LATEST ENVIRONMENTAL INNOVATIONS IN IRONMAKING[1]

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Abstract

There is a constant drive to reduce the environmental impact and reduce energy costs thereby ensuring maximum energy re-use. Within the iron and steel industry the ironmaking processes are acknowledged to be the focus area when the topic of energy saving arises. A lot of attention has been applied to the ironmaking processes with regard the environment and energy saving with established technologies being in place to reach these goals. The following areas of the process are currently the focus of SVAI activity with regard the target to further improve energy saving: MEROS – process for the ultimate sinter plant gas cleaning achievements; MERIM – dry gas cleaning process for ironmaking processes; Dry slag granulation including heat recovery. This paper will present the concepts and latest status of the above technologies. The paper will review the progress to date of these development activities and thus present ideas on options for energy saving and re-use within the ironmaking system. Actual operating data will be presented where appropriate.

Key words: Environment; Reduction; Energy saving; Developments.

AS ÚLTIMAS INOVAÇÕES TECNOLÓGICAS AMBIENTAIS NA ÁREA DA REDUÇÃO

Resumo

Existe uma constante na direção de reduzir impactos ambientais e reduzir custos de energia sempre levando em conta a reutilização da energia. Dentro das siderúrgicas, o processo de redução é conhecido como área foco quando a assunto economia de energia surge. Muita atenção tem sido desprendida nos processos de redução com relação a economia de energia e o estabelecimento de tecnologias que atendam estes objetivos. A área de processo a seguir são atualmente foco da SVAI com o objetivo na melhoria da economia de energia: MEROS – processo de limpeza dos gases da sinterização; MERIM – limpeza de gases a seco nos processos de redução; Granulação de escória incluindo recuperação de energia. Este trabalho irá apresentar os conceitos e últimos status das tecnologias a cima. O trabalho irá rever o progresso atual destes desenvolvimentos e apresentar as ideias com opções na economia de energia e o reuso desta energia dentro da área de redução. Dados atuais de operação serão apresentados quando apropriado.

Palavras-chave: Meio Ambiente; Redução; Economia de energia; Desenvolvimento.

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1 INTRODUCTION

Within industry, there is a constant drive to reduce energy costs, reduce emissions and ensure maximum waste energy re-use.

First topic considered here is regarding the environmental issues. According to IPPC BAT Reference Documents for Production of Iron and Steel (2001) mainly wet technologies are mentioned as preferred topgas cleaning systems. In China a significant number of dry-type filter systems can be seen. Experiences from operators show several benefits of this technology. At first waste water and sludge management can be avoided completely. Furthermore pressure drop and temperature loss is much less than in wet-type systems. Consequently the energy output of the topgas recovery turbine (TRT) can be increased by approximately 20% to 30%. A feasibility study done together with Voestalpine Stahl Linz has shown that a greenfield installation will cost approx. 30% less than a scrubber system including waste water management and also the operational cost can be reduced significantly. Also the space demand for complete installation will be only about 40% of a comparable wet-type facility.

Second topic, the energy saving will be discussed considering the slag handling issue. Throughout the world, approximately 400 million tons of slag with a temperature of around 1,500°C are produced each year. It is generally processed to a suitable by-product without any attempt to utilize the associated lost energy which arises to approximately 1.5 GJ of energy loss per ton of slag. Another driver for process modernization is the recent focus on the reduction of CO_2 emissions from the Iron and Steelmaking plant as a whole. Dry granulation requires no subsequent drying of the product leading to a CO_2 reduction of roughly 30 kg/t compared with a similar sized wet system. The main challenge is to find a way to recover the energy from the slag by a compatible granulation process while producing a slag product that fulfils all of the quality requirements of the cement industry.

2 MERIM – DRY DEDUSTING SYSTEM

Siemens VAI developed its own bag filter technology called MERIM which stands for Maximized Emission Reduction & Energy Recovery for Ironmaking. It offers the opportunity to treat top gases coming from Ironmaking facilities like Blast Furnaces or Direct Reduction Plants (e.g. COREX®, FINEX®) on a dry basis.

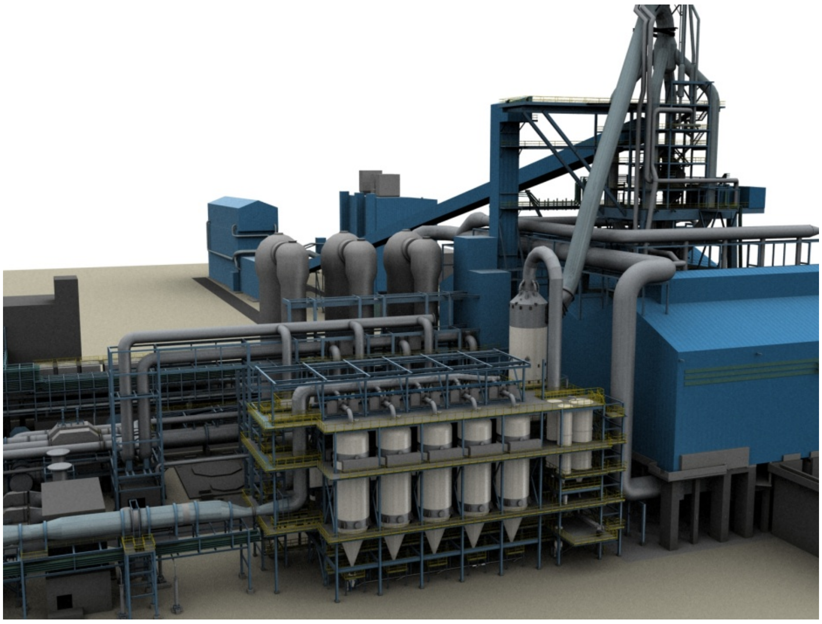

Figure 1. 3D overview of SVAI dry gas cleaning for BF top gas.

The gas cleaning process comprises two important steps: the coarse dedusting in a cyclone and the fine dedusting in a bag filter system.

The highly efficient coarse dedusting takes place in the Siemens VAI cyclone where approximately 85% of the dust is removed. The generated dust can be easily reused in the sinter plant.

Fine dedusting will be done in the newly developed bag filter system. Therefore the fine dust laden gas enters a certain number of pressure resistant filter vessels. Inside this system the dust is collected on high performing filter media which allow a dust concentration in the clean gas of less than 5 mg/Nm³. The removed dust is collected on the bottom of the filter and transported via pneumatic conveying into a storage silo system.

Regarding dust behavior, surveys have shown that this kind of separated dust contains a significant high concentration of unwanted components such as Zn, Pb and Cd. These components affect the BF process negatively; consequently a further dust recycling on the sinter plant has to be checked.

The cleaned top gas from the filter vessels is collected in a main duct which guides the gas stream directly into a top gas recovery turbine (TRT) where the high energy content of the gas is converted into electricity.

Beside the benefits also restrictions could be determined. Mainly handling of the varying top gas temperatures is a major challenge because filter bags only work properly in a temperature window of 80°C up to 250°C. Therefore SVAI and Voestalpine investigated in a top gas conditioning concept which allows shaping high and low temperature peaks.

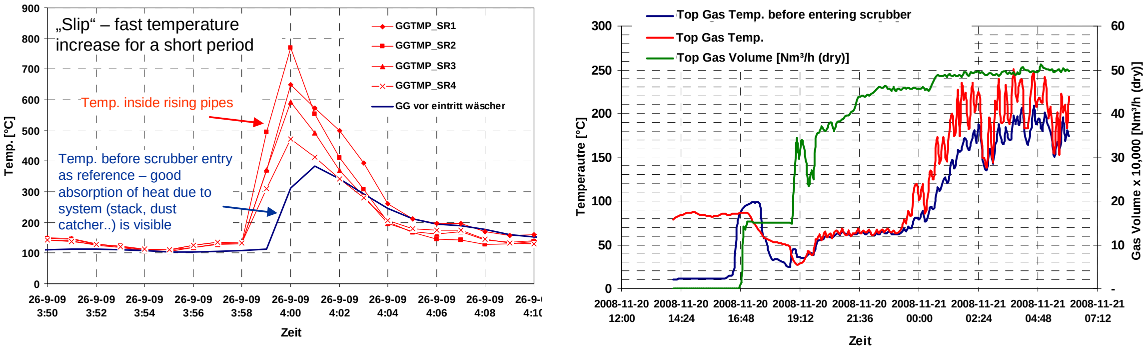

Figure 2. Top gas temperature behavior during extraordinary process situations; (left: high temperature case e.g. slips; right: low temperature case e.g. start up).

Together with POSCO Pohang a test installation has been realized to study a dry dedusting filter system for FINEX® 1.5. Hence the pilot plant was designed to treat 6,000 Nm³/h of cooled offgas of about 200°C. Especially the high dust load of about 20 g/Nm³ up to 40 g/Nm³ and the very fine particles (D(v,0.90): 20µm respectively D(v,0.5): 8 µm) are challenges for the bag filter system.

In a nut shell bag filter systems will find the way into the ironmaking top gas cleaning as state of the art technology. The mentioned significant benefits and the access to high sophisticated bag filter materials support this development. SVAI has picked up this technology to increase its Environmental Technology portfolio with another dry based gas cleaning process.

3 MEROS – DRY-TYPE SINTER OFF-GAS CLEANING PROCESS

MEROS, an acronym for Maximized Emission Reduction of Sintering, is capable of lowering dust, acid gases and harmful metallic and organic components present in the sinter off-gas to concentrations previously unattained with conventional gas-treatment techniques. Due to the high potential to reduce emissions from sinter plants, the environmental authorities in Europe are increasing their focus on emission compounds other than particulate matter, namely SO_2, dioxin/furan (PCDD/F), heavy metals and nitrogen oxides (NOx).

Depending on the local requirements and conditions, two principal desulphurization agents can be employed, either sodium bicarbonate or hydrated lime. The injection of specific desulphurization agents into the off-gas stream promotes DeSOx reactions as well as reactions with other acid gases, e.g., HCl. The relative merits and disadvantages are compared in the Table 1.

3.1 Sodium Bicarbonate (SBC)

The use of SBC is preferred when highest DeSOx degrees are required, if a DeNOx plant is necessary (or expected in future) or where land-filling costs are specifically high.

Acid neutralization with SBC involves a stage of thermal activation, i.e., when brought into contact with the hot off-gas, the sodium bicarbonate rapidly converts into sodium carbonate with a high degree of porosity and specific surface area.

Table 1. Comparison of sodium bicarbonate and hydrated lime for use as desulphurization agents

	Sodium bicarbonate (SBC)	**Hydrated lime (HL)**
DeSO$_x$ degree	> 90% (if required)*	< 90% (40 - 80%) *
Stochiometric factor	1,1 - 1,2	1,5 - 2,5
Residual amount	~ 70%	100%
Reagent costs	~ 200%	100%
Exit-gas temperature	sinter raw gas temperature (no cooling)	~ 100 °C
DeNO$_x$ (if required)	~ 70% gas for reheating to 280°C	100% gas for reheating to 280°C

** depending on additive quality, sinter gas temperature, conditioning temperature.*

3.2 Hydrated Lime (HL)

The moisturized HL particles react with all acid gas components in the sinter off-gas to form reaction products. It was verified that different HL products show major differences in efficiency for desulphurization. In addition to chemical composition and grain size, the specific inner surface of the lime is a key factor.

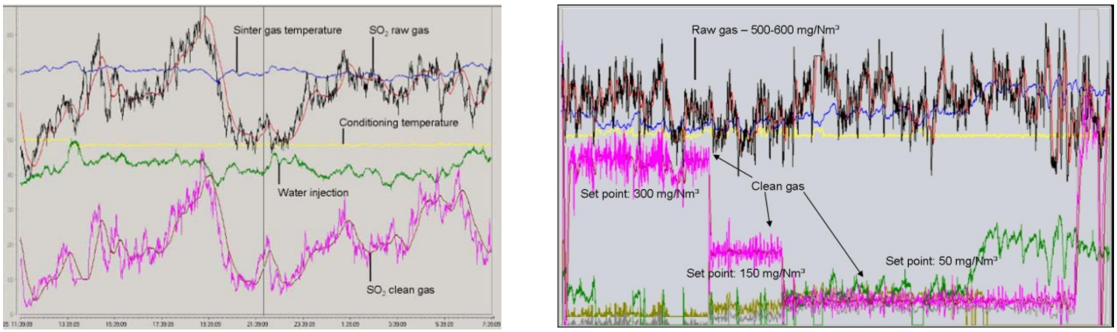

Figure 3. Typical DeSOx curve using $Ca(OH)_2$ and Typical DeSOx curve using $NaHCO_3$.

The Figure 3 shows the difference of the reaction behavior between those additives. Extremely fast kinetic reaction of SBC for DeSOx applications allows controlling the clean gas emissions by set-point operation. The disadvantage of HL is the relative slow reactivity which results in a constant DeSOx amount.

Heavy metals and compounds thereof with low vapor pressure, like mercury salts, cadmium or lead, are removed as particulates at the filter bags. Since the remaining clean gas dust content is extremely low, these parts of heavy metals easily comply with the current regulations. The gaseous portion of these pollutants and metallic mercury, which has a high vapor pressure, is removed by adsorption at lignite or activated carbon. Organic compounds such as dioxins and furans (PCDD/F) and total condensable VOCs were eliminated by more 99 percent.

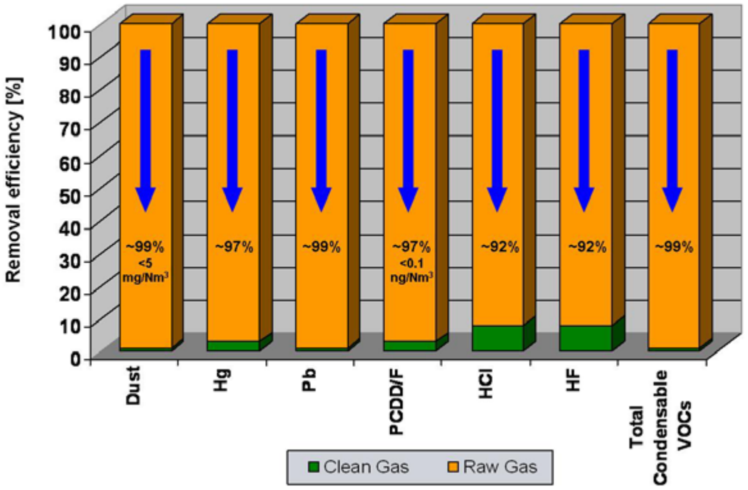

Figure 4. Removal efficiency of heavy metal, organic components, and PCDD/F.

4 DRY SLAG GRANULATION – THE ENVIRONMENTALLY FRIENDLY WAY TO MAKING CEMENT

4.1 Substitution of Cement Clinker With Slag Sand

Traditional manufacturing of cement clinker from limestone, sand, clay and other components requires a high-temperature process (around 1,450°C). It is also associated with high demand for raw materials, high input of primary energy and high specific CO_2 emissions (roughly 1 t of CO_2 per ton of clinker). The substitution of cement clinker by blast furnace slag sand is an attractive economic alternative for the cement industry, because it reduces high energy costs and considerably improves the company's CO_2 balance. Approximately 1 ton of CO_2 can be saved for each tonne of clinker substituted by slag sand because not only primary energy is saved, but also the release of the carbon dioxide chemically bound in the limestone is avoided.

4.2 Wet Granulation – Conventional Granulation Technique for the Production of Slag Sand

In this case the slag is quickly "quenched" in granulation plants using large quantities of water, producing a fine-grained, amorphous but also wet product, known as slag sand. Due to the "frozen" crystallization energy, the slag sand when ground to cement fines, form hydration products in conjunction with water (latent hydraulic behaviour). These products essentially correspond to the hydration products of Portland cement clinker, the main component of Portland cement. The key prerequisite for the use of slag sand as a binding agent in the building material industry is thus satisfied.

Therefore approximately 80% of blast furnace slag sand is used as cement additive and realises valuable revenue rather than being disposed of as land-fill.

The wet granulation process operates with a high water to slag ratio of about 8:1.

This wet process is not susceptible to any fluctuations in the quantity and properties of the slag. Furthermore the wet process has the following drawbacks:

- despite mechanical dewatering in drums, silos or heaps, a residual moisture of about 10% - 12% moisture remains in the slag sand. For the manufacturing of cement, the product therefore first has to be re-dried, with high energy expenditure. Assuming 10% residual moisture, the required drying energy amounts to around 132 kWh/t;
- for granulation with open water circuits, vapour containing sulphur can be released, and a correspondingly large amount of fresh water (about 1 m^3/t) has to be fed into the system. Granulation plants with closed water circuits and condensation systems prevent the emission of water vapour containing sulphur;
- when slag is quenched with water, the high energy potential of liquid slag is wasted to heat and evaporated water. For granulation, cold water is normally used, the circulated water has to be cooled in cooling towers, which are in some cases equipped with electrically operated fans. Finally the heat is released to the environment at a low temperature level without being used.

4.3 Dry Granulation – Alternative Technique for Producing Vitreous Blast Furnace Slag

Huge amounts of water and of drying energy can be avoided by dry dispersion and quick cooling of the liquid slag. The essential prerequisite for the introduction of an alternative dry technique is that the obtained product needs identical or even better properties compared to the slag sand produced conventionally using wet granulation. This applies in particular to the glass content (target > 95%), which is a key parameter for the reactivity and hence the quality of the slag sand.

The glass content has a direct impact on the strength of the cements and concretes. However, the required glass content can only be achieved by sudden cooling below the transformation temperature of approximately 900°C. Due to the less efficient cooling mechanism of water-free quenching, the dry process is technically more challenging than conventional water based granulation.

Obviously “dry” granulation requires no subsequent drying of the product. This leads to a CO_2 reduction of roughly 30 kg/t in comparison with wet process. Given global production of approximately 210 million t of slag sand (2007), this is equivalent to a potential CO_2 reduction of over 6.3 million t per year.

4.4 The Original R&D Focus by SVAI (Formerly Davy – Kvaerner)

The original focus of the dry granulation process on blast furnace slag showed that it is capable of producing a cement grade product in a more environmentally friendly way. In addition, the cement companies can make significant savings, since no drying is required at the grinding plant.

With environmental considerations becoming ever more important and even becoming enshrined in legislation, there was clearly a need for a major improvement in slag handling. The development of dry granulation was aimed at satisfying this need. Initially, blast furnace slag treatment was seen as the chief market for the new dry process, so it was essential that a cement grade granulate with more than 95% glassy slag content could be produced. Early tests using a simple pilot plant showed that this was achievable and work began to determine the design parameters of a dry slag granulator.

4.5 The Concept

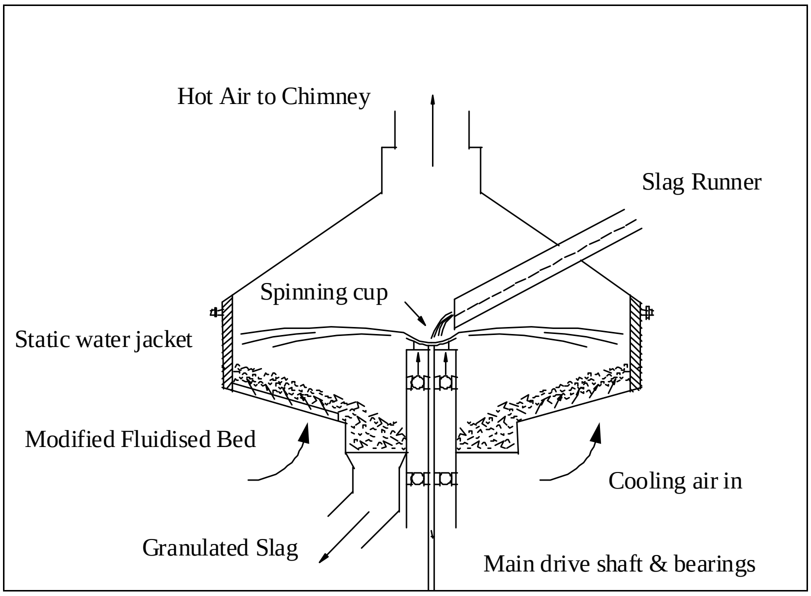

Figure 5. Dry Granulation Concept.

Dry slag granulation is based on molten slag atomisation using a variable speed rotating cup or dish (Figure 5). The slag is delivered on to the centre of the cup from a slag runner via a vertical refractory lined pipe. The rotation of the cup forces the slag outwards to the cup lip where it is atomised. The resulting slag droplets cool in their flight towards the water jacketed chamber wall. On impact with the wall, the droplets are sufficiently solid to ensure they do not stick to the wall. This characteristic is further enhanced by the presence of the water jacket.

The solidifying granules fall into a mobile bed of granules that is designed to ensure that there is no agglomeration. The bed is kept in motion by the design of the cooling air distributor that imparts a circumferential motion to particles.

The cooling particles fall into a discharge trough that forms an inner annulus. Some are recycled to intercept the solidifying particles in flight from the cup to assist in their cooling. The remainders are further cooled as they are blown towards discharge ports and thence on to conveyors for transport to storage.

Some particles are lifted out of the cooling bed and scour the chamber walls, further reducing the possibility of solidifying droplets, in flight from the cup, sticking on the walls. Any carryover of particles in the cooling air is minimised by flow straighteners in the upper levels of the chamber that are designed to reduce velocities in this region. The air is finally discharged via a stack or stacks. For blast furnace slag applications, slag wool arresters and collectors are included.

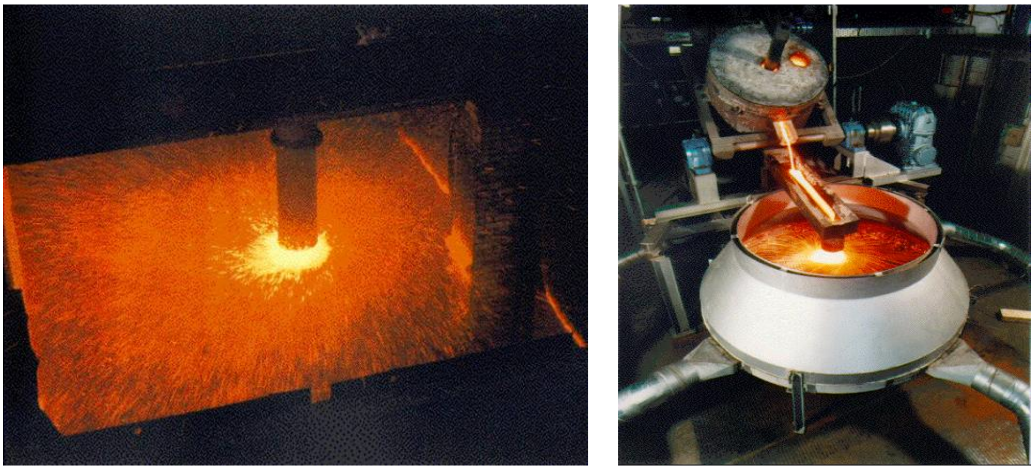

Figure 6. Granulator in operation at Redcar / Mini Granulator.

SiemensVAI UK, over the years, have spent a great deal of time and effort to prove that the Dry Slag Granulation process offers a viable solution for the treatment of Blast Furnace slag including installation of a full scale rotating cup unit on Tata Steel, Redcar No.1 Blast Furnace (furnace iron capacity in excess of 10,000 ton per day. Figure 6 shows pilot plant built in the 1990's at the company's R&D facility in Stockton.
The resulting granules were extensively tested for the following characteristics:

- block strength test (checks made by the Appleby Group in the UK to check for the viability of replacing Ordinary Portland Cement);
- mineralogical inspection (checks made by Corus Technical to check for the "glassy" content of the slag);
- grindability (tests made by Loesche of Germany and the Appleby Group in the UK).

4.6 Chemical and Mechanical Properties

Blast furnace slag is considered unfriendly when fresh because it gives off sulphur dioxide, and in the presence of water Hydrogen Sulphide (rotten egg smell) and Sulphuric acid are generated. These are at least a nuisance and at worst potentially dangerous. Fortunately the material stabilises rapidly when cooled, and the potential for obnoxious leachate diminishes very rapidly after the 'first flush'. However, the generation of sulphuric acid causes considerable corrosion damage in the vicinity of Blast Furnaces. The dry granulation process eliminates H_2S and significantly reduces sulphur emissions, furthermore the leachability of sulphur and other compounds is also reduced due to the glassy nature of the product.
The product quality is as follows:
+95% Glass
Loss on Ignition < 0.1%Average particle size is 1 to 3 mm. This is dependent on cup speed and slag properties.
A typical size analysis is given below:

Sieve sizes & % passing

mm			Microns					
4.74	2.36	1.18	600	425	300	150	75	45
100	85	46	7	4	2	1	0.3	0.2

Figure 7. Dry granulated slag/ Wet granulated slag.

In addition, since slag granulate is to be used as feedstock for the cement industry, the following parameters are also important:
Grinding time to achieve 424 m^2/kg = 105 min (Using ball mill).

Table 2. Comparison of Strength for Ordinary Portland Cement(OPC) and Dry Granulated Slag(DSG).

Curing Time (Days)	Block Crushing Strength (N/mm^3)	
	100% OPC*	50% OPC / 50% DSG
1	14.9	3.5
3	28.0	9.4
7	39.3	14.7
28	49.2	36.4
90	50.1	51.1
Notes	OPC – Ordinary Portland Cement DSG – Dry Granulated Slag	

4.7 Current Designs

There are two methods in which slag can be fed to any slag granulation plant. The first involves a granulator which is located close to the furnace and enables the slag to be delivered to the plant direct from the slag runner. The second is a system remote from the furnace involving the transfer of slag via slag pots and pouring the slag into a granulator via a ladle tilter.

Granulation of slag running directly from a blast furnace is technically more challenging than slag pot delivery of slag where, in principle, the slag flow rate can be regulated. Consequently, there are two basic granulator formats, one for blast furnace slag with direct runner slag delivery and the other, a less complex design for any .

4.8 Heat Recovery Developments

Several systems capable of utilising the energy in hot air delivered from the granulator have been considered. The major complication is the intermittent availability of molten slag.

The temperature of air leaving the granulator is estimated at 400°C. By tuning the cooling air distribution this could be increased significantly, perhaps to 650°C. The hot air could be used for direct heating or drying or for steam raising, in which case an accumulator would be necessary to even out the steam flow. Recovery systems are applicable to both blast furnace slag granulators and to slag pot systems.

The crucial advantage of dry granulation, however, is the additional heat recovery. Depending on the plant setup the energy can be used directly for preheating or heating purposes (Figure 8), or for the production of process steam and/or electricity (Figure 9).

An energy potential of more than 20 MWth or alternatively a power generation of about 6 MWel was calculated for a slag mass flow rate of 1 t/min - which is the average slag flow for a blast furnace with an annual production of 1,7 Million tonnes and a slag rate of 30%.

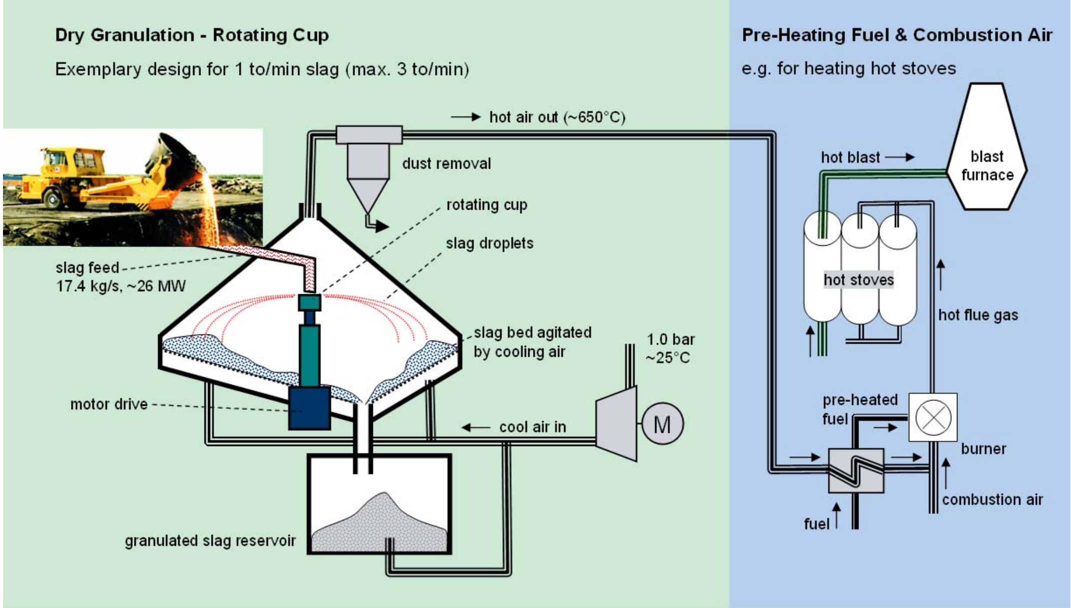

Figure 8. Dry slag granulation with pre-heating – for a slag mass flow rate of 1t/min a pre heating energy potential of > 20MWtherm was calculated.

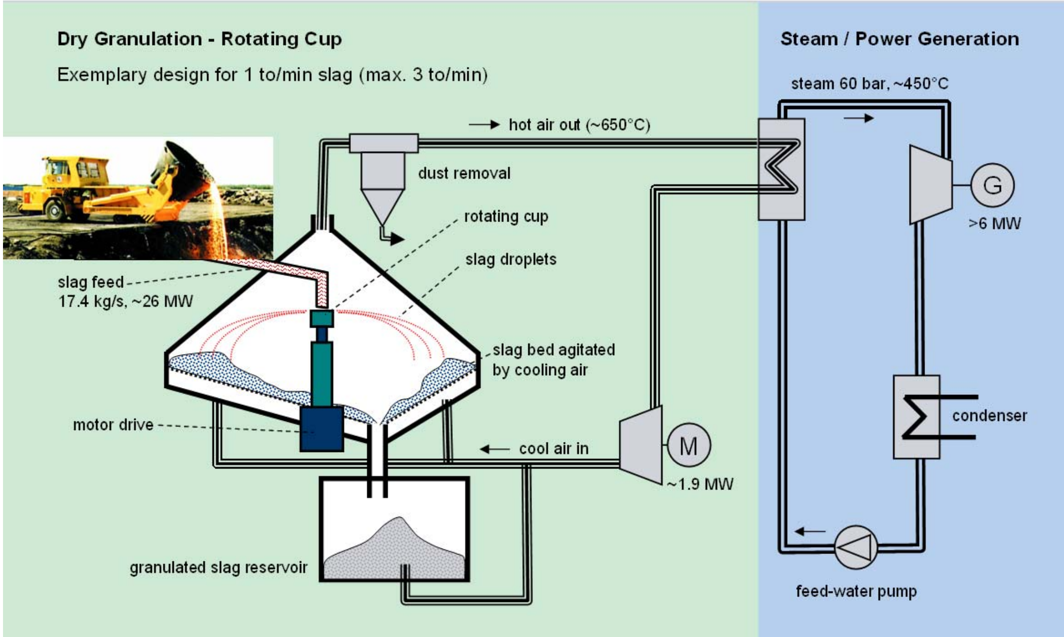

Figure 9. Dry slag granulation with steam / power generation – In case of power generation a potential of ~ 6MWel was calculated for a slag mass flow rate of 1t/min.

5 CONCLUSION

The current technology was developed with the meaning of reduce the environmental impact and reduce energy costs thereby ensuring maximum energy re-use. The main goal was achieved but maturity of the technologies will improve some point still under development. The main advantage of all the technologies descried are the pontencial lower capital cost than an equivalent wet system, potentially lower operating and maintenance costs than an equivalent wet system, elimination of water systems, no ground water contamination, no downstream drying costs or de-watering system.

Some main advantage specific for the dry slag system are:

- high grade granulate that is suitable for use in the cement industry;
- handle able product;
- no steam emissions and associated visibility, environmental and corrosion problems;
- significantly lower sulphur emissions;
- no requirement for highly skilled operators;
- heat recovery is possible due to the prolonged higher process temperature;
- the unit can handle the full slag flow rate direct from a Blast Furnace;
- simple cooling system that gives a granulate that can be removed using conventional equipment.