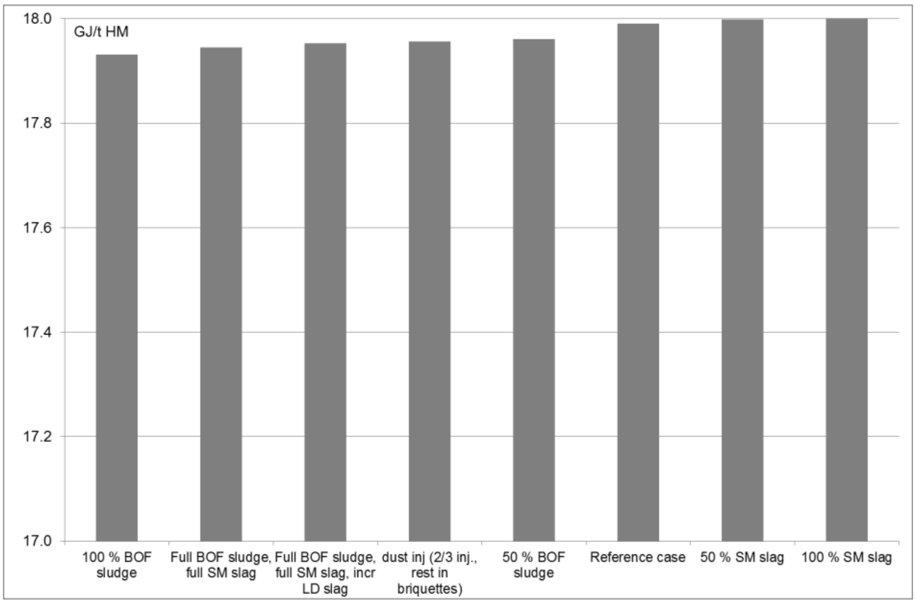


Figure 4: Total energy consumption for each case

Figure 5 shows the pareto analysis of increased deposits versus total energy consumption (GJ/t steel). It can be seen that while decreasing the deposit there is a small penalty in energy consumption in the system. This can be explained by the fact that recycled material with high iron content replaces iron ore pellets with a higher iron ore content. More slag needs to be melted and more energy has to be used. Also controlling the slag with lime stone will in some cases increase the energy consumption in the blast furnace.

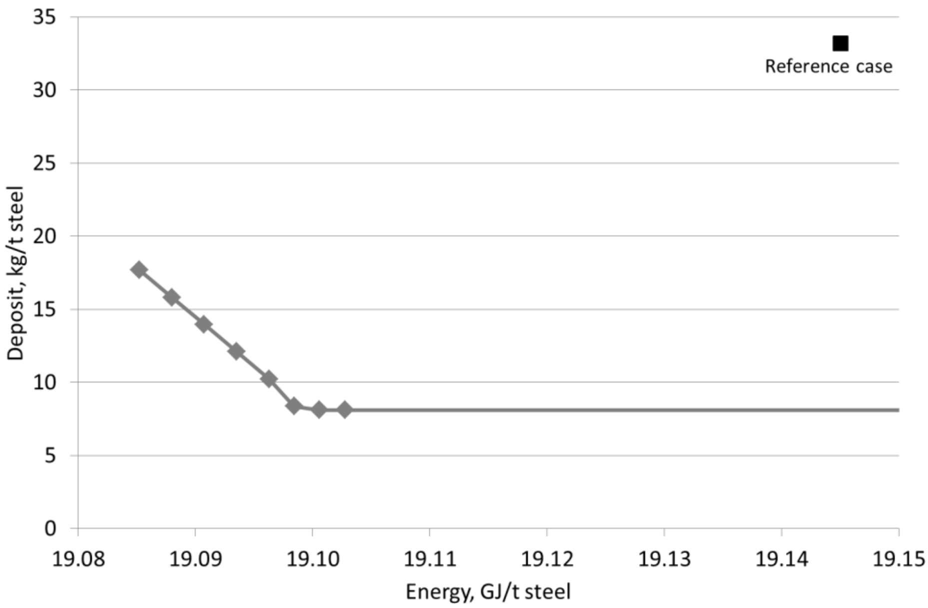


Figure 5: Pareto analysis with multi criteria objectives to minimize both energy usage and deposits

4. Discussion

Recycling material in the steel industry is common practice and dependent on the plant outline, legal restrictions and physical conditions the level of efficient material use can vary between integrated sites. The integrated steel plants of SSAB in Sweden and Finland all have briquetting plants as a mean to recycle fine material. The common practice in Europe is to use a sinter plant which in many aspects changes the conditions of material use in the blast furnace and related units. However the transferability of the results from this investigation covers the common issue of harmful elements in BOF sludge and ladle slag and the savings that can be reached due to increased material efficiency and total energy consumption. For each plant a specific investigation needs to be made with boundaries and restrictions that apply for that plant in that specific region. However conflicting results will apply when trying to minimise deposits with respect to energy consumption and quality parameters in the product. The energy change is mainly related to coke usage in the blast furnace which affects the coke plant. However what have been seen in the results the energy change is small even when recycling is improved. Recent test trials with the new material also show no particular effects on energy consumption and product quality. There is direct cost saving replacing purchased iron ore pellets with high iron content recycled material. With a weakening in iron ore prices which could be seen during 2014 and beginning of 2015 the cost benefit will decrease. Costs for deposits and future predictions of increased taxes on deposits need to be accounted for as well as changes in running costs preparing material for briquetting plant or sinter plant. Increased use of limes stone due to increased recycling material also has a penalty on material costs as well as energy carriers. The best case from the study with 100 % recirculation of BOF sludge saves about 7 kg pellets/t HM. Dependent on raw material prices yearly savings would add up to 2 million USD for iron ore and about 1 million USD in lime stone costs. This shows it is worth going into deeper investigation to recycle more BOF sludge for costs and environmental reasons. Energy savings are also likely to happen but longer industrial trials is needed to prove the feasibility. Long term trials with BOF sludge in briquettes with simultaneous injection of blast furnace dust are planned at SSAB Luleå plant during spring 2015.

5. Conclusions

The approach of using a non-linear heat- and mass balance simulating tool together with a mixed integer linear programming optimisation tool has shown to be a strong method to analyse sustainable recycling of material in an integrated steel plant. A combination to find an optimum of mixed cases when conflicts between objectives exist shows that different solutions can be found dependent on the constraints. The results show that it is possible to achieve resource efficient recycling by saving energy or maintaining the energy consumption. This is good knowledge for companies handling materials that needs to separated and used either as internal recirculation, external purchase or landfill. Major cost savings can be found if internal recirculation can replace raw material such as iron ore, coke and lime stone.

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