IMPROVEMENT OF ENVIRONMENTAL PERFORMANCE OF INTEGRATED STEEL SECTOR THROUGH PROCESS INTEGRATION & OPTIMISATION MEASURES AND INNOVATIVE WASTE MANAGEMENT PRACTICES

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Abstract

The metallurgical and mineral processing industries are always known to be major contributors to environmental pollution. Amongst them, the iron & steel sector finds predominance simply because of the significant volume of effluents, emissions and solid wastes generated from the various process streams. Over the last decade efforts have been made to reduce environmental pollution from the integrated steel sector through various process integration and optimisation measures as well as cleaner technology development. In addition, a large number of innovations in waste management have resulted in implementation of integrated waste management plans in the steel sector as well as development of many value-added products. This paper takes an overview of some of these developments that have contributed significantly to improved environmental performance of the integrated steel sector in India.

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Introduction

Some historians believe that the 1990s will be remembered as the "Decade of the Environment". Stepping into the new millennium, the new decade may probably be called the "Decade of low waste processing". Wasteless chemical processing is always a relative term and it will never be possible to do away with all waste streams from a process. Hence during the next decades, the process designers will focus mainly on *low waste processing* in which effluents and emissions are kept to a minimum so that the self-purifying nature of our environment could be sufficient to prevent irreversible ecological damages.

The metallurgical and mineral processing industries are always known to be major contributors to environmental pollution. Amongst them, the iron & steel sector finds predominance simply because the significant volume of effluents, emissions and solid wastes generated from the various process streams. Over the last decade efforts have been made to reduce environmental pollution from the integrated steel sector through various process integration and optimisation measures as well as cleaner technology development. Some of the measures include heat recovery from sintering and sinter cooling; development of new sintering process options such as top layer sintering, emission optimised sintering & deep bed sintering; incorporation of sectional waste gas recirculation process in the sinter plant; implementation of coke dry quenching technology etc.

In today's context, waste minimization should be viewed as an investment in any company's future. It begins with a concept as simple as "Wastes – if you don't produce it, you won't have to dispose it". At first the statement may seem oversimplified. However, with a close look many have found that very often this simple principle can be applied. Waste minimization need neither be an expensive proposition nor involve high technology. It is the application of basic principles of science and technology with a bit of innovation.

This paper takes a critical look at the benefits of some of the process integration and optimisation measures on reduction in emissions from integrated steel plants. An overview has also been presented about various innovative waste management practices implemented in the integrated steel sector. The paper also summarises the development of a value-added product carried out at NML from steel plant wastes.

Process Integration & Optimisation Measures in Steel Sector

Process integration is a systematic approach for the optimisation of industrial processes for its ability to reduce energy consumption by 10-30%, reduce greenhouse gas (GHG) emissions, reduce water usage and effluent production, increase profitability and increase production capacity at minimum capital cost. Even the most mature and efficient industrial processes may consume between 10 and 20% more energy than necessary. Process Integration (PI) is a powerful analytical method for identifying and selecting concrete technical solutions to correct these inefficiencies and provide an optimum manufacturing solution. This approach is broadly applicable to a wide variety of

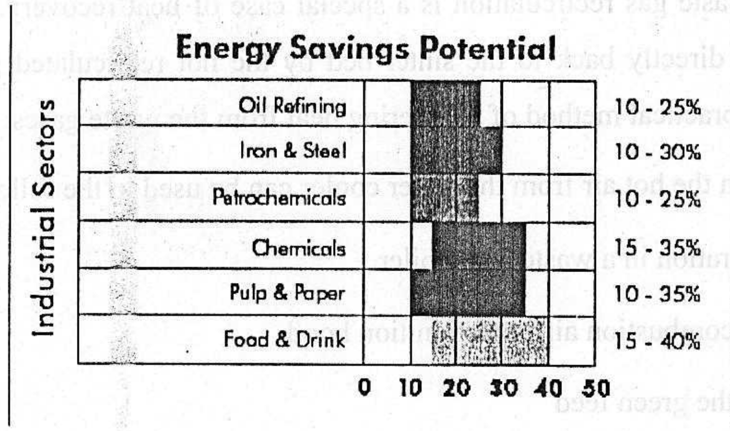

Fig. 1. Potential for reduction of energy consumption through PI techniques

industrial processes (**Figure 1**) and takes into account the characteristics specific to each plant, balancing production, economic or environmental constraints, product quality and controllability [CANMET ETC – Varennes, 2003].

During a PI study, a comprehensive analysis of complex industrial processes or sites is performed to identify projects and strategies that will ensure that the resources required by the industrial activity are used in an optimal way. By taking into account all elements of a process or plant and their interactions, the consumption of energy, water, raw materials as well as operating costs, GHG emissions and other environmental impacts are reduced. PI therefore goes much further than traditional audits, which generally optimise an industrial process by considering each of its individual unit operation separately. A few examples of process integration and optimisation measures that may help in reduction in energy consumption and improvement in the environmental performance of integrated steel sector are summarised below.

Process Integration & Optimisation in Sintering

(a) Heat Recovery from Sintering and Sinter Cooling

This process integration measure is very much required for sinter plants in India as the specific energy consumption and CO_2 emission are both higher by about 60%. Two kinds of potentially reusable waste energy are discharged from the sinter plants : the sensible heat from the main exhaust gas from the sintering machines, and the sensible heat of the cooling air from the sinter cooler [EC BAT Document – Sinter Plants, 1999; LCA Report, 2003].

The sensible heat from the exhaust gases in the stack may be used by means of a heat exchanger. Waste gas recirculation is a special case of heat recovery. The sensible heat is transferred directly back to the sinter bed by the hot recirculated gases. This is currently the only practical method of recovering heat from the waste gases.

The sensible heat in the hot air from the sinter cooler can be used in the following ways:

(1) Steam generation in a waste heat boiler

(2) Preheating combustion air in the ignition hood

(3) Preheating the green feed

The amount of waste heat recovered can be influenced by the design of the sinter plant and the heat recovery system.

Energy Saving Options

1. Waste heat recovery with conventional as well as emission optimised sintering (EOS): The sensible heat of the sinter cooling hot gas is used for producing steam in a waste heat boiler and for preheating the combustion air in the ignition hoods. Reported energy recovery amounts to 18% of the total energy input for the waste heat boiler and ~2% of total energy input for recirculation to the ignition hoods.

2. Sinter cooler and waste gas heat recovery with sectional waste gas recirculation: This option is used at the Sumitomo Heavy Industries Kokura No. 3 sinter plant. Before recirculation, the waste gases from sinter strand and sinter cooler are led through a waste heat boiler. Energy recovery reported in this case is ~23%. The system produces 120 kg steam/t sinter at a temperature of 273°C and a pressure of 9 bar.

3. "Strand cooling" and waste heat recovery with partial waste gas recirculation: This innovation was implemented at the Wakayama No. 4 sinter plant at the Sumitomo Heavy Industries and in this case the sinter cooler is integrated into the sinter strand ("strand cooling"). At this plant, waste gases from both the sintering and the cooling zone on the grate are led through waste heat boilers and subsequently recirculated to the strand. Recovered heat amounts to 30% of the input heat. The system produces 120 kg steam/t sinter at a temperature of 375°C and a pressure of 25 bar.

It can be applied both at new and existing plants. However, investment cost is lower in a new plant as detailed planning can be done from the conceptual stage. The system reduces energy consumption and in some cases also emission of dust, due to pre-installed coarse dust separators. Capital cost will be site specific but application of waste heat recovery reduces operational cost.

In Bhilai Steel Plant (BSP), the Sinter Plant III has most of the desirable features of a modern sinter plant. The hot gases from sinter cooler are fed to ignition hood as well as pre- and post-combustion hood areas for improved heat recovery. This has resulted in an energy consumption rate of 71 MJ/t sinter. The sinter bed height used is 600 mm and lime consumption is ~20 kg/t. In the Sinter Plant II of BSP, the energy consumption has been reduced by 15% through installation of E-plates and special dampers in the vacuum chambers below the ignition hood area.

(b) Emission Optimised Sintering (EOS)

The EOS process was developed by Lurgi and has been demonstrated at the Hoogovens Ijmuiden plant in the Netherlands. In this process it was shown that recycling part of the waste gas from sinter strand can significantly reduce the quantity of waste gas for end-of-pipe treatment, limit emission of pollutants at source and decrease solid fuel consumption. The concept is to recycle a part of the mixed waste gas from the whole strand back to the entire surface of the strand. The recycling rate of the sintering waste gas is of the order of 40-45%, corresponding to a 14-15% oxygen concentration in the waste gas/air mixture in the hood and resulting in a 45-50% decrease in waste gas flow emitted to the atmosphere. The waste gas is de-dusted in a cyclone before recycling. Under these conditions, strand productivity remains unchanged and coke breeze consumption is reduced by 10-15% compared with the conventional practice. Overall the sinter quality remains unchanged. The use of "EOS Sinter" in the blast furnace does not show any adverse effect up to 50% sinter in the total charge [EC BAT Document – Sinter Plants, 1999; LCA Report, 2003].

The use of EOS reduces waste gas flow and thus mass emissions of particulate matters and polychlorinated dibenzo-p-dioxins and furans (PCDD/F). Since the gas volume is reduced, cost of pollution control equipment as well as operational cost is also reduced. The benefits of EOS achieved in a plant producing high basicity sinter (>1.7 CaO/SiO_2) is presented in Table – 1 [LCA Report, 2003].

EOS allows coke breeze consumption to be reduced by about 20% (Typically from 60 kg/t to 48 kg/t sinter). The exact level of reduction will depend on the existing level of coke breeze consumption. However, the application of EOS requires the installation of extra suction fans. This will result in an additional installed electric capacity of 200-400 kW, amounting to an energy consumption increase of 0.003-0.008 GJ/t sinter, which is low compared to the overall potential savings.

The process can be applied both at new and existing plants. Special attention must be given to CO in recirculated waste gas in order to prevent carbon monoxide poisoning of the employees working in the shop-floor area. The system is designed such that, in case of failure, it automatically switches to conventional sintering mode.

Economics : The typical pay-back period is 7-8 years for a sinter plant with a waste gas flow of ~1.2 MNm^3/hour. This would vary from plant to plant.

Table – 1

Emission Reduction Resulting from Implementation of Emission Optimised Sintering (EOS) in Production of High Basicity Sinter

Serial No.	Parameter	Emission Reduction (mass %)
1.	Waste gas flow	40-50
2.	Particulate matter	60
3.	Carbon Monoxide (CO)	50
4.	SO_2	15-20
5.	NO_x	30-45
6.	Hydrocarbons (C_xH_y)	50
7.	PCDD/F	65

(c) Sectional Waste Gas Recirculation

The concept of selective recycling technology is based on local suction of the sintering waste gas under the strand and its local recycling above the sinter bed. This selective suction and recycling is the main difference between this process and the EOS process. In this procedure the O_2 concentration of the recycled waste gas remains high (19%) and the moisture low (~3.5%). A recycling rate of 25% is achieved without negative impact on the sinter quality (the RDI remains practically constant and shatter index increases by 0.5%). A solid fuel saving of 6% is also reported [EC BAT Document – Sinter Plants, 1999; LCA Report, 2003].

There are two advantages for this system compared to conventional sintering :

(1) The unused oxygen in the waste gas can be used effectively by recirculation.

(2) The waste gas from the different sections can be treated separately depending on the composition of the gas. Thus, investment and operational costs of waste gas treatment facilities can be significantly reduced compared to conventional sintering as well as the EOS system. **Table – 2** compares emissions before and after application of sectional waste gas recirculation [LCA Report, 2003].

Table – 2

Improvement Analysis of Sectional Waste Gas Recirculation in Sinter Plant

Characteristics/ Component	Unit	Conventional Sinter Plant (With desulphurisation)	Sectional Waste Gas Recirculation	Improvement
Waste gas flow	Nm^3/h	925000	665000	28%
Particulate matter	mg/Nm^3	50	30	56% by mass
SO_x	mg/Nm^3	26	14	63% by mass
NO_x	mg/Nm^3	408	559	3% by mass
Net energy consumption	GJ/t sinter	1.662	1.570	6%

The process can be applied at both new and existing plants. Investment costs are lower for a new plant. Installing additional fan results in more electricity consumption. However, this increased energy demand is negligible compared to the decreased coke breeze consumption.

(d) Process Optimisation for Minimization of PCDD/F Emissions

Extensive research into formation of polychlorinated dibenzo-p-dioxins and furans (PCDD/F) in the sintering process has shown that PCDD/F are formed within the sinter bed itself, probably just ahead of the flame front as the hot gases are drawn through the bed. It has been shown that disruptions to flame front propagation i.e. non-steady state operations result in higher PCDD/F emissions. The solution, therefore, is to operate the sintering process in as consistent a manner as possible in terms of strand speed, bed composition (particularly consistent blending of revert materials for minimisation of chloride input) and bed height. The use of additions such as burnt lime, control of oil in mill scale to <1% and minimization of air ingress as far as possible should also be followed. The above steps would ensure improvements in operational performance such as productivity and sinter quality [EC BAT Document – Sinter Plant, 1999; LCA Report, 2003].

No specific measure could be identified that enables to achieve the relatively low PCDD/F emission levels, rather it seems to be a combination of a number of measures as mentioned above. The measures can be applied to both existing and new plants. Energy usage is minimised by consistency of operation. PCDD/F monitoring has not been initiated in India as the analysis method is highly sophisticated.

Economics : There are no installation costs and there are operational benefits from consistency of operations.

Process Integration & Optimisation in Coke Making

Coke Dry Quenching (CDQ)

Based on a Swiss patent, the CDQ process was originally developed in the former Soviet Union in the beginning of 1960s and underwent further systematic development from around 1973 onwards. In India, only Vishakhapatnam Steel Plant has the CDQ plant installed in their coke ovens. The carbonised coke initially passes from the battery directly or via a container to the cooling unit where the coke is emptied downwards through an aperture into the shaft. As the coke column descends at a constant rate it emits its sensible heat into a largely inert and counter-flowing gas. The cooled coke (cooled to 180^{o}-$200^{o}C$) is discharged at the bottom of the shaft by way of sluices and conveyed away by suitable equipment. The gas, which is recycled by a blower, has a temperature of 750^{o} – $800^{o}C$ and is relieved of the absorbed heat in a downstream waste heat boiler used for steam generation [~0.5 t steam (480°C, 60 bar)/t coke]. The gas is then fed back to the cooling shaft. Coarse and fine dust precipitators ensure that the boiler and the blower are protected against entrained coke dust. During the process, the inert gas gets enriched with carbon monoxide and other compounds. The excess gas is treated in de-dusting devices, preferably in a bag filter thereby reducing the dust content to <5 mg/Nm^3. It is subsequently fed to the heating gas. The flow of the excess gas is around 50 Nm^3/t coke. CDQ can be applied to new as well as existing plants [LCA Report – VSP, 2002, EC BAT Document – Coke Oven Plants, 1999].

However, in most cases plants operating CDQ facilities also has a wet quenching facility and around the world, the CDQ utilisation rate varies from 50% to 85%. The best utilisation factor is reported by Raahe Steel in Europe (99.9%). In India the Vishakhapatnam Steel Plant has implemented the CDQ facility. Overall the CDQ process has low uncertainty and high reliability [Michels, 2000]. The process needs extra large area for which their retro-fitting in the existing battery-layout has to be examined.

Emission Reduction

As compared to wet quenching, CDQ has the advantages of energy recovery (~1.5 GJ/t coke) and better environmental performance (reduced emission of dust, carbon monoxide and hydrogen sulphide). Preliminary calculations indicate that by using CDQ process, the CO_2 emission can be reduced in the range of 100-125 kg/t coke.

Economic Aspects

The economic aspect is very crucial in the operation of CDQ facilities. It is not economical in the EU countries due to the energy price structure. Hence they are used only in a few plants. In Japan, energy is significantly more expensive. Hence CDQ is considered an energy production unit in Japan and is widely applied. A detailed techno-economic evaluation of CDQ in needed in current Indian context. The investment amounts to 140 Euro/tcs and additional operation & maintenance cost is around 0.5 Euro/tcs. It is expected that the maximum penetration of the technology would be around 2010 [Michels, 2000].

Process Integration & Optimisation in Ironmaking

(a) Energy Recovery from Blast Furnace Gas

A typical blast furnace produces approximately 1200 – 2000 Nm^3 of gas per ton of pig iron. The BF gas consists of 20-28% CO and 1-5% H_2. Carbon monoxide and hydrogen represent a potential energy source and this energy is recovered in most cases. This top gas is cleaned and stored for subsequent use as a fuel. Because of low calorific value of this fuel (2.7 – 4.0 MJ/Nm^3), it is often mixed with coke oven gas and used. Total energy export from blast furnace is approximately 5 GJ/t pig iron, which equals 30% of the gross energy consumption in the blast furnace. The process is applicable in both new and existing plants [EC BAT Document – Blast Furnaces, 1999].

(b) Energy Recovery from High Top Pressure Blast Furnaces

High top pressure blast furnaces provide an ideal opportunity for recovering energy from the large volumes of pressurised top gas which they generate. Energy is recovered by means of an expansion turbine, which is installed after the top gas cleaning device [EC BAT Document – Blast Furnaces, 1999].

Energy Savings

The amount of energy that can be recovered from the top gas pressure depends on the top gas volume, the pressure gradient and the admission temperature. It is viable if the BF gas cleaning device and the distribution network has a low pressure drop. The electricity generated may be as high as 15 MW in a modern blast furnace with a top gas pressure of 2-2.5 bar. Energy savings are estimated at up to 0.4 GJ/t pig iron for a 15 MW turbine. The savings amounts to 2% of the gross BF energy demand. The process can be applied for both new and existing plants. At new plants, incorporation of top gas recovery turbine (TRT) is relatively easy and the BF gas cleaning facility as well as TRT can be adapted to each other in order to achieve high efficiency of both scrubbing and energy recovery. Axial turbines are preferred over radial turbines. The possibilities for implementation are being examined at BF-7 in Bhilai Steel Plant.

Economics

The main drive to install a top gas pressure recovery turbine is the economic benefits. Profitability of the turbine increases with increasing volume and pressure gradient of the top gas and with increasing energy costs. In a modern blast furnace, a pay-back period of less than three years is possible, but, depending on local circumstances and top gas pressure it can be more than 10 years.

Innovative Waste Management Practices

The steel industry consumes large quantities of raw materials, resources and energy for producing steel, and in the process of conversion generates substantial quantities of solid wastes. Some of these wastes such as dusts and sludges generated from pollution control equipment come under hazardous wastes. Earlier most of the wastes were dumped in open low lying areas as there was sufficient land availability and less concern for environment. Unplanned dumping had affected ground water quality and altered top soil characteristics. However, with time the concern for environment as well as regulatory pressure have increased resulting in much greater utilisation of industrial wastes. In addition, industries have realised that waste utilisation makes substantial business sense and improves the bottom line of the company. In some countries, the solid waste generation has been brought down to well below 200 kg/tcs and recycling rates have reached 95-97%. In the Indian steel sector the quantum can be as high as 1000 kg/tcs and the recycling rate varies in the range of 40-70%. In this section, the general practices for waste utilisation in Indian steel plants have been summarised and the various areas for improvement have been highlighted.

Environmental legislation and regulations as well as the economics of disposal are directing the steel industry to look for ways of minimising the generation of wastes and to maximise the recycling of collected materials. Table - 3 presents the data on extent of utilisation of solid wastes in the Indian integrated steel sector [Mukherjee & Chakraborty, 1999; Basu et al, 2002].

The data presented in Table 3 indicates that significant scope remains for increase in the utilisation of BF slag, SMS slag, BF sludge and SMS sludge. Scope also exists in some of the steel plants for increase in the utilisation of BF and SMS sludge. A scheme for recycling of BF sludge has been recently commissioned in BSP.

BF Slag

BF slag forms the greatest portion of steel works wastes and its principal constituents are silica, alumina, lime and magnesia. Initially, the BF slag was primarily used as a substitute for existing road construction materials such as ballast, but with rapid progress in the development of applications for cement materials, the production has rapidly shifted to granulated slag from conventional air cooled slag. As shown in **Table 3**, the level of utilisation in India ranges from 60-80%. Granulated blast furnace slag containing ~ 90% glassy matter is used in cement making. Cement manufacturers have used up to 60% slag in blended cement without any serious deterioration in the cement properties and, utilisation level is restricted by the cost of slag and its availability. Required directives from government agencies are also absent in many instances for wide spread use of blended cement containing higher percentage of slag. Other established ways of using BF slag are:

- For road making
- BF slag as aggregate in concrete
- Slag as a filter medium
- For manufacture of slag wool
- For making soil conditioner

Table 3

Utilization of Solid Wastes in Indian Steel Plants (%)

Type of wastes	Tata Steel (2000-01)	SAIL (2001-02)	VSP (2001-2002)	World Bench Mark
BF Slag	79	87	82	100
SMS Slag	50	67	47	100
Mill Scale	100	100	100	100
BF Sludge	68	NA	100	97
SMS Sludge	98	100*	100	97

(*) LD Sludge

Steel Making Slag

Steelmaking slag is one of the ferruginous wastes generated in steel industry and has high fluxing capacity due to the presence of useful components such as CaO and MgO, with high basicity of nearly 3. It also contains Fe and MnO which are useful for iron making. Recycling of the BOF slag to the blast furnace or sinter plant enables the iron and steel industry to make savings of iron ore and flux materials. The maximum quantity of slag reclaimed is determined by the basicity of the BF slag or the phosphorus content of the pig iron. The use of BOF slag in Indian steel plant lies in the range of 35-50%. Steel slag has several possible applications such as in the building sector, civil & marine engineering, road building, cement industry and in agriculture as soil conditioner. One of the major problems of using BOF slag in cement making is their low glassy content. Efforts should be directed towards increasing the glassy matter content through appropriate cooling arrangements. At Tata Steel, a project has been initiated in collaboration with Lafarge India to make use of LD slag in cement making. LD slag up to 25% has been successfully used without any deterioration of cement quality. Use of BOF slag as a substitute for natural materials such as limestone saves a large amount of energy in cement making and reduces CO_2 emissions to the atmosphere. In most of the engineering applications, the prerequisite is that the slag should be stable and should not swell. The basic problem with BOF slag is the free lime content, which swells under wet conditions. The problem of free lime can be overcome by weathering the slag for 6-9 months to hydrate free lime before the slag is used. BOF slag has also been used in Finland to make multi-layer modern roads that are able to resist de-freezing in the springtime [LCA Report, 2003].

Efforts have been made by steel makers to use BOF slag as a soil conditioner in the paddy fields, tea gardens etc. after grinding the same to –300 mesh. These efforts, however, could not be commercilised due to restrictions of excise duty on the use of LD slag. The flaw in the excise duty laws is that the excise duty is applicable on the entire quantity of slag generated and not on the portion of the which is sold for external usage like soil conditioner or as a replacement of lime stone or clinker. This restriction has put the steelmakers into a situation where they are not motivated enough to find markets for this valuable by-product as the same affects the bottom line of the business (due to payment of excise duty on the entire quantity generated). Consequently, the unutilised portion of BOF slag is being dumped. These dumps pose the problem of surface run off and discharge of high pH effluent from the dump sites into the water bodies, both surface and underground [Basu et al, 2002].

Integrated Waste Management Plan

Mukherjee and Chakraborty [1999] have proposed an integrated plan to allow the maximum use of the dusts and sludges as feed stocks in the steel production process. The system should effectively reduce moisture level, remove zinc and lead and prevent oil & grease from emiting as VOC. The objective of the scheme is to make the dusts and sludges suitable for recycling through sinter plant as much as possible. Major unit operations of the scheme are as follows:

- Removal of zinc, lead and alkali oxides from BF sludge by hydrocycloning
- Centralised sludge dewatering system
- Recycle oily mill sludge by injection in the sinter plant annealing zone or after de-oiling of sludge by microbial method
- Treatment facilities for effluents containing high levels of lead and zinc.

Development of Ceramic Tiles from Industrial Waste

Iron ore tailing, blast furnace slag and fly ash are three industrial wastes which are directly or indirectly related to iron & steel plants. The present investigation has been carried out with the objective of exploiting the possibility of using a combination of these wastes as the raw materials for making ceramic floor and wall tile bodies. All these wastes contain silica and alumina as major oxides and thus, can be used for developing tile bodies. Although, impurities such as iron oxides are considered unfavourable for ceramic tiles, use of iron rich raw materials has been reported [Das et al, 1996a, Das et al 1996b, Bandopadhyay, 1996]. Marghusian et al [1994] reported that production of wall tiles containing up to 65% iron slag by Japanese investigators. Similarly, the Italians are reported to have formulated various iron slag containing bodies with good mechanical properties and little firing shrinkage [Flori et al, 1983]. Lenkei et al [1983] used Hungarian blast furnace slag to produced porous tiles fired below 1100°C.

In our earlier work, we have found that addition of a suitable combination of these waste in limited quantity improved the strength [Das et al, 2000]. The tile compositions were formulated using mix of iron ore tailing, fly ash and blast furnace slag with some other materials such as clay and fluxing minerals. The raw materials were wet milled for 10 hours, screened, dried at 110°C, powdered to break the agglomerate and granulated to small nodules for better compaction using 6-7% moisture. Tile samples were compacted using uniaxial pressing at 250 – 300 kg/cm^2. The shaped articles were fired at 1060-1200°C in air. The rate of heating was kept at 10°C/minute in all the cases. Some of these tiles were glazed with commercially available glaze materials in order to study the matching of glaze with the tile body. The major properties of the tiles developed at NML are listed in Table – 4 and compares well with EN standard.

It can be observed that the tiles produced using waste materials meet most of the specifications. The minor deviation in straightness of sides and surface quality is due to manual operation and can be overcome by mechanised operation. It may be relevant to mention here that the Indian tile industry as a whole consumes around 1000 x 10^3 MT mineral deposits as input for production of tiles per annum. Even with a conservative estimated replacement of minerals by iron ore tailings, the consumption of iron ore tailing works out to be ~300 x 10^3 MT/annum. This definitely results in significant conservation of mineral resource of India.

Table-4

Major Properties of Tiles

Properties	EN Standard specifications	Properties of tiles developed at NML
Dimension tolerance	± 0.5%	As per specification
Thickness tolerance	± 0.5%	As per specification
Straightness of sides	± 0.5%	1% variation
Rectangularity	± 0.6%	As per specification
Surface flatness	± 0.5%	As per specification
Surface quality	95% free from visible defects	Needs some improvement
% Water absorption		
Gr.I	<3	3-6
Gr.II	3-6	7-10
Gr.III	14-16	13-17
Scratch hardness (Moh's)	Min. 5	Min.6
Flexural strength (kg/cm^2) of tiles fired at 1150°C	225	>250
Thermal shock resistance of tiles fired at 1150°C	**To withstand min. 10 cycles**	**As per specification**
Chemical resistance	Class AA	Confirms to class AA

Conclusion

(1) The paper presents an overview of the various process integration and optimisation measures implemented in the integrated steel sector. Most of the measures result in significant improvement in the specific energy consumption and environmental performance in iron & steel production.

(2) Heat recovery measures in sintering process leads to 15-20% savings in energy consumption. Implementation of emission optimised sintering (EOS) may lead to ~60% reduction in emission of particulate matters, 50% reduction in CO emission, 15-20% reduction in SO_2 emission and ~65% reduction in PCDD/F emissions.

(3) Implementation of coke dry quenching would result in the reduction of CO_2 emission in the range of 100-125 kg/t coke and an energy savings of ~1.5 GJ/t of coke.

(4) The integrated steel sector should look into the possibility of implementing an integrated waste management plan. Such a system should effectively reduce moisture level in dust and sludges, remove zinc and lead and prevent oil & grease from emitting as VOC.

(5) The waste materials associated with iron & steel industry such as tailings, blast furnace slag and fly ash can be used as resource material for developing value added products e.g. ceramic tiles. The tiles develop conform to European Nation (EN) standards and have better strength and scratch hardness than the conventional ceramic tiles. Use of such technology have multiple advantages such as gainful utilization of waste, resource conservation, as well as making of cheap and better products.

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