Solid and Hazardous Waste Minimisation and Utilisation in Iron and Steel Making

THESIS

Submitted in partial fulfillment
of the requirement for the degree of
DOCTOR OF PHILOSOPHY

by

RAJ KUMAR AGRAWAL

Under the Supervision of
Prof. Piyush Kant Pandey

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I also wish to acknowledge the assistance rendered by Refractory Material Plant-II collective who helped me in conducting various experiments and studies for development of waste materials to useful product. I also wish to acknowledge help rendered by Shri B. Nandanwar, Shri M.V.V. Prasad, Shri A.S. Achari, Shri Deepak and Shri Shivnath during preparation and organization of the thesis. But for their help, it would not have been possible in bringing this project to successful conclusion.

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BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE

PILANI, RAJASTHAN

CERTIFICATE

This is to certify that the thesis entitled as **"Solid and Hazardous Waste Minimisation and Utilisation in Iron and Steel Making"** and submitted by **Raj Kumar Agrawal, ID No. 2001 PHXF402** for award of **Ph.D. Degree** of the Institute embodies work done by him under my supervision.

Signature in full of
The Supervisor ____________

Name: PROF. PIYUSH KANT PANDEY

Date 30.4.05

Designation: Professor and Co-coordinator Centre for Environmental Science and Engineering, Bhilai Institute of Technology, Durg (C.G).

ABSTRACT

Steel industry consumes large quantity of raw materials resources and energy for producing steel. The process of conversion generates alarmingly large quantities and varieties of waste. Steel industry falls in the list of highly polluting industries because of its impact on different components of both biotic and abiotic environment. The integrated steel plants involve number of industrial operations viz. mining, transport, raw material preparation, coke, iron and steel making and rolling. This study was started with twin objectives. One was delineating the status of solid and hazardous waste and their overall management practices. The second was to experimentally identify the methods for utilization of wastes and the reduction of waste generation.

The methodology adopted is, collection of data for various solid wastes, assessment of extent of generation, recycle and reuse and dumping for Indian & Foreign Plants. The type of waste, quantity and chemical analysis were collected. The wastes have been characterized as per Hazardous Waste Amendment Rules 2000. Specific generation/reuse has been recorded. Finally it was found which route generates maximum and minimum dumped quantities.

For minimisation of waste, measures have been indicated and for recycling/reuse the technologies have been briefly described with the name of developing agency as found in literature survey. The research gaps were identified and experiments have been conducted to utilise solid waste generated in different processes with an idea to establish a new process or manufacturing a new product using the waste material. Experimental work on new recycled products was conducted & methods were established. The aim of these elaborate exercises was to evolve process methodology which could be acceptable in actual practice. Product which satisfied the criteria for suitable engineering and economy were adopted for actual use.

The methods investigated, involved agglomeration techniques such as pelletising briquetting and sintering. Experiments have been conducted to

agglomerate iron ore fines along with binder to be used as a part of charge for small furnace thus improving yield at nominal cost. Rolling Mill sludge has been recycled to increase yield of sinter in sinter making. Metallurgical lime fines were briquetted and reintegrated for use along with prime lime thus suppressing problem of fine disposal in addition to huge savings. Lime fines have also been used as a binding material during production of fly ash bricks. Production of insulating material for steel ladle along with slag fines has been successfully conducted. Dolomite fines were used to replace well filler mass after screening, ventilation dust, flue dust samples have been pelletised and used as coolant in converter to trim the temperature. Pond ash along with clay has been converted to cost effective red building bricks. Sinter Plant ESP fines have been successfully tried for sinter production. Coke breeze along with mill scale and binder were agglomerated and utilized successfully for sponge iron production. Blast Furnace sludge after reducing zinc and lead by hydrocyclone were used for sinter production. BOF sludge was utilized as Dolomite sludge mix or Lime sludge briquette. The first one was used for sinter production where as second one has been tried as a coolant in converter.

Refractory waste was agglomerated, rejuvenated to more costly product at the same time reducing load on environment. Fireclay grog was used for production of new bricks, mortar and tap hole mass. Similarly Magnesia carbon grog was utilized for production of new bricks for converter, steel ladle, skimmer and rocking runner. This has triple advantage viz cost saving, control of environment degradation and better life of refractory material. Similarly high alumina brick grog was used for blast furnace trough mass and steel ladle mortar.

This study also evolved a process to destruct Polychlorinated Biphenyl by incineration in rotary kiln. It is a very high toxic inflammable if burnt at 300°C to 800°C. Hence it was incinerated at a temperature of 1350^0 to 1700^0C.During destruction the heat energy generated was used for sinter production thus saving costly fuel as a bonus.

This work on waste management has established the way for regular use of solid waste. The process adopted to recycle this waste at plant unit level is definitely cost effective and economic way of recycling, reconditioning and reuse.

Some of the above trials are employed by Bhilai Steel Plant a unit of Steel Authority of India Limited and some are under active consideration. Thus plant is reaping benefits cost-wise at the same time helping the environment. Continual innovation towards full utilization will progressively improve the bottom line and protect the environment.

Table of Contents

NOMENCLATURE, ABBREVIATIONS, SYMBOLS, UNITS AND CONVERSION FACTORS

1.1 Nomenclature

1	**AISI**	American Iron and Steel Institute
2	**ASP**	Alloy Steel Plant
3	**BHU**	Banaras Hindu University
4	**BIS**	Bureau of Indian Standards
5	**BSL**	Bokaro Steel Limited
6	**BSP**	Bhilai Steel Plant
7	**CBRI**	Central Building Research Institute
8	**CFRI**	Central Fuel Research Institute
9	**CPCB**	Central Pollution Control Board
10	**CRRI**	Central Road Research Institute
11	**DSP**	Durgapur Steel Plant
12	**EMD**	Environment Management Division
13	**EMP**	Environment Management Policy
14	**EPA**	Environment Protection Agency
15	**IISCO**	Indian Iron and Steel Company
16	**IISI**	International Iron and Steel Institute
17	**IIT**	Indian Institute of Technology
18	**IRC**	Indian Road Congress
19	**ISP**	Integrated Steel Plant
20	**JVSL**	Jindal Vijaynagar Steel Limited
21	**MEL**	Maharashtra Elektrosmelt Limited
22	**MOEF**	Ministry of Environment and Forest
23	**NEERI**	National Environmental Engineering Research Institute
24	**NML**	National Metallurgical Laboratory
25	**RDCIS**	Research and Development for Iron and Steel
26	**RINL**	Rashtriya Ispat Nigam Limited
27	**RSP**	Rourkela Steel Plant
28	**SAIL**	Steel Authority of India Limited
29	**SSP**	Salem Steel Plant
30	**TISCO**	Tata Iron and Steel Company
31	**UNDP**	United Nations Development Programme
32	**UNEP**	United Nations Environment Programme Industry and Environment
33	**VISL**	Vishveswaraya Iron and Steel Limited

1.2 Abbreviations

1	**40CFR**	Title 40 Code for Federation Regulation
2	**APC Dust**	Air Pollution Control Dust
3	**BAT**	Best Available Technology
4	**Benzol (HC,LC)**	Benzol (High Carbon and Low Carbon)
5	**BF**	Blast Furnace
6	**BIS**	Bureau of Indian Standard
7	**BOF**	Basic Oxygen Furnace
8	**CDI**	Coal Dust Injection
9	**COREX**	A Process of Iron Making Developed by VAI/Austria
10	**CTS**	Coal Tar Sludge
11	**DKD**	Dolomite Kiln Dust
12	**DR**	Direct Reduction
13	**DRI**	Direct Reduction Iron
14	**EA**	Environment Audit
15	**EAF**	Electric Arc Furnace
16	**EMS**	Environment Management System
17	**EOF**	Electro Oxy Furnace
18	**ESP**	Electrostatic Precipitator
19	**ETP**	Effluent Treatment Plant
20	**FA**	Fly Ash
21	**GCM**	Gas Cutting Machine
22	**GCP**	Gas Cleaning Plant
23	**GGBFS**	Ground Granulated Blast Furnace Slag
24	**HBI**	Hot Briquetted Iron
25	**HPLA**	Aspiration through High Pressure Liquor Injection in Goose Neck
26	**ID**	Induced Draft
27	**LCA**	Life Cycle Assessment
28	**LD Process**	Linz + Donawitz process of Steel making through Oxygen Blowing.
29	**LF**	Ladle Furnace
30	**LKD**	Lime Kiln Dust
31	**LS Naphtha**	Low Sulphur Naphtha
32	**LSHS**	Low Sulphur High Stock
33	**LSSP**	Location Specific Soil Management Plan
34	**MACT**	Maximum Achievable Control Technology
35	**NCB**	National Council for Cement and Building Material
36	**OHF**	Open Hearth Furnace
37	**PAH**	Polycyclic Aromatic Hydro Carbon

38	**PCI**	Pulverized Coal Injection
39	**PCM**	Pitch Creosote Mixer
40	**PCB**	Poly Chlorinated Bi-phenyl
41	**PLD**	Percent Leaking Door
42	**PLL**	Percent Leaking Lid
43	**PLO**	Percent Leaking Off take
44	**PM**	Particulate Matter
45	**POPs**	Persistent Organic Pollutants
46	**PPC**	Portland Pozzolana Cement
47	**RCRA**	Resource Conservation and Recovery Act
48	**RMHP**	Raw Material Handling Plant
49	**RMP**	Refractory Material Plant
50	**RST**	Radial Settling Tank
51	**SEB**	State Electricity Board
52	**SMS**	Steel Melting Shop
53	**SP II**	Sintering Plant II
54	**SPM**	Suspended Particulate Matter
55	**SR Process**	Smelting Reduction Process
56	**SS**	Suspended Solids
57	**SST**	Secondary Settling Tank
58	**TBDB**	Tar Bonded Dolomite Brick
59	**THF**	Twin Hearth Furnace
60	**TI**	Tumbler Index
61	**VAD**	Vacuum Arc Degassing
62	**VOC**	Volatile Organic Compounds
63	**VOD**	Vacuum Oxygen Degassing

1.2 Symbols

1	**Al**	Aluminum
2	**$3Al_2O_3.2SiO_2$**	Mullite
3	**Al_2O_3**	Alumina
4	**BaO**	Barium Oxide
5	**Ca**	Calcium
6	**CaO**	Calcium Oxide
7	**CaS**	Calcium Sulphide
8	**Cd**	Cadmium
9	**CH_4**	Methane
10	**Cl_2**	Chlorine
11	**CO**	Carbon Mono Oxide
12	**CO_2**	Carbon Dioxide
13	**Cr**	Chromium

14	Cr_2O_3	Chromium Oxide
15	**Cu**	Copper
16	**Fe**	Iron
17	Fe_2O_3	Ferric Oxide
18	Fe_3O_4	Magnetite (Ferrous Oxide)
19	**FeO**	Ferrous Oxide
20	H_2S	Hydrogen Sulphide
21	H_2SO_4	Sulphuric Acid
22	**HCl**	Hydrochloric Acid
23	**K2O**	Potassium Oxide
24	**LCC**	Ladle Covering Compound
25	**LOI**	Loss On Ignition
26	**Mg**	Magnesium
27	**MgO**	Magnesium Oxide
28	**MgO-C**	Magnesia Carbon
29	**Mn**	Manganese
30	**MnO**	Manganese Oxide
31	**MnS**	Manganese Sulphide
32	N_2	Nitrogen
33	Na_2O	Sodium Oxide
34	$NaHSO_4$	Sodium Hydro Sulphate
35	**NaOH**	Sodium Hydroxide
36	**Ni**	Nickel
37	NO_2	Nitrogen Dioxide
38	NO_X	Oxides of Nitrogen
39	**O2**	Oxygen
40	P_2O_5	Phosphorous Pentaoxide
41	**PAH**	Polyaromatic Hydro Carbon
42	**Pb**	Lead
43	**PCB**	Poly Chlorinated Biphenyl
44	R_2O_3	Total of Oxides
45	**S**	Sulphur
46	SiO_2	Silicon Oxide
47	**Sn**	Tin
48	SO_2	Sulphur Dioxide
49	SO_3	Sulphur Tri Oxide
50	TiO_2	Titanium Oxide
51	**TSCA**	Toxic Substance Control Act
52	**V**	Vanadium
54	**Zn**	Zinc

1.3 Units

1.	AP	Apparent Porosity
2.	BD	Bulk Density
3.	BOD	Biological Oxygen Demand
4.	CCS	Cold Crushing Strength
5.	COD	Chemical Oxygen Demand
6.	G Cal	Giga Calories
7.	kg/T	kilogram/Tonne
8.	kg/TCS	kilogram/Tonne of Crude Steel
9.	kg/THM	kilogram/Tonne of Hot Metal
10.	kWh	kilo Watt Hour
11.	PCE	Pyrometric Cone Equivalent
12.	PLC	Permanent Linear Change
13.	T/year	Tonnes/Year
14.	WC	Water Column
15.	%	Percentage
16.	mg/kg	milligram/kilogram
17.	µgL	microgram/litre
18.	mg/L	milligram/litre
19.	ppb	parts per billion
20.	ppm	parts per million
21.	nm	nanometre
22.	mA	miliampere
23.	mL	millilitre
24.	g	gram
25.	kg	kilogram
26.	T	tonne
27.	L	litre
28.	ng	nanogram
29.	mg	milligram
30.	^{o}C	degree celcius
31.	h	hours
32.	W/V	Weight/volume
33.	g/cm^3	Gram per cubic centimetre
34.	g/hr	Gram per hour

1.4 Conversion Factors

1	**G (Giga)**	10^9 (Billion)
2	**k (Kilo)**	10^3 (Thousand)
3	**M (Mega)**	10^6 (Million)
4	**One kWh**	860 k Cal.

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Chapter 1

INTRODUCTION

1.1 Prologue

The destiny of human being has always been closely linked with the nature. A very long period of human history can be classified as "Hunter-Gatherer Societies" where the survival was based on the nomadic gathering of edible plants and hunting. This period was characterised by little accumulated and food surplus. At those time, the small number of people who lived in virtual isolation, made very little use of the vast natural resources. Yet, their entire activities were strongly linked with nature and they worshipped the nature.

However, the tediousness and uncertainness of such a life gave way to the evolution of "agricultural societies" which was able to produce larger and more stable food supplies. The concomitant benefit was the generation of Food surpluses that could be stored. This phenomena lead to abandonment of nomadic ways of life and instead larger settlements and populations started to appear on all inhabitable places of the earth. The clearing of forests for agricultural fields was the first major environmental degradation. Decline or collapse of many civilizations in this period was linked with the degradation of the soils and resource bases. In spite of that, the process of human domination of nature i.e. the anthropocentric view of environment took its birth.

The modern Industrial societies are characterised by the substitution of human and animal labour by machines and increasing urbanization i.e. the living of large population outside natural surroundings. This era has also changed the way and we perceive the environment accordingly. Unprecedented exploitation of resources to feed the billions of people has exacerbated many environmental problems and created new ones.

1.2 Background of Proposed Research

One classic example of the problem as noted above is the iron and steel making. The discovery of iron provided the ultimate material to the mankind using which he could shape his destiny. Historically, steel making has evolved in response to industrial expansion, world wars, technological innovation, economic factors and sheer creativity. The manufacture of steel involves many processes that consume raw and/or recycled materials from around the world and produce thousands of products and by-product. The two major steel making processes are the basic oxygen furnace (BOF) and the electric arc furnace (EAF). At its simplest, a steel mill may consist of liquid pig iron (hot metal), a scrap receiving yard, electric arc furnace/basic oxygen furnace, and a continuous casting machine or Ingot making route, producing a few hundred thousand tonnes of billets/slabs annually. Such a "mini-mill" might occupy a city block and require several tens of millions of rupees in capital investment. The most modern "mini-mills" produce in excess of a million tonnes of steel a year. Large integrated steel plants (ISPs) cover many acres, produce steel in BOFs, and use dozens of semi-fabrication processes, employ thousands of workers, and produce 3 to 6 million tonness of steel products annually. Such a plant represents several billions rupees in capital investment and is generally built over several years. Steel making is a dynamic, ever-changing industry that has improved greatly over the last 150 years. Some processes, such as the Bessemer process, flourished a while and then vanished. Processes, like the Blast Furnace, Basic Oxygen Furnace, Electric Arc Furnace, Continuous Casting Process, and Hot Strip Mill Cold Strip Mill, have evolved continuously over the decades and are likely to remain a part of steel making for the near future.

Yet, in view of large pollution and technological dimensions, there is an urgent need of industry-wide research that will help creating opportunities for achieving the industry's energy, economic, and environmental goals (AISI 1981, AISI 2001). In nutshell, the following two points are the most compelling reasons for research in the area: -

Iron & steel industries' energy consumption account for more than 10% of total societal energy consumption. Iron & steel industries' discharge large volume of waste gas, dust, wastewater, waste solid and so on, which causes a heavy stress on the ecosystem. Put simply in economic terms these means higher costs for the prevention of pollution or disposal to an already battered industry.

1.3 Pollution Economics of an Integrated Steel Plant: -

In a typical year, iron and steel plants dedicate roughly 15% of capital investments to environmental projects. On a national scale, these investments have totalled about $6 billion over the past 25 years in the USA. Although costly, these pollution prevention efforts have successfully reduced discharges of air and water pollutants by more than 90% in the last 20 years. At the same time, solid waste production at a typical mill has been reduced by more than 80%.

However, the Indian Steel industry had been very slow to respond to such changes because of a monopolistic hold over the market for the first fifty years of its existence. This has been a contributing factor to the present gloomy position of the steel industry in India. Internationally also despite significant achievements, further improvements to pollution prevention technologies are needed to reduce costs, improve profitability, and facilitate compliance with changing regulations. In USA the U.S. Environment Protection Agency had been particularly very conscious of its role had hence had given a large number of regulations specifically dealing with the iron and steel industry (U.S. EPA 1990, U.S. EPA 1993, U.S. EPA 1995, U.S. EPA 1995a, U.S. EPA 1995b, U.S. EPA 2000).

Table 1.1: Particulate Emission Abatement Costs Incurred by Bhilai Steel Plant

S. No.	Source	Volumetric Flow Rate (Nm^3/Day)	SPM Abated (Tonnes Per Day)	Total Cost Of SPM Abatement (Rs. Lakhs/Year)
1	Sinter plant (exhaust)	22259102.0	28.63	367.12
2	Sinter Plant (discharge)	17800358.0	22.89	293.58
3	Kiln	17046771.2	99.87	154.42
4	SMS	25870176.0	87.47	856.11
5	Thermal Power Plant	32719660.8	973.61	329.62
6	Coke Ovens	30833912.0	527.63	492.37
7	Blast Furnace	45937437.7	57.05	210.54
	Total		1797.15	2703.77

(Source: Environmental Performance Report, 2000-2001, EMD, SAIL)

The pollution control economics is becoming vital for the Indian integrated steel plants also. An example of Bhilai Steel Plant (Table 1.1) clearly shows the magnitude of the suspended particulate matter captured by the various pollution control equipments and the costs involved in the process. On both the counts, the costs are staggering. The fly ash collected is hardly utilised for any gainful purpose (Table 1.2 and 1.3) and most of it finds its way to the landfill. Land filling further requires valuable land and incurs disposal costs. Hence, any research in making this waste a more useful product would be highly beneficial to the Indian ISP.

Table 1.2: Fly Ash Generation in SAIL Plants

S.No	Plants	Fly-Ash Generation In Tonnes	Generation Rate kg/T of Crude Steel
1	Bhilai Steel Plant	180,838	91.2
2	Durgapur Steel Plant	120,379	140.8
3	Rourkela Steel Plant	437,834	594.6
4	Bokaro Steel Plant	490,750	230.7
5	Indian Iron & Steel Co.	71,131	182.2
6	SAIL (TOTAL)	1,300,932	

(**Source:** Environmental Performance Report, 2000-2001, EMD, SAIL)

Table 1.3: FA Recycled, Sold and Dumped

S.No.	Name Of Plants	Recycled	Sold	Dumped
1	Bhilai Steel Plant	-	-	100 %
2	Durgapur Steel Plant	-	-	100 %
3	Rourkela Steel Plant	25.6	-	74.4 %
4	Bokaro Steel Plant	-	-	100 %-
5	Indian Iron & Steel Co.	-	82.8 %	17.2 %
6	SAIL Plants (Over all)	8.6 %	4.5 %	86%

(Source: Environmental Performance Report, 2000-2001, EMD, SAIL)

1.4 Impetus for this Research: -

Total steel production in India in the year 1999-2000 was about 25.12 million tonnes produced mainly by the large integrated steel plants (ISPs). Further, it is estimated that steel production is likely to increase to 40 million tonnes in 2010. This could lead to considerable increases in the waste generation, pollution loadings and the resource consumption. Iron and steel industry has been popularly epitomized as the "Temples of the Modern Civilisation". Yet, in spite of the huge investments and importance for the nation, the research on waste minimisation and utilisation in steel industry has not been a major focus of attention. Such a research could help achieving lower pollution and better economy. Keeping the above in view, this work has attempted a research on waste minimisation and utilisation in different sectors of an integrated steel plant as enumerated below. This topic is important not only for India but also for the rest of the world, as most of these objectives have been identified as the areas where R&D is required (AISI 1981, AISI 1998, AISI 2000.)

1.5 Objective of the study: -

The objective of this study is to carryout a detailed study on all aspects of solid waste generation, its management and identifying the methods for waste minimisation and utilisation.

Further, it compared the corresponding figures on above counts to that in the developed world. Subsequently the thesis attempted to identify the measures to minimize the generation of waste and maximizing the utilization of solid wastes. The objectives are enumerated in brief as follows: -

i. Study of the present status prevailing in Indian Iron & Steel Industry with respect to generation of various types of waste during iron and steel making process.
ii. Identification of the types of wastes such as solid and hazardous waste.
iii. Assessing the reasons and quantify of the solid waste generated in the operational processes.
iv. Identification of the recycling and/or reuse methods for such wastes.
v. Extent of marketability and dumping of waste generated from Indian Plants.
vi. Identification of the extent of reuse of these recycled products at plant/shop level and other areas.
vii. Identification of the methods for minimising the waste generation at plant level and ways to address the environmental concerns.

The above objectives were chosen as the extensive literature review has revealed that data on above count are fragmented and sketchy. Many companies worldwide are holding a lot of information, either due to their commercial significance or to avoid the undue environmental attention on the performance of such companies. Thus, there exists a clear need for documentation, and research on the finding the novel methods for minimisation/recycling/reuse of the waste materials from steel industry.

1.6 Scope of Study: -

The following areas have been covered under the scope of this study: -

i. Evaluation of integrated steel plants solid wastes generation
   a) Solid waste quantification.
   b) Management of waste (solid) in various integrated steel plants.
ii. Analysis of solid waste.
iii. Comparison of waste generation and utilisation with respect to ISPs in developed countries.
iv. Practices followed for utilisation of waste in India and abroad.
v. Development of technology for waste minimisation and utilisation.
vi. Reuse and recycling at shop level and its techno economics.
vii. New products from wastes.

1.7 Limitations of Research: -

This work had to face the typical challenge of "Lack of adequate and reliable data". This particular malady is somewhat all pervading in any developing country and is more acute in Indian setting. Further, the experimental work always aimed at the feasible and adoptable options for the recycling and/or reuse of the waste product. Obviously, getting a feasible and adoptable solution was a difficult task. Some of the specific problems/limitations encountered in the course of study are enumerated as below:-

i. Non-availability of data on the waste management in Indian Steel Plant wastes especially non-SAIL plants.
ii. The reliability of data

a) Indian steel plants do not maintain any inventory of wastes

b) Some older plants do not have any measuring facilities to furnish quantitative data

iii. Absence of any reference value regarding the wastes

iv. Data on operating cost of recycling of wastes are not available

v. Inadequate implementation of the environmental regulations and consequent camouflaging of data

In view of the above, it has been tried to gather the most recent data on various aspects of waste. Using the method of extrapolation and statistics a picture has been developed. The data of SAIL Plants are given more importance to pursue the scope of research work where annual statistics reports on waste management are given due consideration.

1.8 What is Waste, Waste minimisation and Waste Utilisation?

The legal definition of waste shall mean any substance or object in the categories set out in (Table 1.4), which the holder discards or is required to discard (European Council 1991).

Table 1.4: Waste Categories and their Description

Waste Category	Description
Q1	Production or consumption residues not otherwise specified below
Q2	Off-specification products.
Q3	Products whose date for appropriate use has expired.
Q4	Materials spilled, lost or having undergone other mishaps include contaminated as a result of the mishap including any materials, equipment, etc.
Q5	Materials contaminated or soiled as a result of planned actions, e.g. residues from cleaning operations, packing materials, containers, etc.
Q6	Unusable parts e.g. reject batteries, exhausted catalyst, etc.
Q7	Substances, which no longer perform satisfactorily, e.g., contaminated acids; contaminated solvent exhausted tempering salts, etc.
Q8	Residue of industrial processes, e.g. slag, still bottom, etc.
Q9	Residues from pollution abatement processes, namely scrubber sludge, bag house dusts, spent filters, etc.
Q10	Machining/finishing residues e.g. lathe turnings, mill scales, etc.
Q11	Residue from raw material extraction and processing, e.g. mining residues, oil filed slops, etc.
Q12	Adulterated materials, e.g. oils contaminated with PCBs, etc.
Q13	Any materials, substances or products whose use has been banned by law in the country of exportation.
Q14	Products for which there is no further use, e.g. agriculture, household, office, commercial and shop discards, etc.
Q15	Any materials, substances or products which the generator or exporter declares to be wastes which are not contained in the above categories.

(Source: European Council 1991, Council Directive 91/156/EEC)

Reduction of waste through recycling has been promoted since the 1960s. The concept of recycling to conserve resources is based on the assumption that recycling requires fewer raw materials and less energy, and generates fewer emissions into the environment, than manufacturing new material. However, one can conclude that recycling is not environmentally sound when it requires transportation over unreasonably long distances, using non-renewable fossil fuels. Recycling was more than just a response to the environmental crisis and has assumed a symbolic role in instigating a change to the nature of western societies and the culture of consumerism. Many environmentalists assumed that there would be an inevitable shift from the 'throw-away' society to a post-industrial recycling society. (Gandy 1994, Pongrácz 2004) However, recycling addresses the disposal of the product rather than its generation and thus it only recovers the energy and material included in the product, whereas prevention addresses the energy and material use of the whole production chain (Figure 1.1).

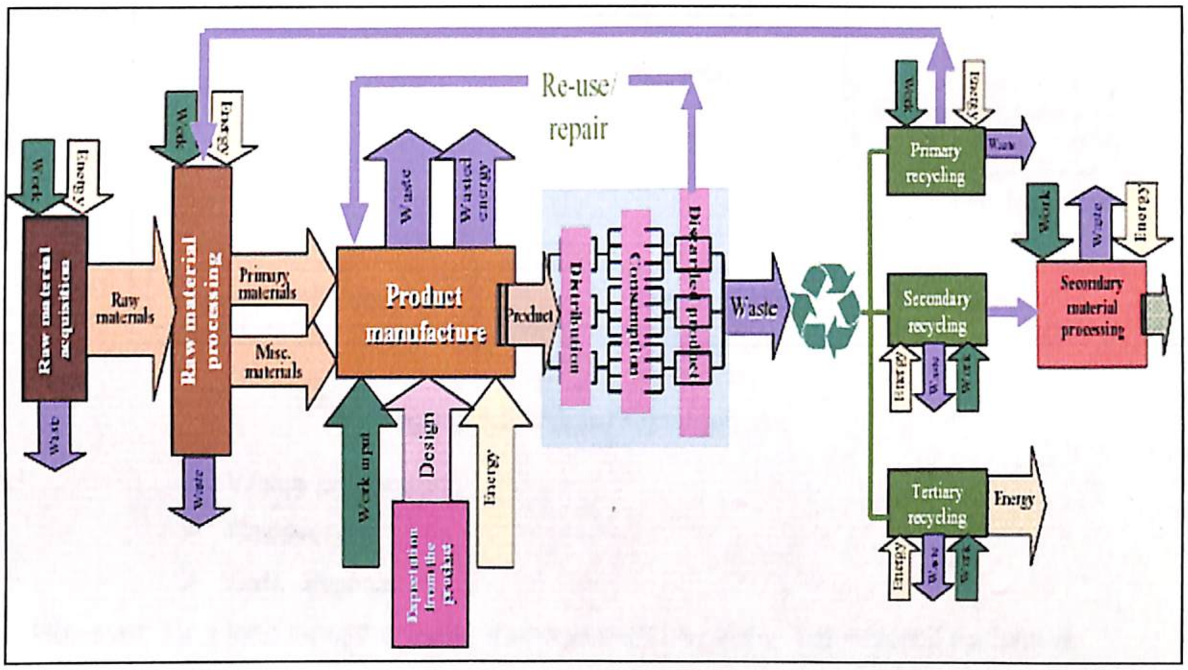


Figure 1.1: A simplified production line

Recycling alone, without avoidance at source, will not result in overall reduction of the amount of waste produced. It is important to stress that, while recycling is a mechanism for achieving environmental goals, it should not become a goal in and of itself. Figure 1.1 also illustrates that the much quoted "life-cycle" (***Extraction - raw material processing – production – use – waste – recycling***) is rather linear than cyclical, because there is insignificant real circulation of materials. In the sense of the natural closed and permanent cycles, recycling of manufactured articles does not take place.

The European Council in its Waste Directive of 1991 sets the hierarchy of waste management options as shown in Fig 1.2 as follows: -

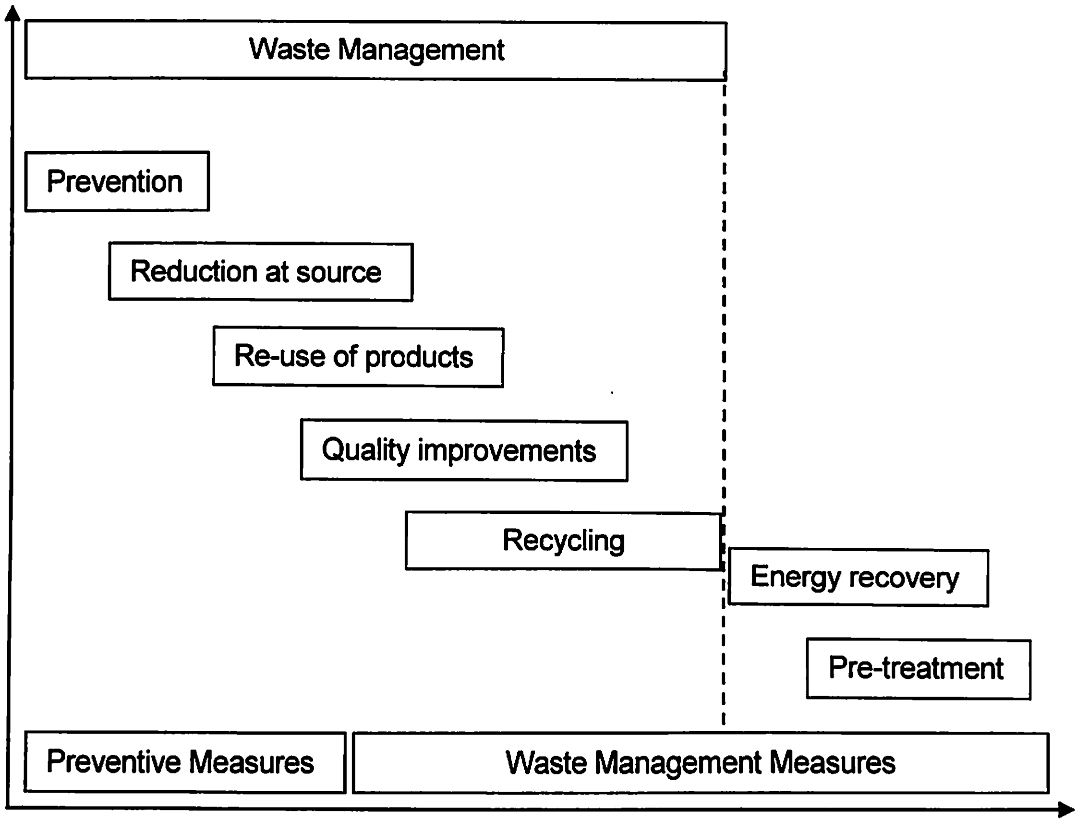


Figure 1.2: Waste Management

- Waste prevention
- Recovery
- Safe disposal

However, for a long time, the waste management hierarchy was ordered as follows (Kirkpatrick 1992): -

- Waste minimisation
- Re-use
- Recycling
- Incineration
- Disposal

Both of the hierarchies are correct, and all of these concepts are widely used. However, when discussing waste and waste policy, every effort should be made to have a common understanding of terminology. Terms should not be used loosely or interchangeably (Vancini 2000).

At a workshop in Berlin organised by the OECD in 1996, a definition of waste minimisation was worked out, according to which it encompasses these three elements in the following order or priority (Riemer and Kristoffersen 1999a): -

- Preventing and/or reducing the generation of waste at source;
- Improving the quality of the waste generated, such as reducing the hazard; and

- Encouraging re-use, recycling and recovery

The OECD Definition of Waste Minimisation is:

"Preventing and/or reducing the generation of waste at the source; improving the quality of waste generated, such as reducing the hazard, and encouraging re-use, recycling, and recovery."

This definition has an overlap with the objectives of the waste management plans. According to terminological work undertaken at OECD, waste minimisation **is a broader term than waste prevention** in that it includes recycling and (if considered appropriate) incineration with energy recovery as discrete activities. Recycling and incineration are distinct from waste prevention (OECD 1996).

The first-ever OECD workshop devoted specifically to waste prevention was held in 1999; and a Reference Manual on strategic waste prevention was published to assist governments with actions that support increased resource efficiency and sustainable development. (Vancini, 2000.)

- Strict Avoidance
- Reduction at Source
- Product Re-use

1.8.1 Strict Avoidance: -

Strict Avoidance involves the complete prevention of waste generation by virtual elimination of hazardous substances or by reducing material or energy intensity in production, consumption, and distribution (Pongrácz 2004). Examples of strict avoidance include those that address:-

- HAZARD, SUCH AS:- Avoiding and/or substituting materials that are hazardous to humans or to the environment (e.g., through bans on PCBs and ozone-depleting substances, or virtual elimination of toxic organochlorines released in bleached pulp mill effluents).
- QUANTITY, SUCH AS: - Avoiding use of materials or stages of production/ consumption (e.g., through eliminating interim packaging for cosmetics and toothpaste, or substitution of continuous casting for ingot casting at steelworks).

1.8.2 Reduction at Source: -

Reduction at source involves minimising use of toxic or harmful substances and/or minimising material or energy consumption. Examples of reduction at source include those that address: -

HAZARD, SUCH AS:-

- Reducing the use of harmful substances in products, in production and sales systems, and in consumption and disposal systems, and
- Reducing the use of substances that hinder re-use or recycling (e.g. "Post-its" on paper, use of chlorinated solvents as cleansing agents).

QUANTITY, SUCH AS: -

- Using smaller amounts of resources to provide the same product or service (e.g. reducing foil thickness, introducing re-use or refill systems, miniaturisation, resource-orientated purchasing and consumption); and
- Using less resource-dependent construction principles and materials

1.8.3 Product Re-Use: -

Product re-use involves, as shown in Fig 1.3, the multiple use of a product in its original form, for its original purpose or for an alternative, with or without reconditioning. Examples of product re-use include those that address: -

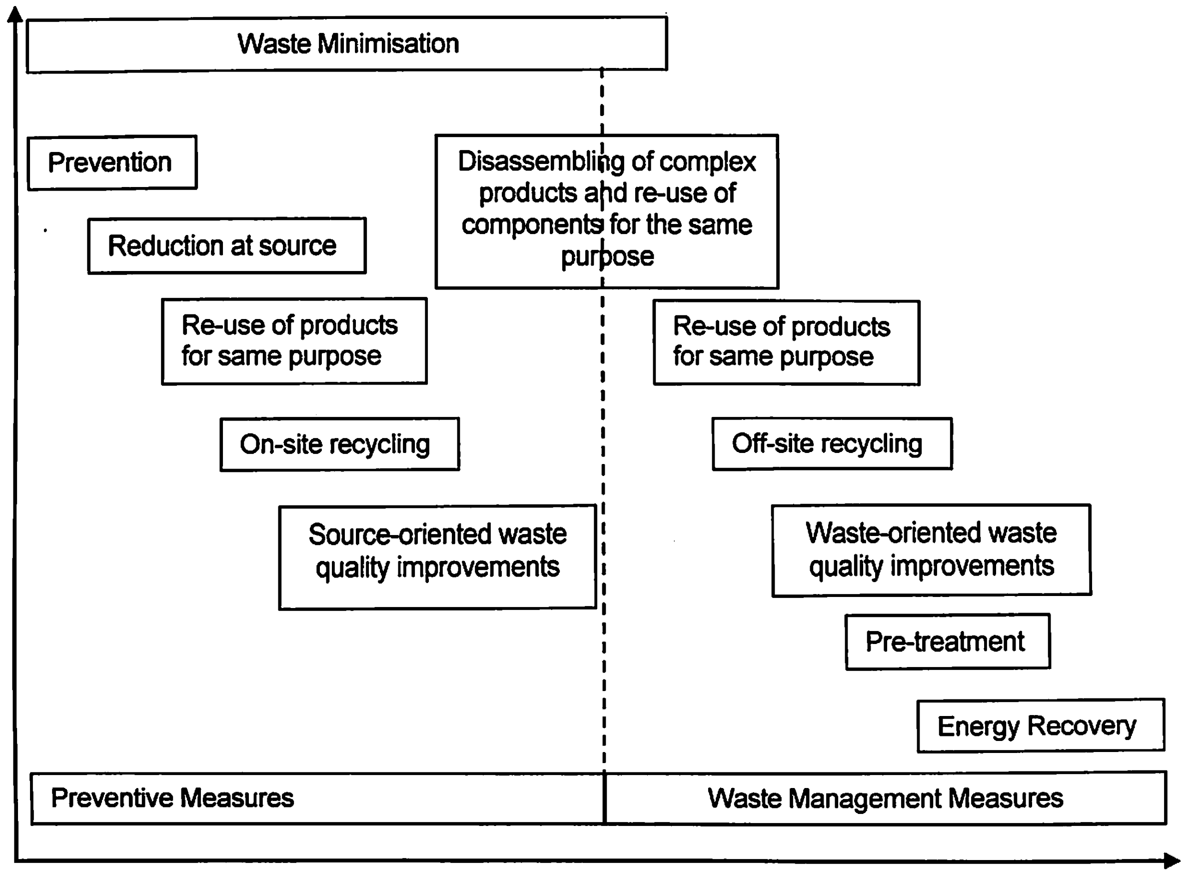


Figure 1.3: Product Re-Use

- Re-use after reconditioning, such as: -

  Refilling glass or plastic bottles after washing, and using empty adhesive barrels as oil barrels after reconditioning.

- Re-use without reconditioning, such as: -

  Using shopping bags more than once.

In the above definition, the cleaner production/waste minimisation is only related to preventive measures (Riemer & Kristoffersen 1999b). However, in detail, this means that waste minimisation includes: -

- **Waste prevention** i.e. reduction of waste by application of more efficient production technologies;
- **Internal recycling** of production waste;
- **Source-oriented improvement of waste quality**, e.g. substitution of hazardous substances;
- **Re-use** of products or parts of products, **for the same purpose**.

According to the definition, waste minimisation does not include: -

- External recycling;

- Improvement of waste quality by sorting of waste;
- Re-use of product or parts of products for any other purpose than the original;
- Any kind of energy recovery

The definition is closely related to the generating source only – on the one hand to the production process, and the other, to the end-of-life products.

For a production engineer, four important strategies are necessary to remember that will contribute to waste minimization:

i. Less material to produce a product, through dematerialization, miniaturization, light weighting.

ii. Create durable/re-usable/repairable products using measures that postpone the product becoming waste.

iii. Avoid waste creation, by changing the production process, so that less production waste is created, improving selectivity; utilizing by-products - upgrading to marketable products.

iv. Use less harmful substances so an expected hazardous waste flow is replaced with a less dangerous one.

1.9 Re-use/Recycling of waste: -

"**Re-use** is use for the second or more time, of a product for the same purpose, under the same form and with the same properties of the material as the first use, the material having constantly remained under the same form between several uses."

Recycling is the operation, which is defined as: -

"**Recycling** shall mean the reprocessing in a production process of the waste materials for the original purpose, or for other purposes, including organic recycling but excluding energy recovery" (European Council 1997).

It is useful to distinguish three different forms of recycling: closed-loop recycling, open loop recycling, and down-cycling, which can be defined as follows: -

"***Closed-loop recycling*** is a recycling process in which a waste material is used for the same purpose as the original purpose or for another purpose requiring at least as severe properties as the previous application so that, after one or several uses, this material can be used back again for the original purpose."

"***Open-loop recycling*** is a recycling process in which a waste material is used for another purpose than the original purpose and will never be used back again for the original purpose."

"***Down-cycling*** is a recycling process in which a (fraction of a) material from a used product is used to make a product that does not require as severe properties as the previous one."

Clear differences exist between the waste re-use and recycle, during re-use, the product will not change its shape; it is continuously used as such. During recycling the product will go through some process, during which its structure is going to be changed.

1.10 The Problem with Recycling: -

The concept of recycling to conserve resources is based on the assumption that recycling requires fewer raw materials and less energy, and generates fewer emissions into the environment, than manufacturing new material. Recycling is not environmentally sound when additional transportation steps using non-renewable fossil fuels must be used to collect the material prior to recycling. For recycling to be environmentally beneficial, the effects of the collection, transportation and reprocessing operations must be less harmful than those resulting from the extraction and processing of the virgin raw material that the recycled product replaces. Recycling actually occurs once the secondary material has been converted into a new product, or is utilized in another way. Thus, the availability of markets for the secondary materials generated is fundamental to the success of recycling. This is principally the role of industry that must ensure the continuing availability of processing facilities to match the increasing amounts of secondary materials that will be recovered.

1.11 Waste Prevention in Practice: -

Any culture concerned with survival in an environment of limited resources would be required to use materials in a most basic sense is an old behaviour pattern of using the resources in a frugal manner. This meant repairing a damaged item rather than creating a new one, saving used materials for re-use, and producing objects and utensils that maximised efficient use of limited raw materials. Still, in the context of current Western culture, waste prevention does present a radical departure from society's way of manipulating materials (Pongrácz 2004). However the very concept of frugal living and minimum waste generation and maximum recycling is a novel concept for developed world. What is more unfortunate that the developing world is aping the western outlook as far as waste generation is concerned.

1.12 Waste Minimization in Industry: -

According to the Philips (2000) for a manufacturing process, waste could mean things, which are 'seen' useless such as:

- Off-cuts or trimmings
- Faulty products
- Contaminated washings
- Packaging
- Quality Control (QC) rejects
- Unsold first quality products

However, waste also includes inefficient use of energy resources. These are less tangible but represent a -profitable cost to industry. Some examples are:-

- Lighting a factory 24 hours a day where as this should be need based.
- A compressed air system, which is leaky or inefficient.
- Poor maintenance of equipment leading to increased power consumption due to frictional losses in bearings.
- Waste costs money, consumes scarce resources and expensive to dispose of and can lead to environmental damages.

Polluting the environment can result in large fines and adverse publicity. There is a Duty of Care imposed on all waste holders (the waste producers and the transfer operatives) to ensure that waste is both handled properly and disposed of according to the regulations. Different regulations exist for special waste (material of a toxic nature e.g. solvents or hazardous chemicals) and for packaging. As well as the legislative reasons for adopting a better waste management policy, there is sound financial benefit for industry since waste often costs around 5% of turnover. This is at odds with the statement often heard from many companies who insist "But we don't produce any waste!" Before making this judgement, it may be helpful to consider the following points:

i. Which resource does not contribute positively to the yield of the final product?

ii. Which material does not end up in the final product?

iii. Which resource does not contribute positively to the quality of the final product?

iv. Which resource adds to the cost of manufacture of the final product without increasing its value?

A waste minimisation policy can help to avoid the production of waste at source, reduce the quantity of material sent to landfill and if properly managed can provide a structured approach for the prevention of accidental pollution. The added benefits of such a policy include cost reduction and workforce education (Phillips 2000).

Tightening environmental legislations are forcing the world steel industry to develop cleaner and more efficient steel making processes. At the same time competition from substitute materials are forcing steel makers to invest in cost saving and quality enhancing technologies. In the long term, the steel industry will likely to continue to move towards more simplified and continuous manufacturing technologies that reduce the capital costs for new mill construction and allow smaller mills to operate efficiently. Thus waste minimisation and waste utilisation is fast becoming a necessity. The companies that excel will be those that have the resources and foresight to invest in such technologies. This thesis has tried to bring the above facts into consideration while studying the various aspects of waste generation, waste utilisation, waste reduction and innovations inn the field of waste utilisations. The work has been presented as follows: -

1.13 Organisation of Thesis: -

I. **Chapter-1 (This chapter):** - It gives an overview of the present research work. It describes the background, pollution economics and impetus of research. It enumerates briefly the definitions of waste, waste minimisation and waste utilisation. A brief introduction to waste prevention, recovery and safe disposal has been made. It also discusses objectives, scope of study, and limitations of research and organization of work.

II. **Chapter-2:** - It gives overall picture of solid waste generated in integrated steel plants in India and in abroad through literature survey. The trend of generation, reduction year by year and earning by sale of these waste products in respect of SAIL plants have been described in detail. Potential technologies for solid waste utilisation from pollution control and production process including refractory wastes have been listed in this chapter.

III. **Chapter-3:** - This chapter presents solid waste generated in Indian and overseas integrated steel plants. The amount of solid waste generated, chemistry of waste and management of solid waste in different plants has been listed. Specific generation of waste and their management into the extent of recycle, extent of reuse and extent of disposal (dumping) have been studied.

The technologies involved in recycling/reuse have been indicated. Then analysis has been made comparing Indian data with those of foreign plants. A micro view of the data has been taken. It is further analysed as to which routes generate maximum and minimum by product and which routes are associated with maximum and minimum dumped quantities.

IV. **Chapter-4:** - In this chapter for minimisation of wastes, minimisation measures have been indicated. For recycling/reuse, the technologies have been briefly described with the name of developer and commercial status in this chapter. Cost data for implementation could not be made available because foreign parties reply only to queries about specific projects. Problems and prospects of managing key by products which are substantially dumped at present like steel making slag, BOF dust/sludge, fly ash and spent refractory have been dealt with a length. Research gap is identified were experiments and studies were required to be conducted to help ISPs to reduce waste and utilise in a most efficient manner.

V. **Chapter-5:** - In the process of steel making, enormous amount of waste is generated which need to be reused by innovative ways. This chapter describes the process of agglomeration such as palletizing, briquetting and sintering and process of reconditioning for developing useful products. Agglomeration or reconditioning of coke breeze, iron ore fines, plate mill sludge, lime fines and dolomite fines, helped to convert them into a useful product at very nominal cost without investing money on costly technology.

VI. **Chapter-6:** - The pollution control equipments collect large amount of wastes in integrated steel plants. This chapter describes the experiments carried out for utilising these wastes.Emphasis was placed more on use of Electrostatic Precipitator Fines, Blast Furnace Sludge, Basic Oxygen Furnace Sludge, Lime Sludge and Mixed Pond Ash for converting and utilizing them in the plant itself.

VII. **Chapter-7:** - Steel making is not possible without refractory. In this chapter methods of use of removed refractory have been described. Utilisation of grog (removed refractory) viz. Fire Clay, Magnesia Carbon, High Alumina and Chrome Magnesite Brick Grog were Step by step converted to new Rejuvenated Bricks, Mortar or useful Masses. The used transformer oil viz. PCB is very hazardous. This chapter also describes the method of its destruction. A method for destruction of this hazardous waste (by incineration) has been evolved and simultaneously the heat so generated is utilised for sinter making gainfully.

VIII. **Chapter-8:** - This chapter presents the conclusions of research. General conclusions are followed by specific contribution of research work. The study has brought out achievements in management of solid & hazardous wastes. Cost involved in implementation and economics of beneficiation are described including cost of conversion and cost benefit of developed product. Recommendations have been suggested to follow up by ISPs operators. Areas that require further study are identified under scope for future work.

IX. **References:** - This includes references consulted for study and research purpose.

X. **Appendices:** - There are three appendices included in the thesis. It includes, papers published/ presented in appendix-I whereas appendices II and III depicts the biography of candidate and supervisor.

Chapter- 2

LITERATURE SURVEY—WASTE MANAGEMENT IN INTEGRATED STEEL PLANTS OPERATION -- WORLDWIDE

2.1 Introduction: -

Steel industry is the core sector industry in any country. The industrial growth and its development can be easily measured by the performance of steel industry and utilisation of steel. On global scale also the prime concern of the steel manufacturers is to increase the steel production while cutting the cost of production and its worldwide marketing.

The globalisation of steel sectors is highly dependent on regional steel market and their demand and supply. Steel industry is capital-intensive yet low return industry. In such a situation it is compelling to decrease the cost of production and the maximisation of waste management activities. A profitable use of the large amount of wastes generated in this industry can be best alternative in another industry.

This chapter is an effort to present the actual scenario of the waste management in various countries. It also details the results of various methodologies adopted for minimisation, utilisation and marketability aspects.

2.2 Literature Survey (SAIL Plants): -

In Nov 1990, a report on Solid By-Products recycling and Marketing Management was prepared after deliberations in a seminar and technical workshop held as joint venture by Environment Management Division of SAIL along with BHPE-KINHILL, whose facilitator was Mr JB Lean.

Thrust of the project work was to find out: -

i. Source of solid waste generation.
ii. Opportunities of recycling.
iii. Marketing the By-products profitably.

The workshop was aimed for marketing of waste generation from processing units and pollution control equipments:-

a) Blast Furnace (BF) Slag.
b) Steel Melting Shop (SMS) Slag.
c) Fly Ash Generation in Captive Power Plant.
d) Other products from Coke Plant.
e) Reproducing Waste etc.

Groups had done extensive work on the following: -

i) Identification of recycling possibility within steel plants and assessing timetable.
ii) Marketing opportunities of solid by-products, utilising know how to produce materials specific to market specification.

iii) Developing future action plan of development and marketing solid by-products and solving limitations faced earlier.

iv) Identify potential users and purchasers.

The team had conducted thorough discussion on the following issues: -

- Environment Control Departments functions.
- Data management of plant production.
- Socio economic implication.
- Environmental impact assessment.

Solid Waste Generation in SAIL Integrated Steel Plants (5 in nos.) is categorized in two heads: -

2.2.1 Types of Waste Generation from Processing Units: -

(a) Blast Furnace (BF) Air-Cooled Slag.

(b) BF Granulated Slag.

(c) Basic Oxygen Furnace (BOF) Slag.

(d) Twin Heath Furnace Slag.

(e) Mill Scale.

(f) Lime Fines.

(g) Dolomite Fines.

(h) Refractory Waste.

(i) Coke Breeze.

2.2.2 Types of Waste Generated from Pollution Control Units: -

(a) Sinter Plant (SP) Sludge.

(b) Blast Furnace (BF) Flue Dust.

(c) BF Sludge.

(d) Twin Hearth Furnace (THF) Sludge.

(e) Basic Oxygen Furnace (BOF) Sludge

(f) Refractory Material Plant (RMP) Sludge/Dust

(g) Acetylene Sludge

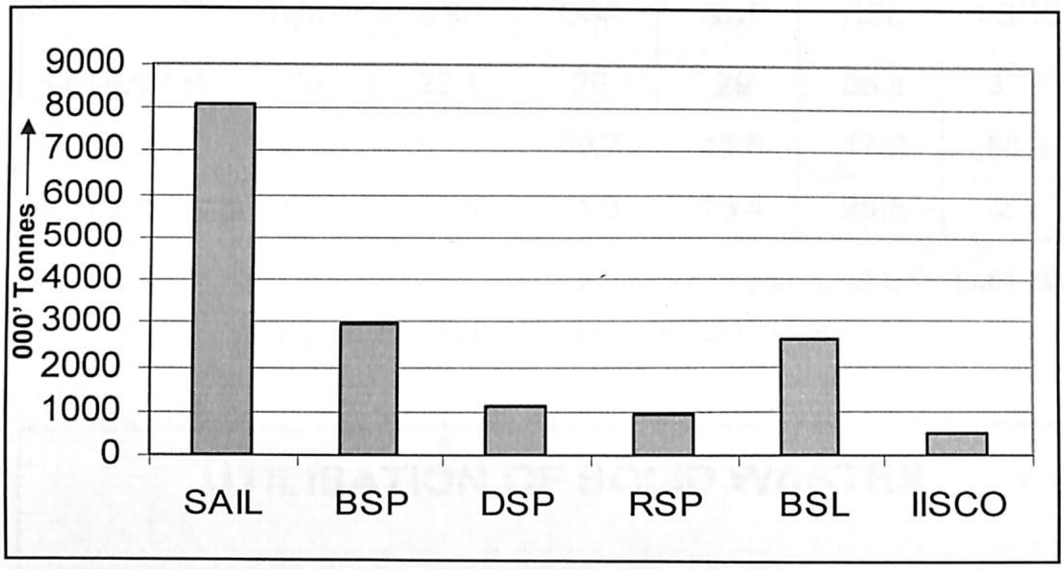
(h) Fly Ash.

SAIL is conscious of its responsibility towards creating, maintaining and ensuring a safe and clean environment. Pollution control/prevention schemes are taken up by the plants and mines on regular basis to comply with the statutory norms. Resource conservation is being taken up as one of the thrust areas whereby it can play a major role in reducing impacts on the environment besides improving the bottom line of the Company's working results. (Environment Management Division Annual Report 1999-2000). Year-wise waste from processing unit and Pollution Control Units are shown in following paragraphs: -

2.3 SAIL Report for the Year 1999-2000: -

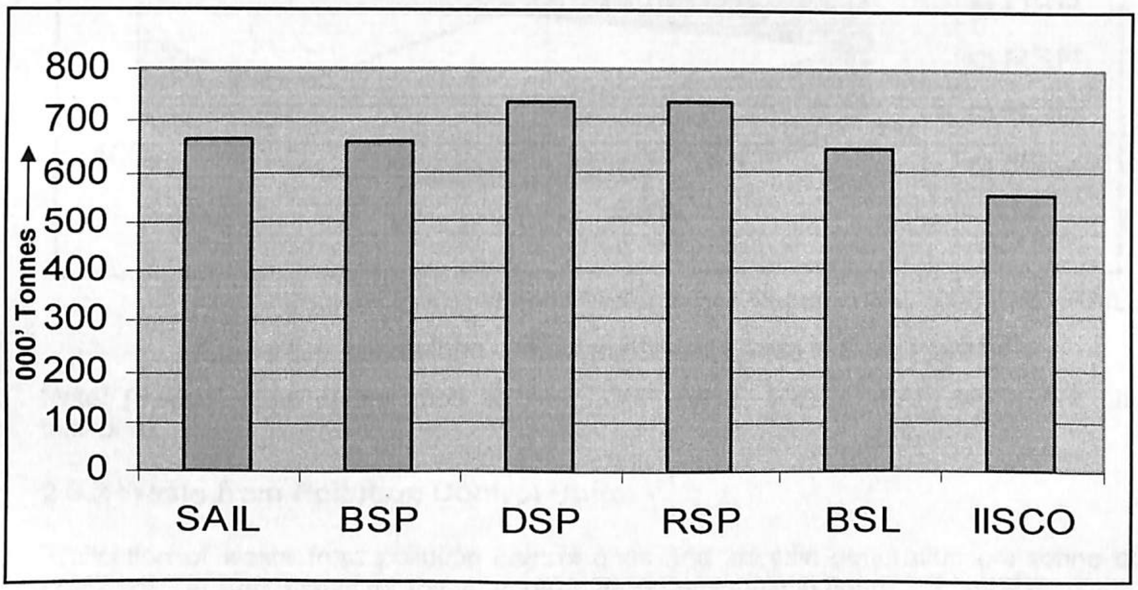
2.3.1 Waste from Processing Units: -

By studying the SAIL reports, published for the years 1999-2000 a fair idea can be obtained about the waste generation tonnage, generation rate in kg per tonne of crude steel and mode of disposal (unit%) for SAIL as a whole and individual plants in particular (reproduced in the following charts). Study reveals that in the year of 1999-2000 waste generations from processing units of SAIL plants are enormous. The same are shown in Fig 2.1 and 2.2. It also computes solid waste generation per tonne of crude steel (EPR 1999-2000).



(**Source:** Environmental Performance Report, 1999-2000 EMD, SAIL)

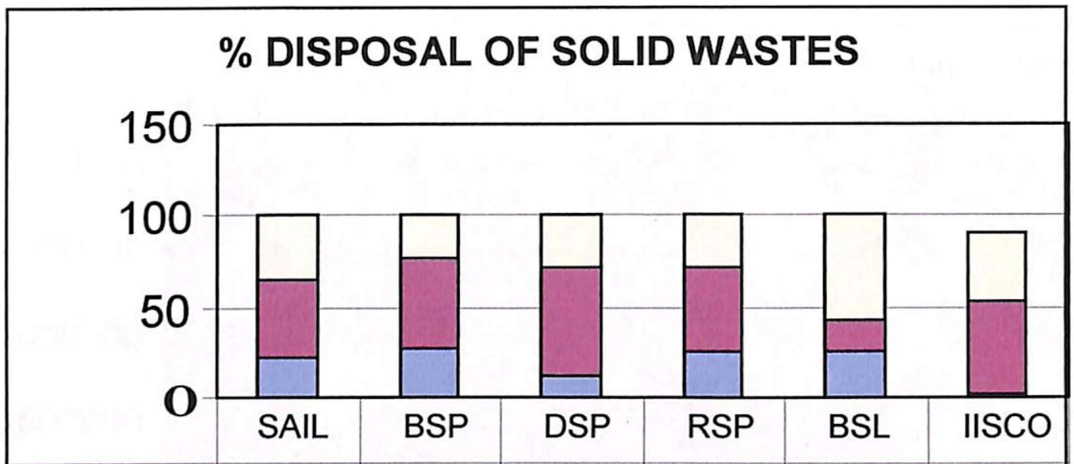
Figure 2.1: Solid Waste Generation in SAIL '99-00. Generation in (Unit X 1000 Tonnes)



(**Source:** Environmental Performance Report, 1999-2000 EMD, SAIL)

Figure 2.2: Solid Waste Generation Rate (kg/Tonnes of Crude Steel)

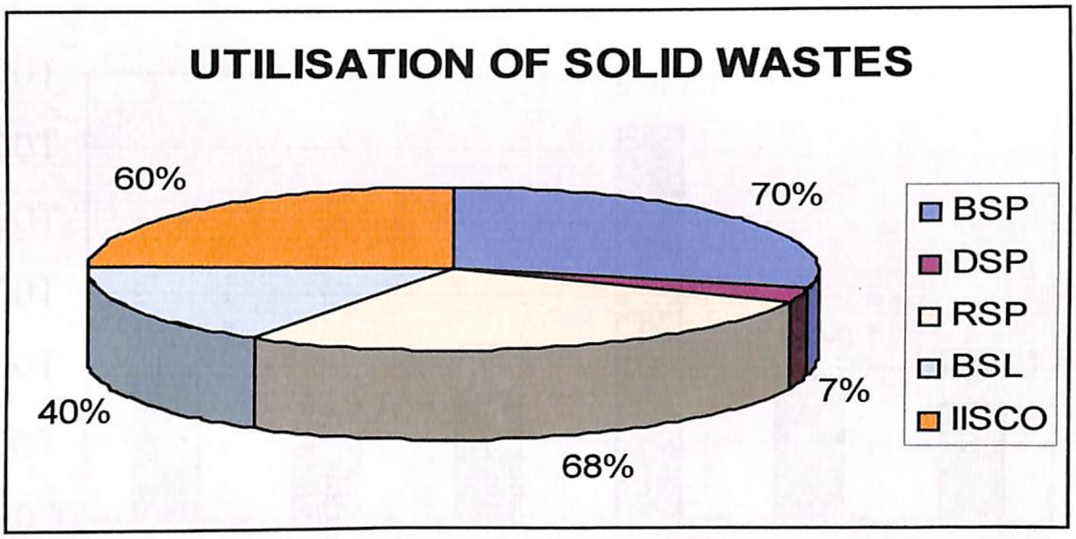
Mode of disposal and utilization of solid waste in steel plants are shown in Fig 2.3 and 2.4.



	SAIL	BSP	DSP	RSP	BSL	IISCO
DUMPED	36	23.1	28	29	56.9	37.6
SOLD	41.2	50.3	60.7	45.6	17.6	50.3
RECYCLED	22.8	26.6	11.3	25.4	25.5	2.1

(**Source:** Environmental Performance Report, 1999-2000 EMD, SAIL)

Figure 2.3: Mode of Disposal of Solid Waste



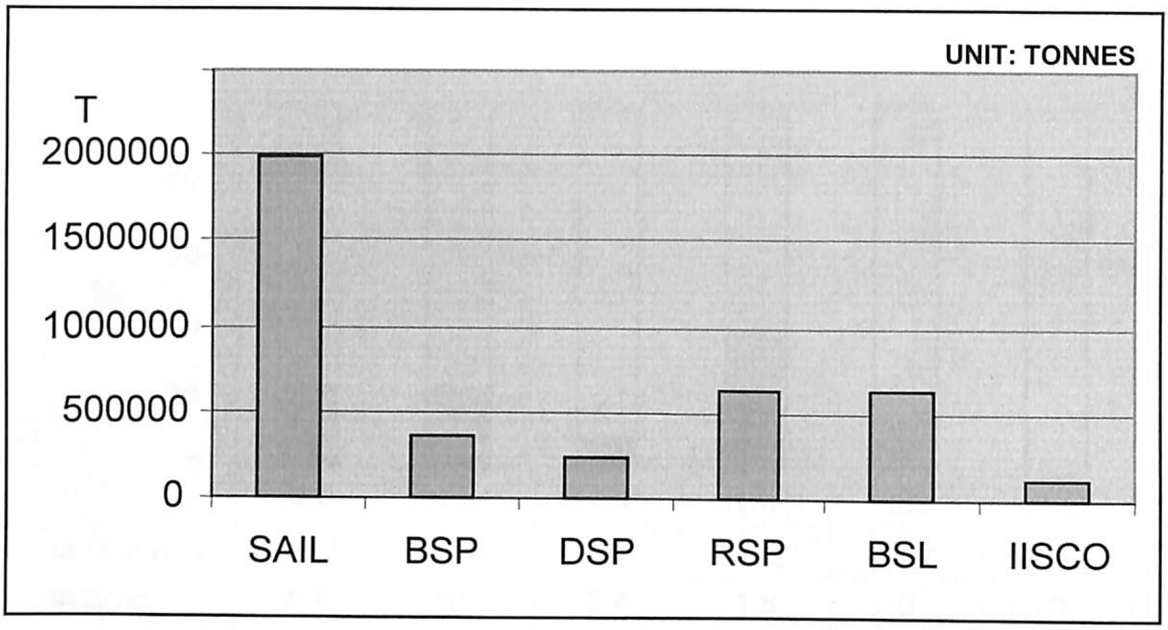
(**Source:** Environmental Performance Report, 1999-2000 EMD, SAIL)

Figure 2.4: Percentage Utilisation of Solid Waste in SAIL Plants

Note: (Special steel plants such as ASP, SSP, VISL, MEL of SAIL family are not included).

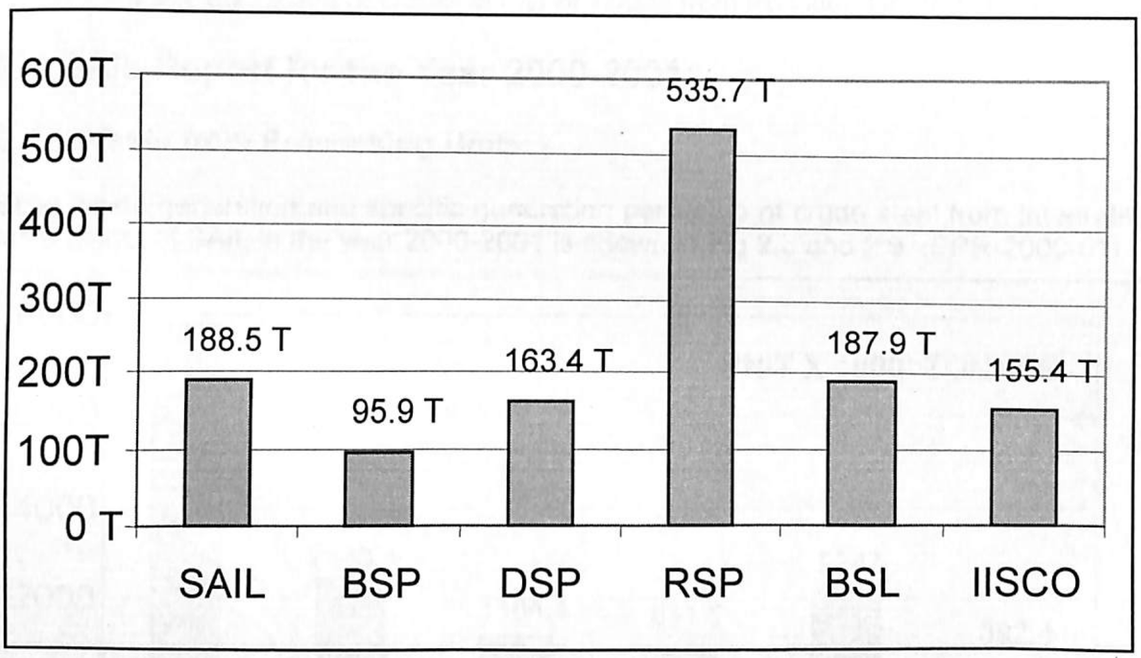
2.3.2 Waste from Pollution Control Units: -

Collection of waste from pollution control units and specific generation per tonne of crude steel in SAIL plants for the year 1999-2000 are shown in figure 2.5 and 2.6.



(**Source:** Environmental Performance Report, 1999-2000 EMD, SAIL)

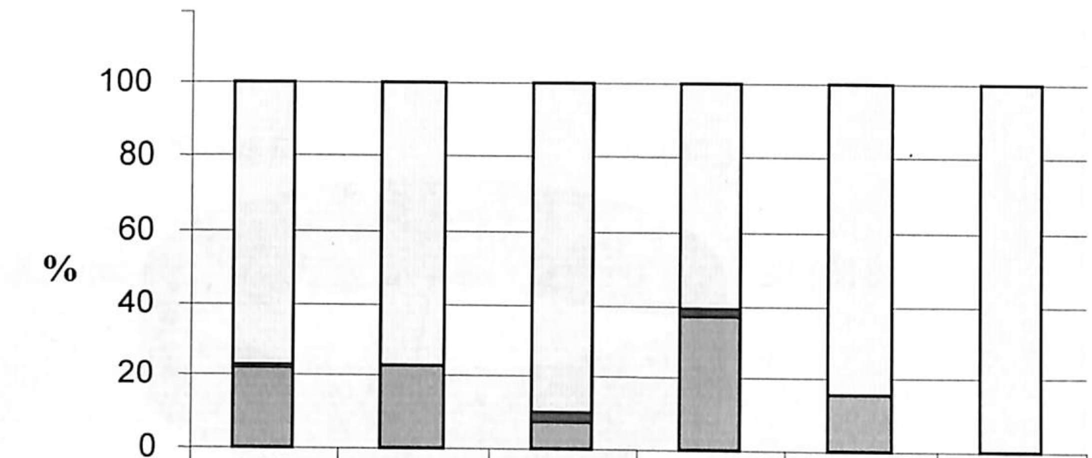
Figure 2.5: Collection of Waste from Pollution Control Units in Tonnes



(**Source:** Environmental Performance Report, 1999-2000 EMD, SAIL)

Figure 2.6: Specific Generation of Waste per Tonne of Crude Steel from Pollution Control Units (kg/Tonne of Crude Steel)

Percentage recycling, reuse and dumping of these waste is shown in Fig 2.7



	SAIL	BSP	DSP	RSP	RSL	ISSCO
Dumped	77.2	77.3	90	60.8	84.7	100
Sold	0.8	0	2.4	1.8	0	0
Recycled	22	22.7	7.6	37.5	15.3	0

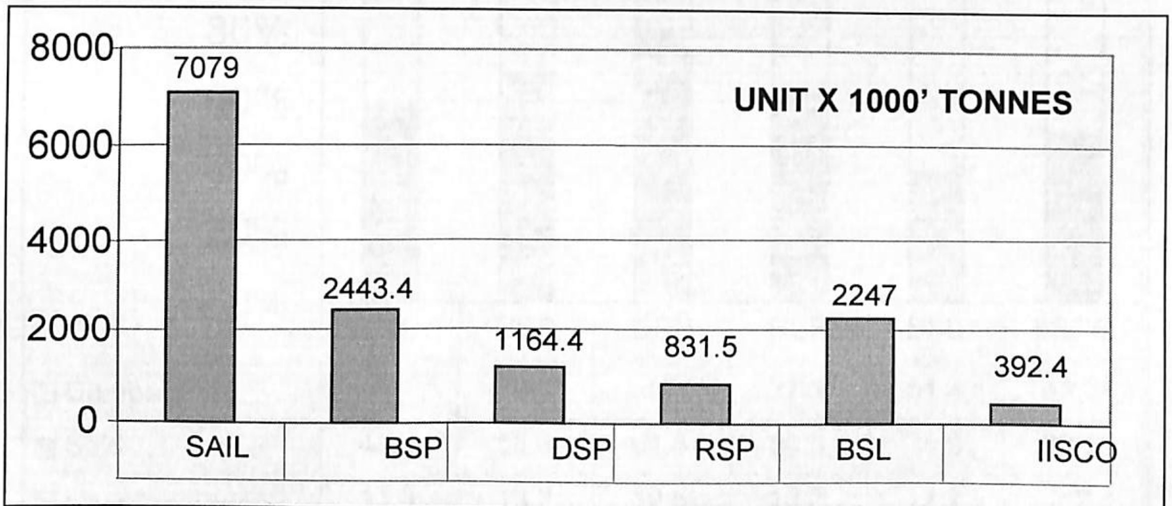
(**Source:** Environmental Performance Report, 1999-2000 EMD, SAIL)

Figure 2.7: Mode of Disposal (%) of Waste from Pollution Control Units

2.4 SAIL Report for the Year 2000-2001: -

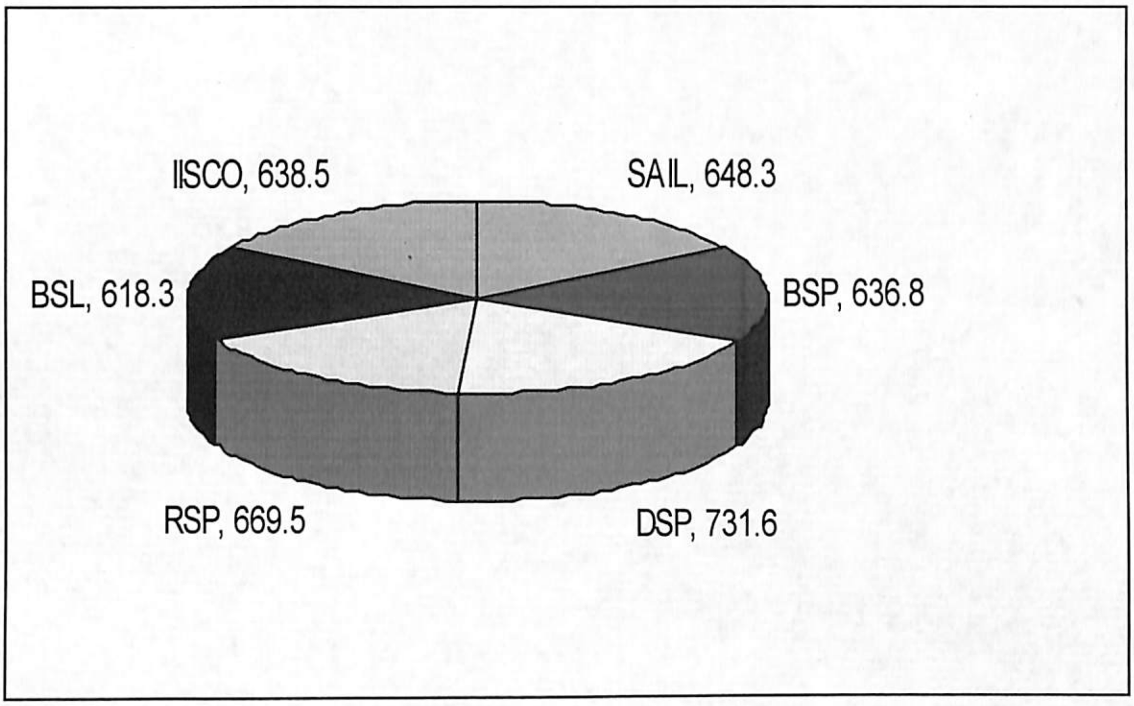
2.4.1 Waste from Processing Units: -

Solid waste generation and specific generation per tonne of crude steel from integrated steel plants of SAIL in the year 2000-2001 is shown in Fig 2.8 and 2.9. (EPR-2000-01)



(**Source:** Environmental Performance Report, 2000-2001, EMD, SAIL)

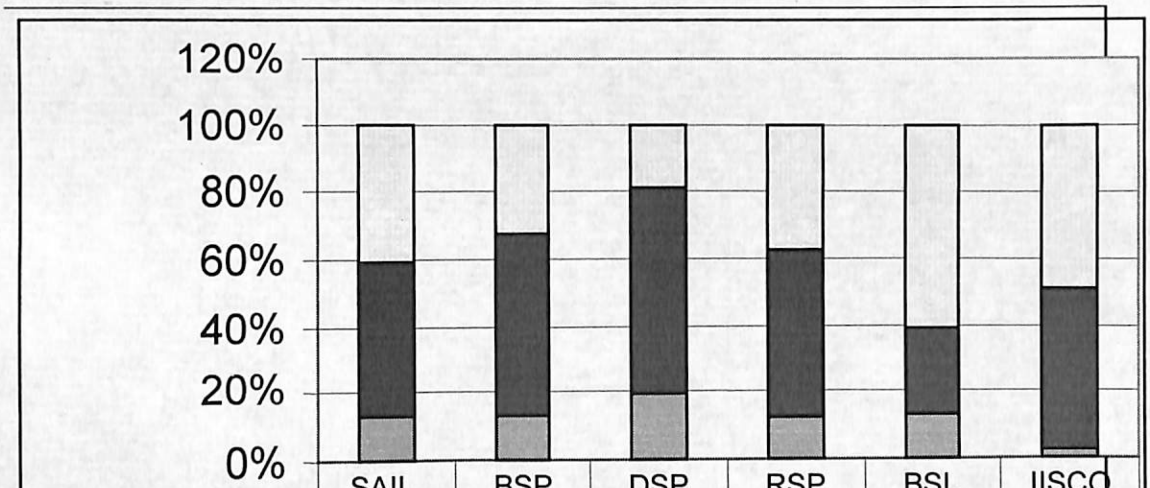
Figure 2.8: Waste Generation from Processing Units (Unit X 1000 Tonnes.)



(**Source:** Environmental Performance Report, 2000-2001 EMD, SAIL)

Figure 2.9: Solid Waste Generation Rate (kg/Tonne of Crude Steel)

Mode of disposal of solid waste in steel plants is shown in Fig 2.10.



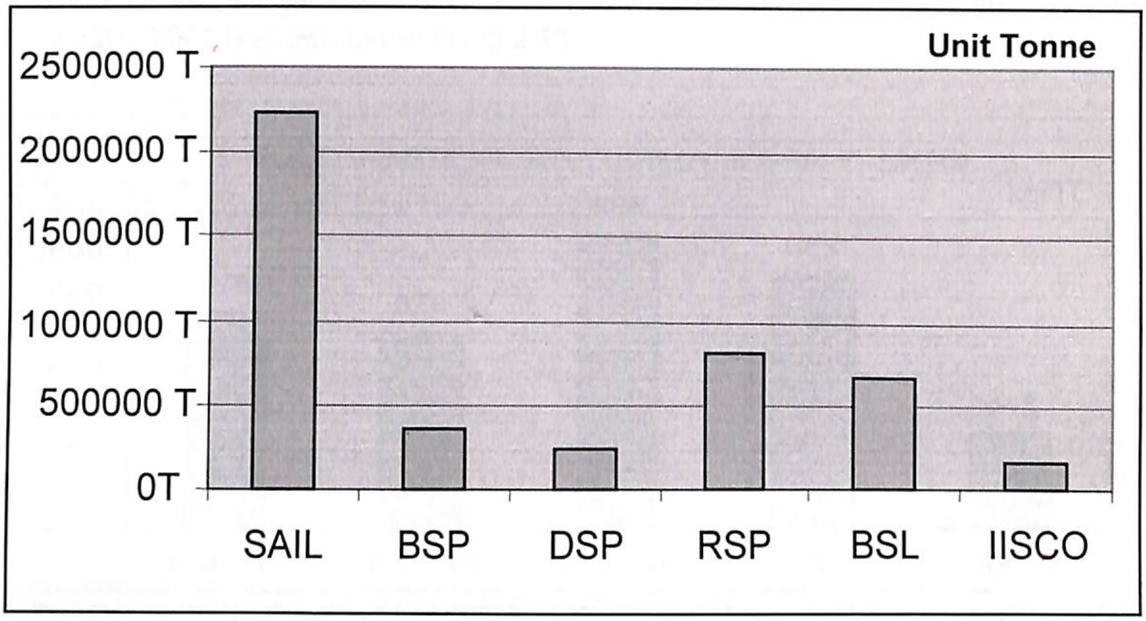
	SAIL	BSP	DSP	RSP	BSL	IISCO
Dumped	41	32.5	19	37.3	61.4	49.2
Sold	45.7	54.3	61.5	50.5	25.9	48.5
Recycled/reused	13.3	13.2	19.5	12.2	12.7	2.2

(**Source:** Environmental Performance Report, 2000-2001, EMD, SAIL)

Fig 2.10: Mode of Disposal of Solid Waste (in %)

2.4.2 Waste from Pollution Control Units: -

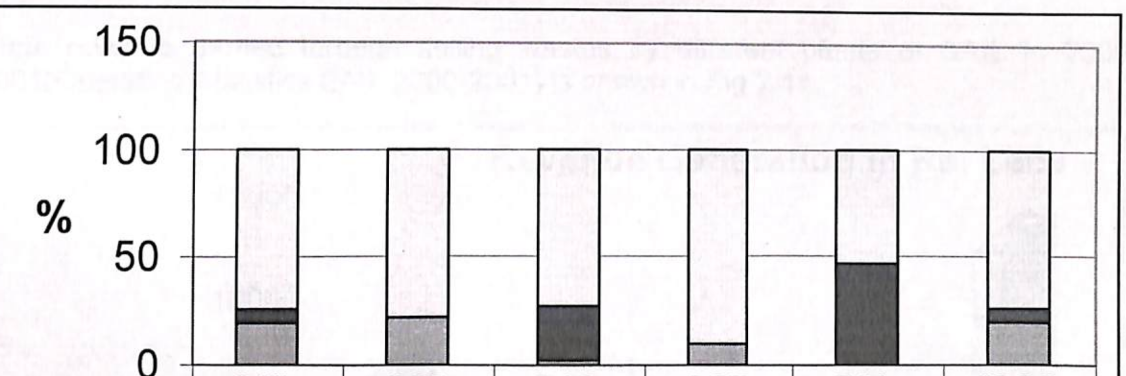
The amount of waste collected from pollution control units is shown below: -



(**Source:** Environmental Performance Report, 1999-2000 EMD, SAIL)

Figure 2.11: Collection of Waste from Pollution Control Units in Tonnes

Mode of disposal of Solid Waste from pollution control units in SAIL ISPs for the year 2000-2001 is shown in Fig 2.12.



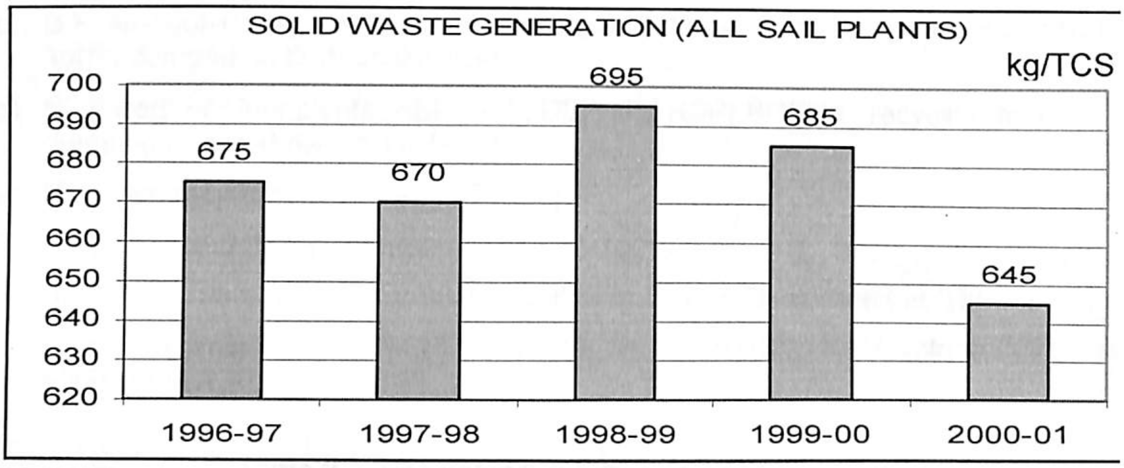
	SAIL	BSP	DSP	RSP	BSL	IISCO
□ Dumped	74.2	77.3	73.4	89.7	53.2	74.2
■ Sold	6.4	0	24.4	0.3	46.8	6.4
▨ Recycled	19.4	22.7	2.2	10	0	19.4

(**Source:** Environmental Performance Report, 2000-2001, EMD, SAIL)

Figure 2.12: Mode of disposal of Solid Waste (in %)

2.5 Trend in Solid Waste Generation and Mode of Disposal in SAIL Plants: -

Trend in solid waste generation rate (kg/Tonne of crude steel) of SAIL plants from1996-97 to 2000-2001 is shown below in Fig 2.13.



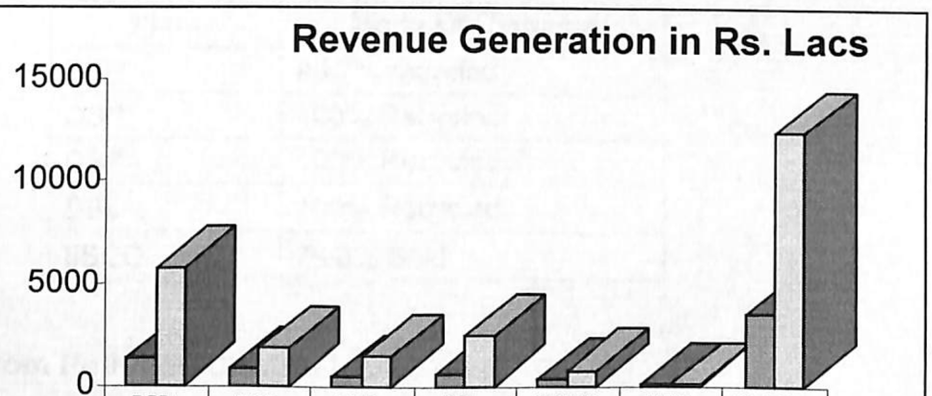
(**Source:** Environmental Performance Report, 2000-2001, EMD, SAIL)

Figure 2.13: Trend in Solid Waste Generation

It is evident that reduction is appreciable as every plant realised its impact.

2.6 Revenue Earned through Wastes by Different Plants of SAIL in the Year 2000-2001: -

Huge revenue earned through selling wastes by different plants of SAIL in 2000-2001(Operating Statistics SAIL 2000-2001) is shown in Fig 2.14.



	BSP	DSP	RSP	BSL	IISCO	VISL	TOTAL
■ SALES (000'T)	1325.92	782.82	401.97	597.95	260.49	66.39	3435.54
□ REVENUE (RS. Lacs)	5778.3	1787.84	1436.47	2451.96	756.55	72.33	12283.42

(**Source:** Environmental Performance Report, 2000-2001, EMD, SAIL)

Figure 2.14: Revenue Earned through Selling Solid Wastes by different Plants of SAIL

2.7 Disposal of Waste from ISPs of SAIL Plants (2000-01): -

From report circulated by SAIL, it was noted that disposal mode of waste from steel plants is: –

2.7.1 Waste from Processing Units: -

a) Coke breeze recycled 100%.

b) B.F. granulated Slag is sold 100%.

c) B.F. air-cooled slag – at BSP – 79% dumped, 21% sold whereas at RSP and BSL – 100% dumped, at DSP 95.9% sold.

d) BOF slag: For four plants (BSP, BSL, DSP and RSP) BOFslag recycling and dumping rate is shown in Table 2.1.

e) Mill scale recycled 75-100% (Table-2.2).

f) Lime fines and dolomite fines-recycled 75-100%.

g) BOF slag – 50% recycled at BSP and 39% at RSP, 97% dumped at BSL.

h) Refractory waste recycled – 35.9% at BSL, 76.3% at BSP, 100% sold at DSP, 50%sold at RSP.

Table 2.1: Percentage of Slag Recycling and Dumping

Plant	Recycled	Dumped
BSP	65.3%	34.7%
BSL	23.6%	76.4%
DSP	43.5%	56.5%
RSP	25.8%	74.2%

Table 2.2: Percentage of Mill Scale Recycling

Plant	Mode Of Disposal
BSP	98.7% recycled
DSP	100% Recycled
RSP	100% Recycled
BSL	100% Recycled
IISCO	76.3% Sold

2.7.2 Waste from Pollution Control Units: -

(a) SP sludge 100% recycled in all plants.

(b) B.F. flue dust recycled 41% at RSP and 100% at BSL.

(c) BOF sludge recycled 100% at BSP.

(d) Acetylene sludge recycled 100% at BSP and 100% sold at RSP.

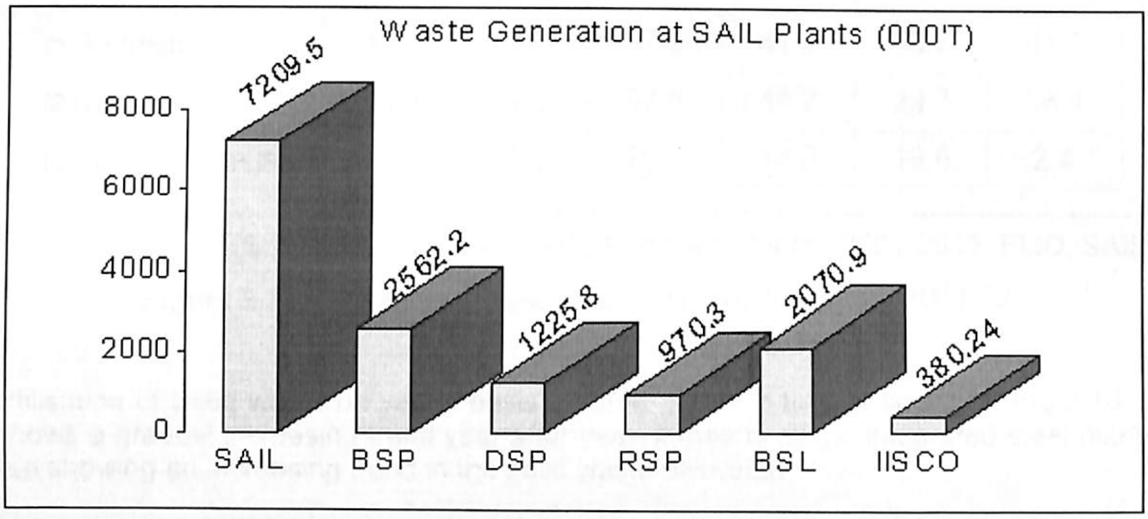
2.7.3 Waste from Captive Power plant: -

Fly ash generated from captive power plant from every plant is dumped.

2.8 SAIL Report for the Year 2001-2002: -

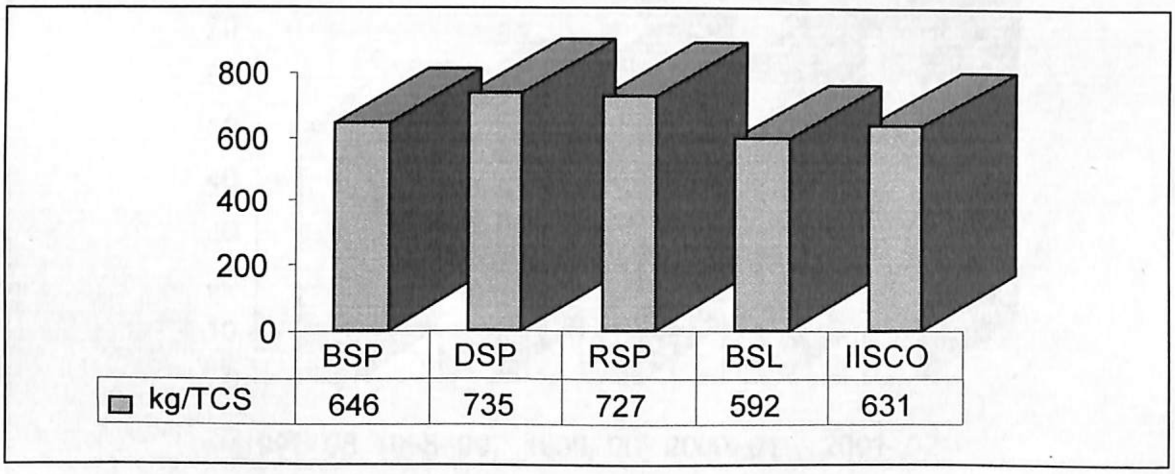
2.8.1 Waste from Processing Units: -

Solid waste management of all the Integrated Steel Plant of SAIL is described here. The quantity of waste generation and rate of generation are given below in Fig 2.15 and 2.16 respectively (EPR-2001-02).



(**Source:** Environmental Performance Report, 2001-2002, EMD, SAIL)

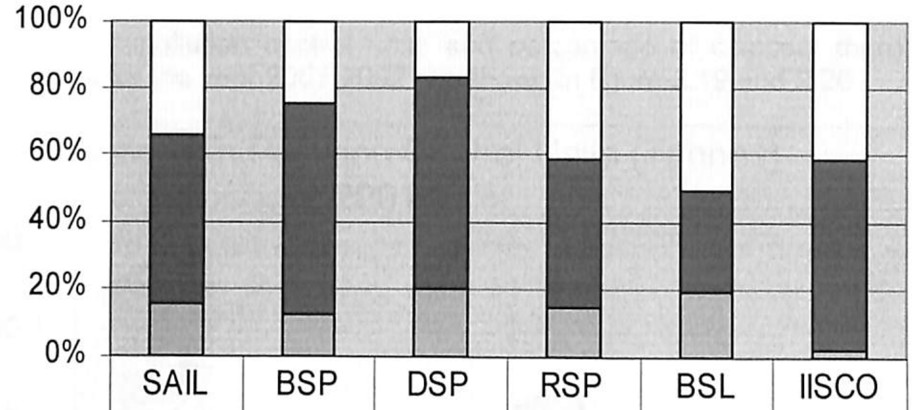
Figure 2.15: Waste Generation at SAIL Plants (Unit X1000 Tonne)



(**Source:** Environmental Performance Report, 2001-2002, EMD, SAIL)

Figure 2.16: Rate of Waste Generation

The percentage of disposal of Solid waste during 2001-02 is shown under in Fig 2.17.

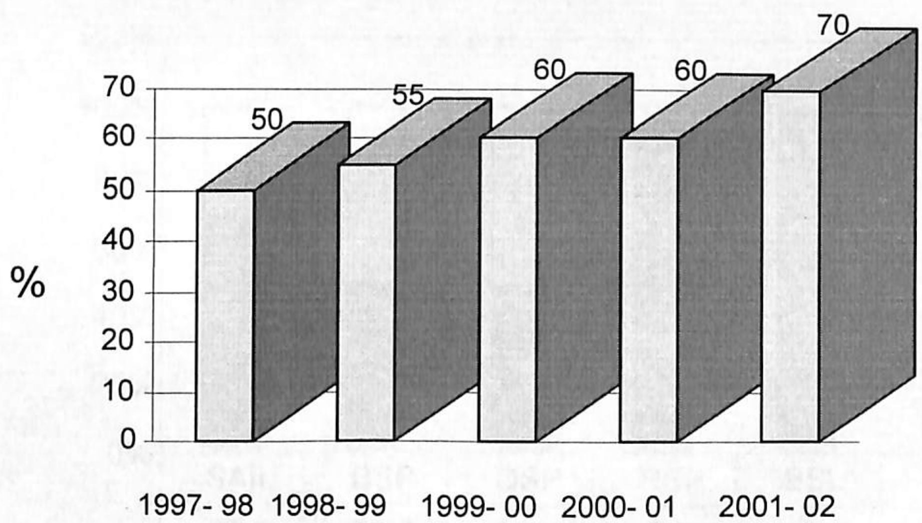


	SAIL	BSP	DSP	RSP	BSL	IISCO
□ Dumped	34.2	25.3	17.2	41.2	50.7	41.2
■ Sold	50.3	62.5	62.6	44.2	29.7	56.4
▣ Recycled/Reused	15.5	12.2	20.2	14.6	19.6	2.4

(**Source:** Environmental Performance Report, 2001-2002, EMD, SAIL)

Figure 2.17: Percentage Disposal of Solid Wastes during 2001-02

Utilisation of Solid waste on yearly basis of SAIL plants in total is shown in Fig 2.18. It shows a gradual increasing trend year after year, it means all the integrated steel plants are showing an increasing trend in the solid waste utilization.

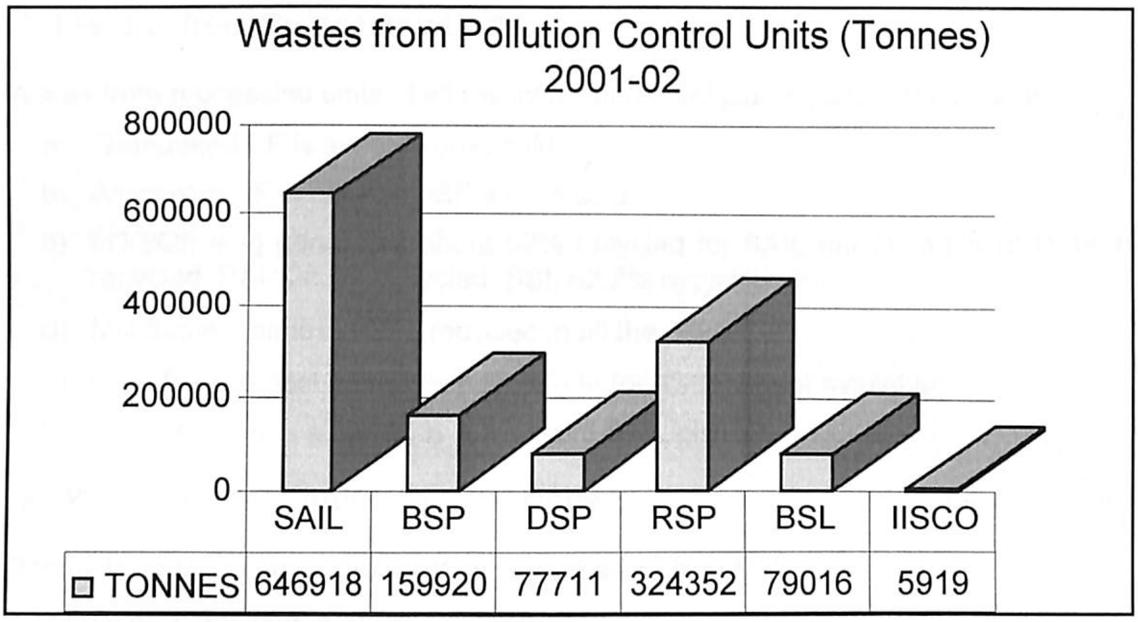


(**Source:** Environmental Performance Report, 2001-2002, EMD, SAIL

Figure 2.18: Solid Waste Utilisation of SAIL on Yearly Basis

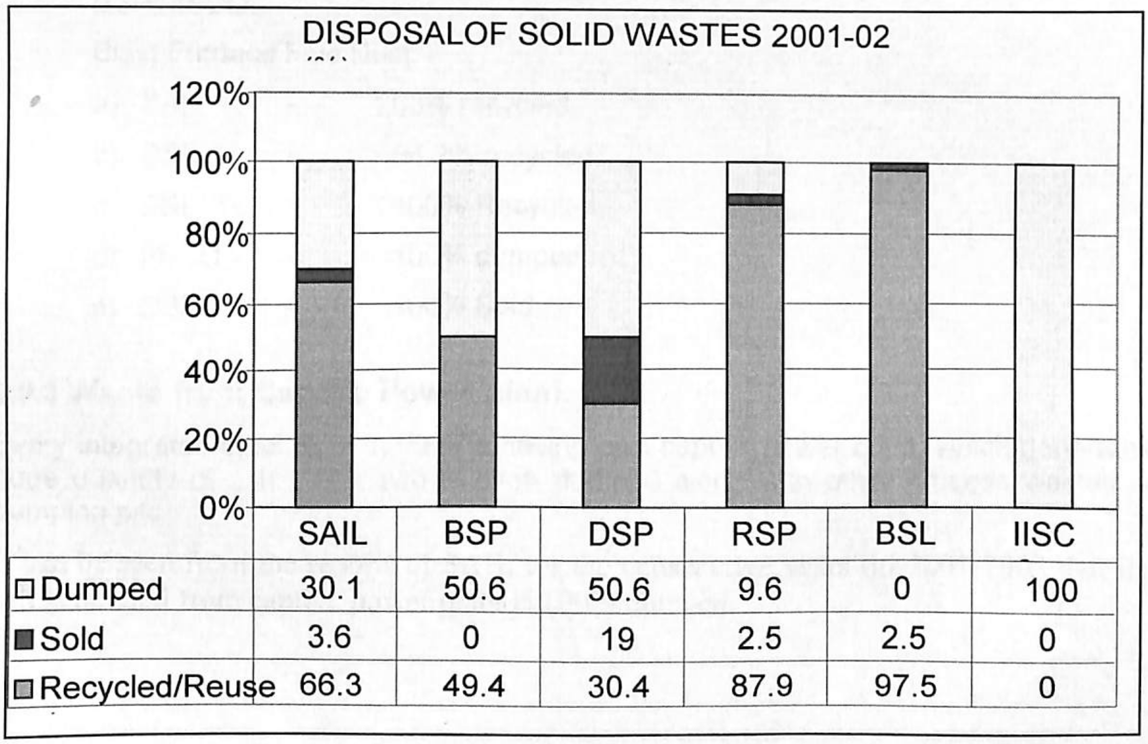
2.8.2 Waste from Pollution Control Units: -

Collection of waste from pollution control units and percentage of disposal there of through different modes for the year 2001-2002 are shown in figure 2.19 and 2.20.



(**Source:** Environmental Performance Report, 2001-2002, EMD, SAIL)

Figure 2.19: Wastes Collection from Pollution Control Units of Integrated Steel Plants of SAIL Generation (in Tonnes)



(**Source:** Environmental Performance Report, 2001-2002.EMD, SAIL)

Figure 2.20: Percentage of Disposal of Solid Waste from Pollution Control Units

2.9 Disposal of Waste from ISPs of SAIL Plants (2001-02): -

Figures of generation and disposal of waste of SAIL yearly report – points out the following:-

2.9.1 Waste from Processing Units: -

Wastes from processing units of all the integrated steel plants (SAIL) claims that:-

a) Granulated BF is almost 100% sold.

b) Air-cooled BF in case of DSP 97.5% sold.

c) LD/BOF slag generated about 52% recycled for SAIL out of which BSP 66.8% recycled, RSP 28.5% recycled, BSL 62.2% recycled.

d) Mill Scale – almost 100% recycled in all the plants.

e) Lime fines almost 100% recycled (Data for IISCO is not available)

f) Refractory fines about 51% recycled in SAIL plants.

2.9.2 Waste from Pollution Control Units: -

Wastes from Pollution control units of SAIL plants show that: -

i. Sinter plant sludge 100% recycled.

ii. LD sludge about 100% recycled at BSP.

iii. Acetylene sludge 100% recycled in BSP, where as it is 100% sold in BSL and RSP.

iv. RMP sludge/dust is 100% recycled in DSP and BSL, whereas 100% dumped in BSP, IISCO.

Blast Furnace Flue Dust: -

a) SAIL	-	63% recycled.
b) BSP	-	66.2% recycled.
c) BSL	-	100% Recycled.
d) IISCO	-	100% dumped.
e) DSP	-	100% Sold.

2.9.3 Waste from Captive Power plant: -

Every integrated steel plant in India is having own captive power plant, which generates huge quantity of ash. This ash is often dumped along with other process wastes in dumping pits.

It can be seen from the reports of SAIL for the consecutive years till 2001-2002 that fly ash generated from captive power plant is 100% dumped.

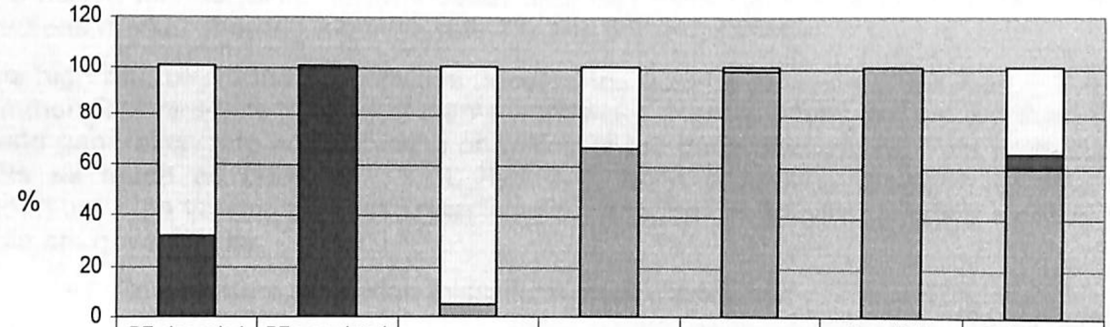
2.10 Waste From Processing Units of BSP (2001-02): -

Table 2.3: Waste from Processing Units at BSP (2001-02): -

(Unit X1000 Tonnes)

Type of Waste	Quantity (Unit X1000 Tonnes)
BF Air Granulated slag	328.34
BF granulated slag	1494.84
OHP/THF slag	366.99
LD/BOF slag	199.90
Mill scale	82.38
Lime fines & dolomite fines	64.74
Refractory wastes	25.30
TOTAL	2562.22

The percentage of Disposal of Solid Waste through different modes in BSP during 2001-02 is appended in Fig 2.21.



	BF air cooled slag	BF granulated slag	THF slag	BOF slag	Mill scale	Lime+Dolo fines	Refractory waste
□ Dumped	68.2	0	95	33.2	1.2	0	35.1
■ Sold	31.8	100	0	0	0	0	5.6
▨ Recycled	0	0	5	66.8	98.8	100	59.3

(**Source:** Environmental Performance Report, 2001-2002, EMD, SAIL)

Fig 2.21: Percentage of Disposal of Solid Waste through different Modes in BSP during 2001-02

2.11 Revenue Earned through Selling Wastes by Different Plants of SAIL in the Year 2001-2002: -

All these exercises are done in all the steel plants of SAIL with prime intention to generate revenue and it is worth to learn about the revenue earned by SAIL, by selling plant wastes. Break up is given where some of special plants figures are also included: -

Table 2.4: Earnings from Disposal of Solid Waste during 2001-02.

Plant	Quantity sold (Tonnes)	Earning (Rs. Lakhs.)
BSP	1745207.00	7426.90
DSP	812050.00	2384.90
RSP	437347.00	1609.50
BSL	622691.00	3083.70
IISCO	274814.00	836.70
ASP	146.00	7.74
SSP	347.00	2.76
VISP	87501.00	162.20
MEL	32047.00	102.60
TOTAL		15617.00

Socio economic activities of present century are based on mass production, mass consumption and mass disposal. SAIL is the biggest conglomerate of steel making in India. Figures of saleable steel produced and sold in the financial year 2002-2003 is 10.3 million tonnes (SAIL news release) and 10.1 million tonnes sold in domestic and overseas market showing a growth rate 7% and 6% respectively.

This high rate of production activities boosted the volume of waste generation. It is a common feature exists in all steel plants worldwide. Hence, efforts are on to reduce the waste generation rate and recycling or selling of the generated arising from production units as much as possible. SAIL has long been promoting recycling of wastes generated from various process units. Waste management activities in steel industry in India are governed by: -

- Environment regulation (classification of waste).
- Financial incentives (disposal fees)

However, the problem of fly ash generation from captive power plants of SAIL steel Plants remains the biggest challenge. As per the Central Govt's Rules and Regulations it has become mandatory for plant owners to recycle fly ash instead of dumping in the land areas. Disposal of fly ash generation in captive power plant is a major problem the world over.

Some pioneering work has been carried out by the following agencies: -

- Central Building Research Institute, Roorkee.
- Central Power Research Institute, Bangalore.
- AEC Cement and Construction Ltd., Ahmedabad.
- RDCIS, Ranchi.
- R R L Bhopal

The potential technologies for fly ash utilisation are mentioned below: -

2.12 Literature Survey- Potential Technologies for Solid Waste Utilisation from Pollution Control Units: -

2.12.1 Fly Ash: -

Fly ash, generated in captive power plants, is generally disposed of in slurry form along with ground sinder ash. They are dumped, in mixed form, in ash ponds especially dug for this purpose. Digging of ponds has become very expensive, furthermore the regulation restricts for the dumping of fly ash. Therefore, massive utilisation is the only solution and for captive power plant owners, it has become mandatory to utilise fly ash effectively for areas such as brick making, cement and base stabilization for road making, glazed tiles, light weight aggregate and refractory products etc. (Kumar and Sharma 1999).

A) Brick Making: -

<u>i) CLAY-FLY ASH BRICK MAKING:</u> -

Central Building Research Institute, Roorkee, Central Power Research Institute, Bangalore, AEC Cements and Construction Ltd., Ahmedabad and RDCIS, Ranchi has developed the clay-fly ash burnt brick/block manufacturing technologies (Prabhakar *et al* 1999).

<u>ii) LIME-FLY ASH BRICK MAKING: -</u>

Central Fuel Research Institute, Dhanbad, Central Building Research Institute, Roorkee and RDCIS, Ranchi has developed technologies for manufacturing lime-fly ash bricks in which strength is imparted by autoclaving. M/s AEC Cements and Construction Ltd. claim to have developed fly ash lime stabilised brick making technology. This technology does not require heating, steaming or autoclaving.

<u>iii) FLY ASH, LIME AND GYPSUM BRICK MAKING: -</u>

Fly ash, Lime and Gypsum are the constituents of brick/block. Process is known as Fal-G technology with the company's headquarters at Visakhapatnam.

B) Portland Pozzolana Cement (PPC): -

Depending on the quality of cement clinker and the fly ash, it is claimed that 10-25 percent fly ash can be blended in the cement to produce Portland pozzolana cement. Dry fly ash is preferred in production of PPC as well as for mixing on site (Kathal and Mukherjee1999).

C) Aggregate Making: -

Aggregate making technology have been developed by Central Power Research Institute, Bangalore, Aardelite Holding BV of Netherland and RDCIS, Ranchi. CPRI, Bangalore uses heat-hardening technique for imparting strength whereas RDCIS reports indicate that process requires autoclaving and Aardelite steam curing for 16-18 hours.

D) Road Making: -

Fly ash can be used for soil stabilisation for road construction and in highway and embankment construction. In this process fly ash is mixed with an appropriate amount of soil and lime and then compacted. IIT, Kanpur and Central Road Research Institute, New Delhi has done extensive work in this area.

E) Refractory Products: -

Regional Research Laboratory, Bhubaneshwar claim to have developed technology for producing hot face insulating refractory and fire clay range of products. By using beneficiated fly ash up to 60% and plastic fire clay and grog in different proportions the fire clay range of refractory materials and hot face insulation bricks are produced.

F) Ceramic Tiles: -

Central Power Research Institute, Bangalore has developed technology for production of fly ash based wall tiles, floor tiles and acid resistant bricks and tiles.

G) Soil Amendments: -

Fly ash can be used for soil amendment, which helps in higher production of agriculture and horticultural species. RDCIS has done detailed studies on the effects of fly ash addition in soil for growing various horticultural species. The study is continuing in collaboration with Birsa Agriculture University, Kanke, Ranchi on" Effect of Fly Ash on Agricultural and Forestry Species". It has been concluded from the studies so far that the fly ash amended soil leads to higher production. There is a possibility of using fly ash for landscaping and growing trees by the steel plants.

H) Road Making: -

Developed countries like France, Australia and Holland are making and using gravel slag and all slag roads in which up to 100% of steel plant wastes like BF and SMS slag, granulated BF slag and fly ash are utilised. RDCIS is conducting a study (with samples from Bokaro) jointly with Central Road Research Institute, New Delhi and is trying to develop a suitable combination for making high density-heavy duty roads with steel plant wastes. SAIL is exploring avenues to utilise blast furnace slag in the form of boulders for arresting erosion of the embankment of river Hoogly and Digha sea beach.

2.12.2 Slag Utilisation: -

A) Rail Ballast: -

SAIL's SMS slag has technically been found suitable for use in rail ballast. Negotiation is therefore going on between SAIL and the Railway authorities. SAIL plants must ensure installation of necessary crushing and sizing facilities so that sized material can be supplied to the Railways (Mukherjee and Chakraborty 1999).

B) Road Making: -

SMS slag has already been successfully used as road making aggregate in BSP, BSL & RSP in place of stone chips. Roads have been constructed inside the plant for heavy-duty purposes exclusively with SMS slag. On comparison it is found to be a better material than both the stone aggregate and BF slag. Necessary efforts must be taken to gain approval by IRC & BIS for these products so that regular utilisation by Road Authorities takes place (Agrawal and Bajpai 2000).

C) Soil Conditioner: -

The basicity of the SMS slag makes it a good liming material for acidic soil. Phosphorous in the slag acts as nutrient to the soil. Therefore SMS slag can be used as soil conditioner. However, SMS slag is required to be ground to very fine size for this purpose. Therefore, a special arrangement for auto grinding technique has been developed. In this process, suitable additives carrying CaO are added to the molten SMS slag and stirred well. On dumping and cooling; the slag disintegrates on its own and becomes powder.

D) Filling Material: -

The finer SMS slag received after crushing and screening of bigger pieces can be used as filler material along with fly ash and fine size BF slag.

E) Cement Making: -

The literature indicates that China, Japan and Germany are already using SMS slag in varying amounts in cement making. RDCIS has initiated a joint study with the National Council for Cement and Building Materials (NCB), where SMS slag is proposed to be used as (i) Raw materials for production of Ordinary Portland cement and (ii) An Admixture in Portland slag cement. SAIL, is also jointly working with R&D Group of ACC for making steel slag cement The effect of grinding characteristics shall also be studied for conventional and newly developed auto grinding techniques so that grinding cost is reduced(Ghal and Noseworthy 1998).

2.12.3 Refractory Waste: -

The waste refractory is disposed in three manners: (a) reusable parts of salvaged refractory are recycled to the plant, (b) broken pieces are recycle/sold to outside parties, (c) remaining debris is dumped as a waste. The source of salvaged basic refractory is OHF/THF, Converter, Lime/Dolomite Plant and Rotary Kiln. They are reprocessed to produce various granular products in the mass powder shop in Bokaro and Bhilai Steel Plants. Other plants get it recycled through external refractory processing units in their vicinity. DSP and RSP are recycling their basic refractory through external agencies (Agrawal and Bajpai1999).

RDCIS has developed the technologies for reuse/recycling of the following removed refractory: -

- Salvaged MgO-C refractory can be reused for production of carbonaceous mix.
- Fire clay/High alumina refractory can be used to produce different grades of castable and mortar.
- High alumina castable can be made out of the salvaged slide gate refractory like plate, nozzle, etc.

The technology developed by RDCIS for production of chemical bonded Mg-Chrome bricks and ramming mass out of the salvaged basic refractory like Magnesite, Mag-Chrome and Chrome-Mag is being used by IISCO through a private firm at Asansol (M/s Kavita Refractory). This technology can be used and implemented in all other plants for higher earning/saving through recycling.

2.12.4 Acid Sludge: -

Benzol refining scheme at BSL and BSP involves washing crude benzol with concentrated sulphuric acid (98%) to remove unsaturated hydrocarbons and sulphur products prior to distillation into saleable products – Benzene, Toluene, Xylene etc. Acid washing of benzol generates about 4000 T/Year of acid sludge at BSP and BSL. This is a waste product and pollution hazard, posing a serious problem of disposal. Besides this, there is loss of sulphuric acid and benzene (Viswanathan and Gangadharan 1996).

A process technology has been developed by RDCIS after extensive laboratory, bench and pilot scale experimentation for regeneration of this sludge into usable acid.

The amount of regenerated acid produced corresponds to an annual saving of 840 tonnes of sulphur, which will have to be otherwise imported. Thus there is an annual saving of Rs.25 lakhs in foreign exchange in each plant.

The process enables recovery of sulphuric acid to a level of 85-90% of 20-21% strength from acid sludge and used polymer as fuel.

2.13 Survey Report in Japan Steel Industries - Year 2000: -

In Japan, against a background of alarmingly strained capacities of waste disposal system, the recycling need and global environment issue, the basic laws for promotion recycling society have been enacted. Legislation prescribes minimization of wastes by re-use of products, recycling, efficient heat recovery etc. Initiatives for a sustainable society based on total recovery and recycling of resources were taken up.

Nippon Steel is the leading steel company of Japan. Nippon Steel – apart from recycling products generated in their own industry (steel) are attempting to recycle produce of other industries such as tyres, plastic etc. Japan produces about 100 million tonnes of steel products yearly, which are used in manufacturing/constructing or varied other important application such as manufacture of buildings, roads, bridges, automobiles, electrical machines etc. About 1.3 billion tonnes of such used products are accumulated throughout Japan. Once structural members, and these products have served their original use then the steel itself is retrieved and reused for new application as valuable raw material. At present about 30 million tonnes are retrieved annually (Environmental Report 2000).

2.13.1 Recycling of By-Products: -

Each year approximately 40 million tonnes by-products are generated from steel making process. Recycling rate in % year wise is as follows: -

- In the year 1976 was 69%
- In the year 1980 was 89%.
- In the year 1998 was 99%.
- In the year 1999 was 99%

Goal for the 2010 is 99%.

Of these recycled material 90% comes from slag use. In steel industry100% BF slag is reused annually as raw material for cement, material substitute for sand etc.

About 96% BOF slag used for soil conservation, civil construction, stabilization and construction of roads beds etc. About 90% of dust and sludge is also recycled.

Nippon steel in the year 1999 – realised a recycling rate of 98% and one of the main target of R&D was focused on removing Zinc from dust and sludge and improving the quality of slag (Shigemi and Fujita 1980).

2.13.2 Disposal Targets Achieved and Goal Set in 2010 Year: -

Disposal target year	Unit x 1000 Tonnes.
1990	385.0
1998	130.0
2010	100.0

2.13.3 Recycling Steel Can in Japan: -

Year	% Recycled
1900	45%
1995	73%
1998	82%

Various steps are taken together to recycle the used product and also provide financial help/support to recycling facilities. This helps to achieve these figures.

2.13.4 Recycling of Dust and Sludge: -

Nippon Steel recycles and sells about 85% dust generated in steel plants by introducing new technological process (Shigeru *et al* 1997).

2.13.5 Recycling BF and BOF Slag: -

Total slag produced in Japan is yearly about 1165 MT/year. It is mostly recycled for producing processed materials and supplied to: -

Cement industry	40%
Concrete industry	5%
Soil improvement	7%
Road sub base	14%
Civil construction	15%

Blast furnace slag cement (not granulated slag cement) produced by Nippon Steel has been awarded ecology mark and is used effectively for resistance to temperate cracking in large structures, durability against salt damage and alkali aggregate in coastal structure. Apart from above, its contributes to the protection of global environment through conservation of energy and saving CO_2 emission reduction as is evident from Table2.5

Table 2.5: CO_2 Emission and Comparison of Fuel Consumption

Comparison	CO_2 Emission (Carbon Equivalent)	Fuel Consumption		
		Lime	Fuel (Coal Equivalent)	Power (kWh)
Portland Cement (A)	207 kg	1,049 kg.	110 kg.	104
BF Cement (B)	122 kg.	592 kg.	63 kg.	88
(A) – (B)	85 kg.	457 kg.	47 kg.	16

Recycling of plastics (waste) process developed by Nippon Steel (which has a special importance to Indian society and industries to follow) and company is experimenting with good results of using waste plastics in coke ovens, BFs etc. At Nagoya works and at Kimitsu works waste plastics re-commercialisation system came on stream in the month of October and November of 2000 respectively. Each system has a recycling capacity of 10,000 tonnes/year. Japan government approved the process. It is known as chemical recycling technology.

2.14 Literature Survey on South Korean Steel Industry: -

Posco steel is the leading steel manufacturer of South Korea. Following is the excerpt from environmental progress report on a sound and sustainable developments (SHE Report 2000): -

For by product management in iron and steel making process, plant has developed: -

- Improved technology to reduce by product generation.
- Value addition to by-product.

Posco generated about 20 million tonnes by-products in the year 2000 in which major constituent is from: -

49% BF slag.

29% BOF slag.

7% Dust and sludge.

As per survey report, from 77% in 1997, recycling ratio has increased to 96% in the year 2000. Main use of BOF slag is in civil works and sludge used as raw material for cement. BF granulated slag is 100% recycled and put in cement industry. Air-cooled slag was used as roadbed material. Some of B.F. slag is used as fertilizer and building material. Steel making slag after processing (in house practice developed) is processed in plant to reclaim/retrieve residual iron for recycling. The fine particle of steel making slag is used in cement making and large pieces are used in making roads, harbor and other civil works. 82% of sludge is recycled in the year 2000.

POHANG WORKS OF POSCO, KOREA : -

Generation and extent of recycling/reuse at iron making are furnished in Table 2.6: -

Table 2.6: Generation and Extent of Recycling/Reuse of Waste Materials

Shop	Type of Waste	Generation-T/year	Recycling/Reuse-%	Treatment Method
Blast Furnace	DC Dust	185144	100	Blending
	CH Dust	17639	100	Sale
	Bin Dust	41777	100	Reuse
	Sludge	95011	0	Landfill
Sinter Plant	REP Dust	103371	100	Reuse
	WEP Dust	16113	0	Landfill
Lime Kiln	Sludge	108000	28	Sale, Landfill
	Dust	29952	100	Blending
	Flue Dust	7200	100	Reuse
	Coal Dust	20676	100	PCI
Spillage		102000	100	Blending
Fines of TiO_2		58203	100	Blending
TOTAL		813886		

(Source: Environmental Progress Report, 2001, POSCO)

In plant recycling of iron making waste is being maximized. (Chul Ho kim and Jung1997).

Pohang plant utilises 98% dust generated while figure shows 91% at Kwangyang works.

PASCO'S THRUST AREA: -

i. Constant up gradation of process, by-product generation at source has reduced.
ii. Technology development to recycle slag generation per tonnes of steel produced.
iii. Operating on environment friendly manner to increase volume of waste recycle.
iv. Technology development for value addition to recycle by products.

As per Posco management, these steps are important in the interest of conserving resource and restricting pollution of environment. Global warming is a threat to all and to prevent it by suppressing production of CO_2 and other green house gases. Hence technology development is underway to reduce CO_2 emission in atmosphere and to cut down consumption of fossil fuel use (Ho Kim and Jung1998).

2.15 Literature Survey Corus Stall BV (Germany): -

SHE Report 2000 of Corus Stall BV (Germany), paper has given a special attention to a very important area i.e. water pollutants by various suspended solids and other harmful contents .Suspended solids discharge T/year varied is as follows: -

Year	Discharge (Tonnes)
1985	about 6000
1998	about 900
2000	about 200

Whereas suspended solids kg/Tonne of crude steel (TCS) is as follows: -

Year	Rate (kg/TCS)
1995	1.20
1998	0.30
2000	0.10

Pb (Lead) discharge is about 0.2 kg/T of crude steel. Zn (Zinc) discharge is about 0.6 kg/T of crude steel. One more important pollutant of water is oil discharge from Rolling Mills.

Chlorination of cooling water: - To prevent biological growth in cooling water system, massive work was done to add oxidizing biocides to cooling water.

In year 2000 waste products and residues released during production of steel is about 2.9 million tonnes but reduction is about 150,000 tonnes from previous year.

99% of waste is recycled. Almost 2.0 million tonnes of waste products are usually used outside steel industry. This includes BF slag, BOF slag. CORUS Steel has undertaken Location Specific Soil Management Plan (LSSP) to remove the risks that existing soil contamination poses problem for people and the environment.

2.16 Environnent Report 1998 (Plant Rautaruukki – Finland) : -

The plant in Finland is quite advanced in respect of waste recycling. More thrust has been given for in plant recycling (Environ mental Report 1998 Rautaruukki).

2.16.1 By Products and Internal Recycling: -

Some of the valuable by products produced during the manufacture of steel: -

- Tar, Benzol, Sulphur recovered as by-products at coke plant and sold as raw material to chemical industries.
- Gases recovered from coke oven and blast furnaces are used for electricity production and as fuels waste heat produced used in inside works and sold as district heating of local community.

But only with a question mark about emission of CO_2 and NO_2 though use of these gases reduces electricity charge, may be it takes care of negative cost of the process.

Zinc dross from galvanizing process is recycled and sold as raw material for zinc product. Recycled BF slag granulated and air-cooled sold outside in other related industries.

Similarly BOF slag reprocessed in the plant and than sold out. Figure shows pattern of– uses of slag at Raahe and Koverher work in the year 1997: -

Road cycling	42%
Industrial sale	22%
Soil improvement	22%
Export & Trading	2%
Steel Works Services	12%

Rautaruukki Steel Management gives a very special attention towards transportation of raw material and finished product as mode of transport is mainly on road transport and than by ship and rail. About 9.0 million tonne steel is transported. Main objective of environment control is to introduce on road transport and avoid noise pollution.

2.17 Literature Survey: -

The problems and issues have been addressed on the waste minimization and management. To mention few: -

i) Severe problems arise for BF operation of recycled in BF through sinter of the residual metals, Zinc and Lead and non volatile metals "Copper" report to hot metal.

ii) A Coke plant waste present special problem with toxic organic constitutes.

As a solution development for Pt (i), he has suggested "use of hydro cyclone process for removing costly Zinc +Lead in the Blast Furnaces/Sinter Plant circuit. A plan was proposed for one of Bethlehem's integrated steel plant – USA.

Another concludes with the suggestion is that, treatment of steel plant waste to facilitate maximum recycling needs 1) Funds 2) To search out vendors who can offer effective, low cost technical solution (Weidner 1990).

Kakogawa Steel Works continuously approach to deal with various slag, dust, sludge generation in plant and also about technological developments adopted to sort out the problems of arising at present condition and management system to understand problem and its solution.

2.18 Raahe Steel Works (Rautaaruukki Group) Finland: -

Of the total generation of 9,76,000 T of by-products in 1991, about 25% are recycled and 67% are upgraded into marketable products and sold out and the balance 8% is dumped. The share of 67% among the market segments is 10% to steel industry, 15% to civil and road construction, 6% to building material industry, 13% for soil improvement and 23% to export market. (Pamplet SKJ 1997).

2.19 United States: -

Generation of electric arc furnace (EAF) slag in USA in 1994 was 11.6% of crude steel production. Generation of scale and generation of dust in USA during the same year were 2.8% and 1.6% respectively of crude steel production.

Compared to the above, the generation of EAF slag, scale and dust during 1994 by the ace producer of steel in USA, Chaparral Steel, is 10.95%, 1.9% and 1.15% respectively. It may be noted that Chaparral Steel is dedicated to a zero waste program, called Project STAR - Systems and Technologies for Advanced Recycling.

Chapter 3

QUANTIFICATION, CHARACTERISATION AND MANAGEMENT OF SOLID WASTES IN STEEL PLANTS – INDIAN AND GLOBAL SCENARIO

3.1 Introduction

The quantity of generation of by-products in an industry is an indicator of its operational efficiency. In 1998, the world steel industry produced 780 million tonnes of crude steel and approximately 300 million tonnes of solid by-products. Thus, an average of about 400 kg of solid by-products is generated in the steel industry per tonne of crude steel (Fleischandrl and Sanert 2000). The lion's share (70-80%) of this is slag. Indian steel industry, though has had limited growth over the decade, has a working capacity of about 31.45 million tonnes /year of crude steel and produced 25.42 million tonnes of crude steel in 1999-2000 (Joint plant committee 1999-2000). This gives an idea about the enormity of steel plant solid by-products to be managed annually by the Indian steel industry, particularly in view of high generation of by-products (about 400-1000 kg/T of crude steel) in India.

Legislations/regulations in our country for disposal of solid wastes are quite limited and are at the early stage of development.

Different types of by-products are generated from production shops of a steel plant. For that a study has been carried out for integrated steel plants operating in India, adopting various process routes are shown in Table 3.1.

Table-3.1: Process Route of Indian Steel Plants

S. No.	Category of Steel Plant	Process Route	Plants Considered
1	Integrated Steel Plants	A] BF-BOF-CC-Rolling Mills	SAIL (BSP, BSL, RSP, DSP & IISCO), TISCO & RINL
		B] COREX-BOF-CC-Strip Mills	Jindal Vijayanagar Steel Ltd (JVSL)
		C] DR (Gas based) – Electroxy steel making facility – Combined Thin Slab Casting and Hot Strip Rolling	Ispat Industries Ltd. (IIL)
		D] DR (Gas based)-EAF-CC-Hot Strip Mill	Essar Steel Limited

Steel, one of the most environmentally friendly products, is an outcome of human activities, which are not so environmentally benign. Steel industry falls in the list of highly polluting industries because of its impact on different components of both

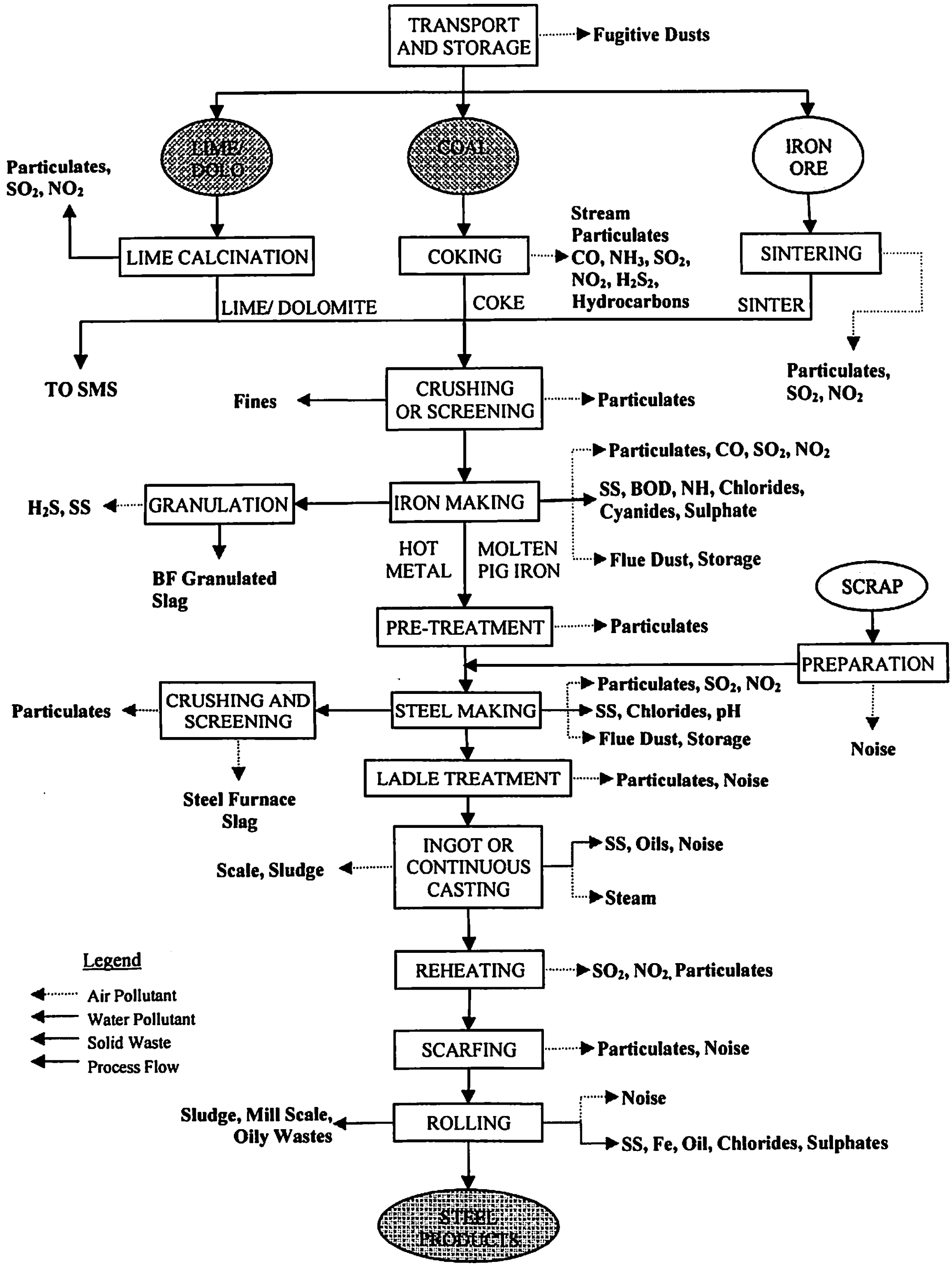


Figure 3.1: Pollutants and principal operations in an Integrated Steel Plant

biotic and abiotic environment. The integrated Iron & Steel industry involves a number of industrial operations which are complex in nature including mining, transport, raw material preparation, coke making, iron making, steel making and rolling etc. These contribute to generation of various types of pollutants in significant proportions. The production flow line diagram and pollutants generated in an integrated steel plant is shown in Fig 3.1.

3.2 Integrated Steel Plants in India

The by-products from coke ovens and by-products of a BF based integrated steel plant are spent refractory, neutralized acid sludge and decanter sludge. Any other by-product from this shop, say nut coke or coke breeze, is either used within the plant or sold out. Neutralized acid sludge is produced after neutralization of acid sludge obtained from acid washing of benzol in benzol plant. This generation may be minimized and gainfully utilized, if acid regeneration plant is provided. In that case, whatever neutralized acid sludge is generated is recycled into crude tar processing unit. This is the case with Bhilai Steel Plant and should be followed by other steel plants also.

Decanter sludge is basically coal dust mixed with tar. This by-product finds immediate market outside as a fuel and is completely sold out Spent refractory are presently partly reused and partly dumped. This will be deliberated subsequently along with spent refractory from other production shops. Therefore, in today's context, coke ovens and by-products plants may be considered to yield only by-products, which are gainfully utilized.

With regard to any modern sinter plant of a BF based ISP, all by-product arising are recycled, it operates as a closed circuit system. It also acts as a scavenger to the steel plant as a whole.

In view of the above, coke ovens and by-products shop and sinter plant of a BF based ISP are not deliberated further with regard to management of solid by-products.

The other solid by-products generated in ISP are as follows:

- BF flue dust
- BF sludge
- BF slag (granulated and air-cooled)
- Corex flue dust
- Corex sludge
- Corex slag
- DRI/HBI sludge
- Hot metal pretreatment dust
- Hot metal pretreatment slag
- BOF dust/sludge
- BOF slag
- EAF dust
- EAF slag

- Electroxy steel making dust
- Electroxy steel making slag
- Secondary steel making dust
- Secondary steel making slag
- Limestone and dolomite fines
- Lime and calcined dolomite fines
- Mill scale from hot rolling mill
- Mill sludge due to hot rolling mill
- Mill scale/sludge due to cold rolling mill
- Fly ash from captive power plant
- Bottom ash from captive power plant
- Coal mill reject from captive power plant
- Spent refractory from the various production shops.

Generation and management of solid wastes for various ISPs based on responses received from them are furnished in tables 3.2 to 3.6 (IISCO-SAIL, Operating Statistics, 1997-1998,BSL-SAIL, Operating Statistics, 1999-2000, DSP-SAIL, Operating Statistics, 1999-2000,Operating Statistics, RINL, 1999-2000, Operating Statistics, RSP-SAIL, 1999-2000). National average (weighted) figures of BF based ISPs indicated in table 3.7. Generation and management of solid wastes for various SAIL plants are given at Table 3.2 and other ISPs are given at Table 3.3 to 3.5. (Joint Plant Committee 1999-2000). Generation and management of solid waste of overseas plant are furnished in Table 3.6

Representative figures for the specific generation of by-products, management of such by-products into extent of recycling, extent of reuse (including sale to outside parties) and extent of dumping for all the ISPs taken together have been described in following paragraphs. Also technology adopted and it's sourcing for recycling and reuse of by-products for Indian plants and technology adopted for recycling and reuse of by-products for foreign plants have been furnished in the same place.

3.3 HAZARDOUS WASTE.

Landfill is currently through most widely practiced method for disposing of hazardous waste. When waste is disposed off on land, the toxic ingredients leach out polluting ground and surface water sources.

Hazardous waste is generally defined as the waste that requires special precautions in storage, collection, transportation, treatment and disposal to prevent damage to person or property.

3.3.1 Identification of Hazardous Waste: -

There are four main characteristics of hazardous waste –

- Reactivity

- Ignitability
- Corrosivity
- Toxicity Characteristics Leaching Procedure

3.3.2 Categorization: -

In order to protect health and environment and to conserve valuable energy resources, Resource Conservation and Recovery Act (RCRA) has been formulated. It has ten subtitles in which subtitle "C" deals with hazardous waste management. RCRA requires Environmental Protection Agency (EPA) to promulgate and enforce regulation for hazardous waste management. EPA issues hazardous waste management regulations. It is complied annually into title 40 of Code of Federation Regulations (40 CFR) in which parts 124, 260 to 268, 270 and 271 are related with hazardous waste.

A solid waste is classified as listed hazardous waste, if it is not excluded from regulation and it is identified on any of the list in 40 CFR 261 sub part "D".

The list includes –

a) Hazardous waste from non specific sources (F-list)
b) Hazardous waste from specific sources (K-list)
c) Discarded chemical commercial product, off specification species, container residues and spill residues there off (p- list and u-list)

COKE MAKING: -Hazardous waste associated during coke making is –

- K141 - Process waste from coal tar recovery operations
- K142 - Tar storage tank residues
- K143 - Process residues from recovery of light oil.
- K144 - Wastewater sump residues from light oil refining
- K145 - Residues from naphthalene collection and recovery Operation
- K060 - Ammonia still lime sludge.
- K070 - Decanter tank tar sludge.

The formation of these residues is not described in detail.

IRON MAKING: -There is no RCRA listed hazardous waste during sintering and iron making operation through blast furnace.

STEEL MAKING THROUGH BOF: -There is no RCRA listed hazardous waste during steel making through BOF route. However, sometimes dust can show hazardous because of presence of lead and chrome waste primarily health concerns.

ROLLING AND FINISHING: – No RCRA listed hazardous waste is generated during rolling and finishing process.

All the above types of by-products have been depicted, furnishing source of generation, typical chemistry and characterization as per Hazardous Wastes (Management and Handling) Amendment Rules, 2000 of those by-products.

As per Hazardous Waste (Management and Handling) Amendment Rules, 2000, (Ministry of Environment and Forests, Govt. of India, Notification, 2000) hazardous waste means,

i. Waste substances which are generated in the process indicated in column-2 of schedules-1 and consist of wholly or partly of the waste substances referred to in column-3 of the same schedule;

ii. Waste substances which consist wholly or partly of substances indicated in Schedule-2, unless the concentration of the substances is less than the limit indicated in the same schedule; and

iii. Waste substances indicated in Part-A, list 'A' and list 'B' of schedule-3 applicable only to rule 12, 13, and 14 unless they do not possess any of the hazardous characteristics in Part-B of the same schedule.

The Basel Convention on the Control of Trans boundary Movements of Hazardous Waste is the first global attempt to regulate and monitor the international transport of hazardous wastes. One of the Convention's main objectives is to protect countries from uncontrolled dumping of toxic wastes within their borders emanating from foreign sources. In addition, the Convention seeks to promote environmentally conscious disposal of wastes. Basel provides for extensive regulation of the movement of wastes, which will prove beneficial in guaranteeing safe and proper disposal. The provisions of the Convention that call for a reduction in waste generation on the part of the signatories are a step in the right direction toward eventually banning waste trade.

3.4 Analysis of Data

Generation of different by-products and their management have been compared with respect to those of the foreign plants.

The details of various aspects of waste management in Indian ISPs were collected and the data on the various by-products are given below: -

3.4.1 BF Flue Dust, Sludge and Slag: -

A) BF Flue Dust: -

Generation of BF flue dust is somewhat in the high side. The ratio of the BF flue dust to BF sludge is 2:1 in Indian plants, whereas the same is about 1:1 in the developed world. BF flue dust is mostly reused via sinter plant through out the world. IISCO cannot use BF flue dust since it does not have any sinter plant. The scenario is the same in foreign plants. BF sludge is mostly dumped in foreign countries due to presence of considerable amount of zinc, lead and alkali oxides.

However, some foreign operators process the sludge in hydro cyclone for size separation and a recovery of about 75% of iron and carbon in the underflow (coarser fraction) and zinc rejection of about 82% in the overflow (finer fraction) have been reported. In India, BF sludge is mostly dumped, except at RINL which reused it fully through sinter plant.

Since agglomeration facility is now currently available at JVSL, it is able to utilize even the Corex dust. Both Corex dust and Corex sludge are being re-used in their pellet plant. The problem of zinc, lead and alkali oxides in blast furnace has so far not been reported for Corex.

Flue dust generation in blast furnace is 17 kg/T of shop production. Out of which 71% is reused and 29% is dumped in Indian plants. In foreign plants 5-25 kg/T of hot metal production, flue dust is generated. Recycling rate is 5% and 95% is reused. Technology employed for reuse is as follows: -

- Velco injection technique (Wolf *et al* 2000).
- Briquetting (Landow *et al* 1998).

Briquette must possess adequate hot strength for charging directly to BF (Process developed by M/s. National Recovery System, USA)

Chemistry of BF Flue Dust: -

Flue dust of coarser particle is collected in dust catcher located before wet scrubbing.

Its chemistry (%) is shown below: -

Fe (total)	C	SiO_2	Al_2O_3	TiO_2	CaO	MgO	MnO	P_2O_5	S
37.00%	23.69%	9.01%	7.26%	0.87%	6.37%	5.46%	2.02%	0.25%	0.27%

This is as per S. No. 8 of Schedule-I as per Hazardous waste characterization.

B) BF Sludge: -

Specific generation of sludge is 8 Kg/T shop product. Reuse of waste is 42% and dumping is to the extent of 58%. In foreign plants 10-25 kg/T sludge of shop production is generated. Recycling is done after minimization of zinc content, wherever necessary, by hydro cyclone process. Dumping is done to the extent of 99%. Flue dust of fine particles is trapped by scrubbing and finally settled at sludge pond. Its chemistry (%) is shown below: -

Chemistry of BF Sludge: -

Fe (total)	FeO	Fe_2O_3	C	S	P	Na_2O
20-30%	7-12%	25-35%	30-40%	0.5-0.8%	0.09-0.12%	0.1-0.2%

K_2O	ZnO	CaO	SiO_2	MgO	Al_2O_3	MnO
0.5-0.7%	0.2-0.4%	8-10%	5.0-7.0%	0.3-0.5%	0.8-1.3%	0.5-0.8%

This is as per S. No. 8 of Schedule-I as per Hazardous waste characterization.

C) BF Slag: -

The average generation of BF slag is 380 kg/T of hot metal, which is considerable higher than the upper level for foreign plants. Obviously, this is primarily due to high gangue content and high Al_2O_3/Fe ratio in Indian iron ore. The average extent of air-cooled BF slag utilization in the country is about 42%, about 19% of which is sold out at present. Most of the granulated BF slag is sold out to cement manufacturers. In Indian plants, the extent of reuse is 63% where as 37% is dumped.

Almost 100% of BF slag finds useful applications in foreign plants, mostly in the cement and construction industries. In foreign plants generation of BF slag is 207-329 kg/T of hot metal produced.

About 100% of BF slag is reused as a major ingredient for cement manufacturing, or an aggregate in general construction. (ECReport1998). Some quantity is used for production of glass.

The technology adopted for the purpose of BF slag is: -

a) Wet slag granulation
b) Dry slag granulation - environment friendly process (Featherstone and Holliday 1998)
c) Air/water quenching in slag pit (if there is no facility for granulation or there is no market for granulated slag)
d) Vitrification of BF slag is done for glass production.

Then alternative uses reported are the production of zeolite and refractory using BF slag as raw material and the manufacture of bricks from sand mixed with BF slag.

Chemistry of BF Slag: -

CaO	SiO_2	Al_2O_3	MgO	FeO	MnO	S
30-31%	32.33%	18-22%	8.10%	0.2-0.6%	1.5-3.0%	1.5-1.7%

This is as per Basel No.B1200 and B1210 (OECD No.GC080) of Part-A of Schedule-3 (OECD 1995).

3.4.2 COREX Dust, Sludge, Iron Ore Fines and Slag: -

A) COREX Dust and Sludge: -

Corex dust and sludge is generated at the rate of 16 kg/T of hot metal and 55 kg/T of hot metal respectively in Indian plants and entire quantity is dumped.

In foreign plants, specific generation of waste is 40-45 Kg/T of shop product.

Extent of recycling is10% as a granule to be recycled to the COREX. via the coal feed. In this process granulation of sludge is done. This is adopted at Saldhana Steel Works (Holmes and Greenwalt 1997). Extent of dumping is 90%.

Chemistry of COREX Dust:

Dust catcher chemistry before wet scrubbing of COREX plant is shown bellow: -

Fe_2O_3	FeO	Fe (metallurgical)	CaO	C	SiO_2	Al_2O_3	Residue
44%	12%	5%	19%	12%	3%	2%	3%

This is as per Sl.No.8 of Schedule-I.

B) Iron Ore Fines: -

Iron Ore fines generation is 20 kg/T of shop product in India. Iron rich hydraulic cement for briquetting and pelletisation of iron ore fines can be done.Technology is available from RRL, Bhubaneshwar. However 100% fines is being dumped in Indian plants.

Specific generation of fines is 10 Kg/T shop product in foreign plants. In some plants this is used as under: -

a) As feed for pelletising, prior to charging into the reduction smelt furnace of COREX plant.

b) As feed to sinter plant for production of sinter for further recycling into the COREX plant.

c) In some plants, 100% is dumped.

C) COREX slag: -

326 kg/T is specific generation of slag in Indian plants and 100% is sold out at JVSL. In foreign plants, specific generation is 380 kg/T of production. 90% is reused. The slag after granulation and subsequent milling operation is used as a major ingredient for cement production and about 10% is dumped. Corex slag rate at JVSL is much lower due to selective use of raw materials.

<u>Chemistry of COREX Slag: -</u>

CaO	MgO	SiO_2	Al_2O_3	S	FeO	Basicity
36.88%	11.90%	32.58%	15.28%	1.44%	0.25%	1.13%

This is as per Basel No.B1200 and B1210 (OECD No.GC080) of Part-A of Schedule-3.

3.4.3 DR Plant (Gas based) Fines and Sludge

A) DRI Fines: -

DRI fines generated are 55kg/T of product and 100% is recycled in Indian plants. Technologies adopted are: -

1) Low-pressure briquetting of DRI fines.

2) Electrolytic iron powder from DRI fines (both technologies available from NML, Jamshedpur).

In foreign plants specific generation is 60kg/T of product and 100% is used as a metallic input in EAF through injection technology adopted at Hamburger Stahlwerke Germany.

<u>Chemistry of DRI Fines: -</u>

Fe (total)	Fe (metallurgical)	FeO	C	Cu	Ni	Cr	Mo	Zn	CaO
79.12%	54.62%	31.50%	1.29%	0.02%	0.06%	0.04%	0.05%	0.01%	2.21%

MgO	SiO_2	Al_2O_3	S	P	Mn	K_2O	Na_2O	Pb
0.29%	2.18%	1.08%	0.01%	0.07%	0.09%	0.05%	0.05%	0.02%

B) DRI/HBI Sludge: -

The sludge is collected at sludge pit. In Indian plants, generation rate is 7kg/T of product. In foreign plants, generation rate is 65kg/T of product and 100% is reused as granules to be charged in Corex through injection technique developed at Saldana steel works (South Africa).

3.4.4 Hot Metal Pretreatment Dust/Slag: -

0.94kg/T of dust and 14kg/T of slag are generated and 100% is dumped in Indian plants. In foreign plants total dust generated is recycled. Slag generation rate is 25 kg/T and 75% of slag is dumped. 25% is used as an ingredient of steel slag cement.

- Slag cement: - Grinding/ Dry granulation
- Soil conditioner for agriculture purpose: -Crushing to 4mm size, dry granulation less than 5mm
- Sinter mix: - Crushing prior to charging.
- Soil conditioner: - Milling to –1mm size.

A more attractive technology being practiced by many operators in USA and also by Port Talbott works of then British Steel. Briquetting of dried BOF sludge and mill scale in desired proportion with a binder and recycling of the briquettes into the BOF is being practiced. This is economically more attractive because waste products in this case are directly contributing to the liquid steel production, whereas for reusing in sinter plant, the direct contribution is in sinter production. This technology has been developed by National Recovery Systems (NRS), USA. Another advantage of this technology is that, it is not affected by zinc, lead and alkali content, if any, in the sludge since, if they are there, they would build up in concentration due to repeated recycling and when the concentration becomes economical to extract the valuable metals, the sludge is then not recycled but reused for extraction to the metal values.

3.4.5 BOF Dust/Sludge and Slag: -

A) BOF Dust/Sludge: -

Average generation is comparable to the international scenario.42% of the dust generated in India is reused through sinter plant. BSP, RINL and Tata Steel are reusing 100% of this dust. For BSL, BF sludge and BOF sludge are dumped in the same yard. This makes the overall iron content leaner. As a result, BOF sludge in BSL remains dumped. However, recently RDCIS has developed a technology for utilization of ferruginous wastes of integrated steel plants through micro pelletisation-sintering route. This is likely to bail BSL out of impasse in its efforts to reuse of BF/BOF sludge. The international scenario in management of BOF dust/sludge is 41% reuse in steel works, 3% applications in external to steel works and the balance quantity is stored in special stockyards or land filled. Thus, the scenario is not different from that in our country. However, since the material is characterized hazardous, there is increasing pressure from various global bodies and the public, not to dump this material. As a result, new ways of solving the problem are being explored.

BOF flue dust/sludge is collected in gas cleaning system either in dry or wet sludge forms.

Chemistry of BOF Dust: -

Fe (total)	SiO_2	Al_2O_3	TiO_2	CaO	MgO	MnO	P_2O_5	S
52.25%	5.92%	1.1%	0.43%	18.26%	5.98%	2.59%	0.36%	0.18%

Chemistry of BOF Sludge: -

Fe (total)	CaO	SiO_2	P	MgO	Al_2O_3	S	Na_2O
50.84%	15.39%	2.19%	0.17%	4.31%	0.71%	0.29%	0.51%
K_2O	Zn	C					
0.06%	1.10%	2.58%					

Specific generation of waste is15kg/T of shop product.42% is reused after micro-pelletisation by sintering (Developed by RDCIS) and 58% is dumped. In foreign plants generation rate is 10-23kg/T of product.

a) 20% of BOF dust/sludge is recycled as follows: -

i) Cold Briquetting (developed by National Recovery System Inc).

ii) Hot briquetting in cases where dry dust collection systems are in operation.

b) 60% of BOF dust/sludge is used as follows: -

i) Sinter

- Conventional Method of Charging
- Base Blending Process

ii) Feed to Pellet plant

- Conventional Method of Charging

iii) Production of DRI/HBI in rotary hearth furnace

- Fastmet process
- Redsmelt process
- Romelt process. (Heinz *et al* 1999).
-

iv) Hot Metal Production

- Hamborn shaft furnace

v) As a Cement Work

c) Balance 20% of BOF dust/sludge is dumped.

B) BOF Slag: -

Specific generation of slag is 173kg/T shop product. 40% of it is reused as road making aggregate using a mix of by-products (developed by RDCIS, SAIL Ranchi and CRRI New Delhi). About 10% of BOF slag is utilized as follows: -

i. Raw materials for production of ordinary Portland cement

ii. Blending material in Portland slag cement.

The technology has been developed by RDCIS, SAIL Ranchi and National Council for Cement and Building material, (NCB). An auto grinding of lime-BOF slag mixture due to crystallo chemical transformation is accomplished and recovery of iron accompanies this. (Developed by RDCIS, Ranchi). Balance 50% is dumped.

The use of BOF slag can be made through the sinter route to utilise the lime content. However this route can cause problem of phosphorous build up. Hence only an intermittent mixing can be practiced. The use of BOF slag in civil engineering and road making is yet to pick up momentum in India.

In foreign plants, specific generation of slag is 100-223kg/T shop products. Extent of recycling is 70% as follows: -

i) Sinter mix (duration of at-a-stretch use in sinter plant as a flux material is governed by phosphorous build up). This method, therefore, may not be considered as a perennial measure of management of BOF slag. The slag is crushed prior to charging.

ii) As an aggregate for road construction. After crushing, owing to presence of free lime in the slag, it is necessary to resort to some stabilization processes, which are as follows: -

a. Natural ageing process.
b. Hot water immersion aging process.
c. Open yard steam injection process.
d. High-pressure steam aging process.

As a rule, metal should be extracted from slag before further processing. The scrap thus obtained should be recycled in steel making. Generation of BOF slag is somewhat high, yet comparable with world scenario. About 25% of BOF slag generation in the world is reused in steel plants. About 50-55% of generation is used outside the steel works in applications like road building, civil and marine engineering, cement industry and agricultural use. It is important for civil and marine engineering application that the slag should be stable and not prone to swelling. It should therefore contain little free lime for such applications. The remaining 20-25% of the BOF slag is land filled.

Chemistry of BOF Slag: -

CaO	FeO	SiO_2	P_2O_5	MgO	MnO	Al_2O_3
40-50%	20%	15-17%	2.45%	3.9-4.5%	4.5%	5.2-6.3%

This is as per Basel No.B1200 and B1210 (OECD No.GC080) of Part-A of Schedule-3.

In recent years, a technology, known as CEMSTAR and developed by TXI, USA using EAF/BOF slag for manufacture of Portland cement has been commercialized

3.4.6 EAF/Electroxy Steel Making Dust and Slag: -

A) EAF Steel Making Dust: -

Specific generation of EAF dust is 8-16kg/T of steel. 100% is quantity is dumped in Indian Plants.However technology is available from RRL Bhubneswar for it's recycling. In this plasma smelting of dust and sludge for recovery of metal values like Zn Pb Cd etc. is done.In foreign plants, generation is 18-20kg/T of steel and reused in following ways: -

i. Aggregate for road construction - Natural ageing process

ii. Ingredient of slag- Slag granulation (wet/dry)

iii. Soil conditioner for agriculture- Slag granulation (wet/dry)

Average generation to EAF dust is comparable to those of the developed countries, but with regard to utilization, it is a dismal picture. About 5% of this dust is recycled in the EAF, and about 35% is sold out for reuse outside the steel plant and the balance 60% is land filled (mostly after stabilization) in the developed world (Ban and Lim 1994). 100% of EAF dust is dumped in India, though it is a hazardous dust (K061) as per EPA, USA and also as per Hazardous Waste (Management & Handling) Amendment Rules 2000 of our country. a) About 5% electroxy steel making dust is recycled in two ways: -

i) In the form of dust by

- Velco injection technology
- Carbofer process
- Briquetting

ii) In the form of IRM (Iron Rich Metal)

- HRD Process
- Waelz Kiln process
- Flame reactor process

b) About 30-35% electroxy steel making dust is reused.

i) For extraction of zinc, lead etc. The technology adopted is as follows: -

- Waelz kiln process
- Flame reactor process
- ZTT ferrolime process
- MRT process
- Laclede steel process
- Ezinex process

ii) For extraction of zinc & iron: Coke Bed smelting reduction process is employed (Matsui 2000, Yamada *et al* 1998).

iii) As a fertilizer additive: - for the production of glass ceramic family of materials and used as ingredient in the manufacture of many other commercial products like roofing, granules, ceramic floor tiles, abrasives etc. by glassification process.

c) 60-65% is dumped after stabilization treatment by some process like Super Detox process. (If required under environmental regulations)

Chemistry of Electric Arc Furnace Steel Making Dust: -

Fe (total)	Fe_2O_3	CaO	SiO_2	S	ZnO	C
25-35%	35-50%	5-15%	2-10%	0.1-0.6%	15.35%	0.5-25%

This is as per Sl.No.8 of Schedule-I.

B) Electroxy Steel Making Dust: -

Electroxy steel making involves use of both electric arc and oxygen blowing for steel making (hybrid steel making). The patented processes of this type are CONARC developed by MDH.

ARCON developed by Concast Standard AG and CONTIMET developed by Voest Alpine among which only the first one i.e. CONARC process has been commercialized. IIL is the only Indian operator of this process. Electroxy steel making dust, generation level is same and also characteristics are similar to those of an EAF particularly one using hot metal. Presently IIL dumps this dust. Specific generation of EAF dust is 19Kg/T of shop product in India whereas 10-18 kg/Tof crude steel in foreign plants. In foreign plants about 10-20 kg/T of this dust is generated.

EOF dust collected in bag house/ venturi scrubber during cleaning of EOF flue gas, after filtration of EAF flue gas.

Chemistry of Electroxy Steel Making Dust: -

Fe (total)	Fe_2O_3	CaO	SiO_2	S	ZnO	C
25-35%	35-50%	5-15%	2-10%	0.1-0.6%	15.35%	0.5-25%

This is as per Sl.No.8 of Schedule-I.

C) EAF/Electroxy Steel Making Slag: -

EAF Slag generation is 140-210 kg/T of crude steel. About 10% of this slag is reused mostly for road making where as 90% is dumped.

In foreign ISPs specific generation of EAF slag is 110-160 kg/T of crude steel. 75% of slag is utilized for civil engineering, road construction, rail bed preparation and road surfacing. For the last application, slag combined with asphalt provides a surface with improved anti skid properties. The balance quantity is land filled. The granulated slag (wet/dry) is also used as an ingredient of cement and also as a soil conditioner for agriculture.

Electroxy steel making slag generation is 144kg/Tof crude steel in India. M/s IIL dump the entire quantity. Generation in foreign plants is 180-190 kg/T of crude steel. In recent years, a technology, known as CEMSTAR is developed by TXI, USA (Cemstar1998). It uses EAF slag for manufacture of Portland cement. It has been commercialized.

Chemistry of EAF Sludge: -

SiO_2	CaO	MgO	Al_2O_3	TiO_2	Fe (total)	Fe (metallurgical)	MnO	S
14-18%	20-33%	9-11%	3-4%	0.5%	20-23%	1-2%	0.5-1.0%	0.02%

This is as per Basel No.B1200 and B1210 (OECD No.GC080) of Part-A of Schedule-3.

Chemistry of Electroxy Steel Making Slag: -

SiO_2	CaO	MgO	Al_2O_3	P_2O_5	FeO	Mno
18%	49%	6%	1%	2%	20%	4%

This is as per Basel No.B1200 and B1210 (OECD No.GC080) of Part-A of Schedule-3.

3.4.7 Limestone and Dolomite fines & Lime and Calcined Dolomite fines: -

These items are not treated as wastes in India also.

3.4.8 Mill scale/Mill sludge for Hot Rolling Mill: -

The generation figures are comparable to those of the global average figures. The world practice of reuse of mill scale with oil content of less than 2% is 100%, mostly via sintering plants and small quantities via cement plant, Ferro-alloy plant and EAF. The scene is similar in India also. This item is globally considered a by-product. But scale with oil content more than 3% is mostly land filled in foreign counties. Of late, technologies to de-oil mill scale have been commercialized and thus de-oiled mill scale and mill sludge can be used in sinter plant. (DOE 1983).

Mill sludge contains about 2.15% oil. Most of it is land filled in foreign countries. The situation in India is that about half of mill sludge is reused through sinter plant, though it is established that it is unsafe to use mill scale containing more than 3% oil in a sinter plant due to problems in electrostatic precipitators of gas cleaning system.

A) Mill scale: -

Specific generation of mill scale in hot rolling mill is 18 kg/T of production.100% is reused via sinter plant in India. In foreign plants generation rate varies between 15-25 kg/T of shop product. Relatively coarse mill scale is collected from reheating furnaces and dry processing areas like cooling beds, straighteners, shears and saws.

Chemistry of Mill Scale: -

Fe (total)	FeO	Fe_2O_3	C	S	P	Na_2O
62-68%	60-70%	15-25%	0.3-0.5%	0.12-0.25%	0.15-0.25%	0.05-0.1%
K_2O	ZnO	CaO	SiO_2	MgO	Al_2O_3	MnO
0.01-0.03%	0.04-0.06%	0.3-0.5%	0.8-1.5%	<0.01%	0.1-0.2%	0.3-0.5%

Entire quantity is reused in one of the following ways: -

a) Sinter mix (oil content should not exceed 1%): - In sintering process.

b) Sinter mix (oil content up to 3%): - Top layer sintering process; however Coreco process may be used before sintering for oil contents up to 12%.

c) Reductant/ Input material in BF (oil content up to 15%): Injection of oily mill sludge into BF.

d) Constituent in the mix for cold Briquetting of BOF sludge: - Process developed by National Recovery System Inc., USA

e) One of the ingredients of cement production milling operation.

f) Constituent in production of ferro alloy.

B) Mill Sludge: -

Specific generation of mill sludge in Indian plant is 1-4 kg/T of shop product. About 50% of this sludge is reused in whereas 50%is dumped.

In foreign plants specific generation of mill sludge is 2-7 kg/T of shop product. As the mill sludge contains higher percentage of oil it is not suitable for reuse. And thus almost all sludge is dumped. However microwave treatment of mill sludge makes it suitable for use as sinter mix after oil removal. Fine mill scale contaminated with oil is collected in sludge pit.

Chemistry of Mill Sludge: -

Fe (total)	CaO	SiO_2	P	MgO	MnO	Al_2O_3	TiO_2	Cr_2O_3	LOI	Oil
64.4%	0.6%	4.0%	0.085%	0.22%	0.44%	1.85%	0.07%	0.08%	0.4%	10-11%

3.4.9 Cold Rolling Mill Scale/ Sludge: -

Specific generation of mill scale/ sludge is 3.5 kg/T shop product.100% of this sludge is reused in Indian plant. Specific generation of waste is 3-6 kg/T shop product in foreign plants.100% is reused there also as a sinter mix (oil content should not exceed 1%) in sintering process. Chemistry is shown below: -

Chemistry of Mill Scale/Sludge: -

Fe (total)	CaO	SiO_2	P	MgO	MnO	Al_2O_3	TiO_2	Cr_2O_3	LOI	Oil
64.4%	0.6%	4.0%	0.085%	0.22%	0.44%	1.85%	0.07%	0.08%	0.4%	10-11%

3.4.10 Fly Ash and Bottom Ash: -

The combustion of coal results in a residue known as ash consisting of inorganic mineral constituents of the coal and un burnt organic matter. The ash is known as bottom ash (collected at the bottom of the boiler unit) and fly ash (collected by air pollution control equipment before the flue gas passes through the stack). The ratio of bottom ash to fly ash produced varies depending upon the type of coal used, the mode of combustion, the type of boiler, etc. Generally, bottom ash is around 20% of the total ash produced.

The iron and steel industry is one of the seven energy-intensive industries, namely iron an steel, fertilizer, aluminium, textiles, cement, chemicals, pulp and paper, which account for nearly 80% of the industrial energy consumption. The iron and steel industry is the largest consumer of energy in the industrial sector. The primary sources of energy utilized by ISPs are coking coal, non-coking coal, liquid hydrocarbons and electricity. They draw their power requirements from their captive power plants and the utility station. Therefore, the iron and steel industry is also one of the important coal ash generators apart from the utility thermal power plants in the country. In fact, the quantity of fly ash generated in a steel plant with captive power plant is only next to iron and steel making slag, which constitutes the largest quantity of the solid wastes generated.

While granulated iron making slag is being utilized almost fully but steel-making slag, fly ash generated (323 kg/MWh) is mostly dumped (meager 6% reuse on national average for steel plants) by steel producers, even though the national average of utilization of fly ash is 13%, mainly due to the utility thermal power plants. Current annual generation of fly ash in India is about 90 million tonne. The land area occupied by the ash pond is about 26,300 hectare, presently. International scenario of specific generation of fly ash is close to one tenth of that in India (35-40 kg/MWh), which directly linked to 30-45% ash in Indian coal and less than 10% ash is coal in the developed countries. Utilization in the Netherlands, Italy, Denmark and Germany is more than 90% to 100%.

Bottom ash in DSP is fully sold out but in other ISPs, it is dumped only.

In Indian power plants Specific generation of fly ash is 323 kg/MWh shop product. Extent of reuse only 6% balance 94% is dumped. In coal based power plants specific generation of bottom ash is 249kg/MWh. Extent of reuse is 13% whereas 87% is dumped. Coal mill reject generation is 2.4 kg/MWh which is 100% reused.

Fly ash is collected in Electrostatic precipitators of gas cleaning system.

<u>Chemistry of Fly Ash: -</u>

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO3	LOI
49-67%	16-29%	4-10%	1-4%	0.2-2%	0.1-2%	0.4-0.6%

This is as per Basel No.B1200 and B1210 (OECD No.GC080) of Part-A of Schedule-3.

The technology available for reuse is as follows: -

a) Clay-fly ash burnt brick/block.
b) Lime-fly ash brick/block.
c) Fly-ash pallets crushed to the required size after curing as a substitute of stone aggregate -Brick making from fly ash aggregates.
d) Fly ash from soil amendment in growth of flowering plants and tree species (Developed by RDCIS, SAIL, Ranchi).
e) Synthetic granite tiles from fly ash (Developed by NML, Jamshedpur).
f) Wear resistant ceramic liners using fly ash
g) Heat and sound insulation sandwich panels using fly ash.
h) Mullite fly ash aggregate for refractory castables - all the above technologies available from NML, Jamshedpur.

i) Sintered light weight aggregate from fly ash and other metallurgical solid wastes (Technology available from RRL, Bhubaneshwar).

3.4.11 Coal Mill Rejects from Captive Power Plants: -

This is sold out as a by-product.

3.4.12 Spent Refractory: -

Generation of spent refractory in a steel plant in India is close to 3-10 kg/T of crude steel.

Refractory bricks are costly inputs to the steel manufacturing process. The dismantling of the furnaces for relining, both at the steel melting shops and rolling mills, is a crucial stage with large scope for recovery of bricks which can be used in less critical applications. The systematic recovery procedures can recover spent refractory; substantially.

The refractory grog arising from the fire clay, basic and other bricks are collected and used to produce refractory mortars in the captive mortar shop. The consumption of the recovered materials covers up to 25% of the total raw material consumption at the mortar shop.

Sintered dolomite fines of less than 2 mm size are utilized for the production of well filler mass of steel ladles.

High alumina refractory are recovered from discarded slide gate plates of steel ladles and used in production of runner mass for the blast furnace. The improvement in runner life along with the cost advantage and waste utilization aspects are the benefits. The steel shell of the slide gate is recycled as scrap.

Now a day, a large portion of the dolomite based refractory from converters and transfer ladle linings is fed, after processing, to the sinter plant because of the calcium oxide and magnesite it contains. Rejected silica bricks may be used for paving of roads. The extent of reuse including sale outside the steel works in SAIL plants is about 15-40%. The remaining part is dumped.

Major part of spent refractory in foreign countries is dumped. Extent of reuse varies widely from country to country. It is zero or near zero in some countries, including USA, to about 33% in Germany. The remaining part is reused as salvaged bricks for less critical applications or as raw material for manufacture of bricks/mortars.

Generation of waste refractory is 5.5kg/T of steel. About 40% is reused.

Development of magnesia ramming mass from salvaged magnesia brickbats: -

i) MgO-C brick from salvaged MgO-C bricks.

ii) Al_2O_3-C slide gate plates used for making high-alumina mortars (all the above technologies developed by RDCIS, SAIL Ranchi.

3.5 Macro-view: -

Having had a grasp of individual by-products in the three major categories in steel plant, it will be interesting to get a holistic picture about generation and management of steel plant solid wastes. To bring out the same, it is necessary to go for the concept of model plants since if any specific plant within a category is considered, there will be variations in rated capacities of the plants, not to speak of the production figures which changes for the same plant from one year to another.

For conceiving a model plant, the first thing to be decided is the annual capacity of such a plant. Keeping in view the usual capacities of the steel plants and ease of comparison, 3 million tonnes annual capacities have been considered for the model plant.

Then, for each process route of steel plant furnished in Table 3.1, representative facilities with production quantity from each such facility have been envisaged.

With the knowledge of specific generation of solid by-products and their management as specific recycle, specific reuse (including sale to outside parties), and specific disposal (dumped quantity), the point of generation of wastes have been identified and annual quantities of generation of wastes and their management on annual basis have been estimated. The management of solid waste of modern plants thus established has been depicted in drawing numbers, RKA/04/BITS/01-03. Total generation of solid wastes and total dumped quantity are presented at a glance in Table 3.8. Specific total generation and specific total dumped quantity are also furnished in the same table. The same is again pictorially represented for ease of understanding in Fig. 3.2 to3.6. A look at the table and figures reveals the following. The capacity of the captive power plant for the BF-BOF based model plant having capacity of 3.0 MT/yr has been estimated to be 130 MW.

Generation of wastes in DR (gas based)-EAF-CC-Rolling Mill and then by DR (gas based)-Electroxy steel making facility -Thin slab casting-cum-hot strip rolling mill route of ISP is less and topped by BF-BOF-CC-Rolling Mill route of ISP.

Dumped quantity, however, is the least for DR (gas based)-Electroxy steel making facility – Thin slab casting – cum – Hot strip rolling mill route of ISP, and topped by COREX-BOF-CC-Rolling Mill of ISP. The development of the state-of-the-art technologies like electroxy steel making and thin slab casting-cum-hot strip rolling mill is really sustainable.

The amount of solid waste generated, types of solid waste normally gets generated from different production shops during operation and how these are managed are shown in Tables 3.2 to 3.5 in the integrated steel plants in India. For comparison Table 3.6 can be seen, how the waste are managed in foreign steel plants such as at British steel plant, French steel plant and Japanese steel plants. Table 3.7 gives National averages of generation and management of steel plant wastes in India through BF-BOF-CC and Rolling Mills route. Table 3.8 gives an idea which route of steel making as noted in Table 3.1, generate maximum and minimum by product tonnage/year and also the routes of steel making associated with maximum and minimum dumping of the waste quantities. Figures 3.2 to 3.5 give the distribution quantity of different types of generated waste out of total dumped quantity for ISP following different production route in a year.

3.6 Summary: -

Steel plant waste material has been a growing problem to the steel industry for the past few decades. For years and years, these wastes generated from process were managed as a waste for no use and dumped as landfill. But due to strict regulation of steel plant emission norm, many steel plants in western countries, could not bring emission standard norm under control had to shut-down some of their units, such as many sinter plants from operation.

Due to ecological pressure, when Environmental Protection Agency (EPA) listed Electric Arc furnace dust as hazardous waste under the regulation of Resource Conservation and Resource Act (RCRA), steel industry began to recognize that something had to be done with waste generated and also when RCRA's further ban on land filling of waste from steel plant unless EPA authorizes exception, which further emphasized the need for Recycling and Reuse of waste generated from steel industry. However in India, regulation are yet to be framed, but importance of the control of waste by management process cannot be overlooked and has to be adopted by Indian ISP. Hence, it is very important to identify the waste generation, its quantification, characteristics of the solid waste so that management process to tackle this problem effectively can be developed and can be made mandatory to incorporate in the working process of steel plant units operation.

A detailed elaborate production data with figures and facts has been furnished, showing generation and management of solid waste at all SAIL steel plants, other ISP of India and few foreign steel plants for comparison. National norms are also noted for generation solid waste from ISP through Blast Furnace (BF) – Basic Oxygen Furnace (BOF) – Continuous Casting (CC) – Rolling Mill route. With this study it has been presented the enormity of the mind-boggling problem of waste. The emphasis is put on to counter it by adopting various management process to run steel plant economically and environment friendly way. And the other important point that, the larger the plant it will have more waste and therefore the larger problem. Hence the need for installation of waste controls equipment along with main production unit, which should be incorporated at design stage or the plant equipment and installed during erection of the plant.

Table-3.2: Average Generation and Management of Solid Wastes at Rourkela, Bhilai, Bokaro and Durgapur Steel Plants of SAIL (Three Years Average).

Shop	Name of Solid Waste	Average Annual Output x 10^6 T				Total Waste Specific Generation-kg/T of Production				Management of Waste							
										Specific Reuse - kg/T of Production				Specific Dumping-kg/T of Production			
		RSP	BSP	BSL	DSP	RSP	BSP	BSL	DSP	RSP	BSP	BSL	DSP	RSP	BSP	BSL	DSP
Coke ovens	Coal throughput	1.51	3.875	3.486	1.577												
	Coke production	1.16	2.95	2.694	1.227												
	Undersize of coke					223.21	192.34	175.71	223.21	223.21	192.34	175.71	157.69				
BF plant	Hot metal Prod.	1.390	4.283	3.941	1.629												
	BF flue dust					28.51	18.82	13.60	16.19	19.68	13.10	13.60	11.75	8.63	5.72		4.44
	BF sludge					1.05	12.00		1.05				0.05	1.05	12		14.07
	BF slag incl. Air cooled slag					407.99	424.47	368.20	407.99	243.97	274.35	94.61	376.51	164.02	150.12	273.59	27.86
BOF shop	Liquid steel production	1.187	1.65	3.33	1.394												
	BOF dust + sludge					13.39	8.00	18.00	19.74	1.96	8	--	5.27	11.43	10.99	18.00	14.47
	BOF slag					190.29	125.00	161.33	190.29	47.35	62.54	62.38	69.86	142.94	146.02	98.95	157.70
Refractory Materials Plant	Production of calcined lime and burnt dolomite	0.213	0.153	0.229	.0.146												
	Limestone + Dolomite fines (e)					119.97	299.73	245.78	119.97	119.97	299.73	245.78	195.97				
	Lime + calcined Dolomite fines (e)					107.39	241.64	100.33	157.37	107.39	241.64	100.33	157.37				
Continuous Casting Plant	Production	0.79	1.664	0.795	0.61615												
	Caster scale					3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25				
	Caster sludge (e)					0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75				
Hot Rolling Mill	Production	1.11	4.376	4.7315	1.2719												
	Mill scale (e)					12.00	18.32	17.71	27.50	12.00	18.32	17.71	27.50				
	Mill sludge (e)					3.00	3.92			3.00					3.92		
Cold rolling mill	Throughput	0.391		0.9773													
	Mill scale/ sludge					1.50		5.30	1.50	1.50		5.30					
Acetylene Plant	Prod. (MNm³)	0.129	0.579	0.187													
	Lime sludge (kg/Nm³)					12.63	4.18	6.79		12.63	4.18	6.79		11.43			
Captive power plant	Gen. (x10⁶MWh) x10^6MWh)	1.231	0.8525	1.126	0.7166												
	Fly ash (kg/MWh)					354.73	202.50	473.47	232.70	75.70				279.03	202.50	473.47	232.70
	Bottom ash (kg/MWh)					42.20		-	48.58	42.20		-	48.58				
Spent Refractory						4.47	7.47	13.812	11.512	4.47	2.65	10.319	9.39		4.82	3.49	2.12

Note: - e denotes estimated quantity.

Table-3.3: Generation and Management of Solid Wastes at Other Indian Steel Plants(Three Years Average).
(1) M/s. Tata Iron & Steel Company, Jamshedpur (2) Rashtriya Ispat Nigam Ltd., Vizag (3) Jindal Vijaynagar Steel Ltd., Vijaynagar

Shop	Name of Solid Waste	Annual Quantity of Shop Output x10^-6 T			Total Waste Specific Generation-kg/T of Production			Management of Waste					
								Specific Reuse- kg/Ttof Production			Specific Disposal-kg/T of Production		
		TISCO	RINL	JVSL (Corex plant)	TISCO	RINL	JVSL (Corex plant)	TISCO	RINL	JVSL (Corex plant)	TISCO	RINL	JVSL (Corex plant)
Coke ovens &	Coal throughput-estimated	2.62	2.060										
By-products plant	Coke production	1.837	1.540										
	Undersize of coke (coke breeze only)				128.9	218.76		128.9	218.76				
Hot metal	Production	3.64	2.872	0.396									
	BF flue dust				15.6	13.68	15.66	6.32	13.68		9.28		15.66
	BF sludge				9.5	4.51	55.05	6.61	4.51				55.05
	BF slag incl. Air cooled slag				335.42	366	325.76	335.42	238.55	325.76		127.45	
BOF shop	Production	3.318	2.474	0.372									
	BOF dust/sludge				16.83	7.51	22.04	16.83	7.51				22.04
	BOF slag				241.16	116.42	199.73	134.8	28.33	49.73	106.36	88.09	150
Refract Materials Plant	Production	0.46	0.189	0.035									
	Limestone + Dolomite fines				5.48	245.48	351.43	5.48	245.48				351.43
	Lime + calcined Dolomite fines				247.4	404.14	123.43	247.4	404.14	123.43			
Continuous casting plant	Production	2.673	2.270	0.372									
	Caster scale (e)				3.12	1.58	4.97	3.12	1.58				4.97
	Caster sludge (e)												
Hot rolling mill	Production	3.5	2.583	0.608									
	Mill scale				21.79	15.42	23.68	21.79	15.42				23.68
	Mill sludge				0.67						0.67		
Cold rolling mill	Throughput of CR coil/sheet	1.31											
	Scale/Sludge				1.5			1.5					
Captive power plant	Production	1.11	1.963										
	Fly ash (specific fig. In kg/MWh)				246.11	333.42					246.11	333.42	
	Bottom ash (specific figure in kg/MWh)				249.4						249.4		
	Spent Refractory				5.532	4.298		4.627	0.828		0.905	3.47	0

Table-3.4: Generation and Management of Solid Wastes at M/s. Essar Steels Limited, Gujarat.

Shop	Name of Solid Waste	Annual Quantity of Shop, Output, X 10^6 T	Total Waste Specific Generation-kg/T of Production	Management Of Waste Specific Recycle-kg/T of Production	Specific Reuse- kg/T of Production	Specific Disposal-kg/T of Production
		Three Years Average				
DR Plant/ HBI Plant	Production	1.66				
	DRI/HBI sludge					
	Iron ore fines		18.21		18.21	
	DRI fines		128.9		128.9	
	Spent refractory		0.11			0.11
EAF Shop	Production	1.52				
	EAF dust		16.26			16.26
	EAF slag		210.07		20.93	189.14
	Spent refractory		2.76			2.76
Refractory Materials Plant	Production	0.13				
	Lime + calcined Dolomite fines		52.11	52.11		
Continuous casting plant	Production (e)	1.47				
	Caster scale + sludge		4.06		4.06	
	Spent refractory		0.16			0.16
Hot rolling mill	Production	1.52				
	Mill scale		31.25		15.52	15.73
	Spent refractory		1.1			1.1

Note: - e denotes estimated quantity.

Table-3.5 Generation and Management of Solid Wastes at M/s. Ispat Industries Limited, Dolvi

Shop				Management Of Waste		
	Name of Solid Waste	Annual Quantity of Shop, Output, X 10^{6} T	Total Waste Specific Generation-kg/T of Production	Specific Recycle- kg/T of Production	Specific Reuse- kg/T of Production	Specific Disposal-kg/T of Production
		Three years Average				
DR Plant	Production	1.07				
	DRI/ETP sludge		7.41			7.41
	Iron ore fines		123.18		123.18	
	DRI Fines		55.39		55.39	
CONARC shop	Production	0.58				
	Conarc dust		9.16			9.16
	Conarc slag		141.23			141.23
	Spent refractory (e)		0.75		0.376	0.376
Refractory Materials Plant	Production	0.03				
	Lime fines		177.615		177.615	-
Compact strip production (CSP) plant	Production	0.79				
	Dry/oily scale		3.615		3.615	
	Mill sludge from filtration plant		0.403			0.403

Note: - e denotes estimated quantity.

Table-3.6:_Generation and Management of Solid Wastes in Foreign Plants
(1) French Steel Industry (2) Teesside Works of Corus Group of Companies – earlier British Steel (3) Mizushima Works of Kawasaki Steel Corporation, Japan

Shop	Name of Solid Waste	Annual Quantity of Shop, Output, X10^6 T			Total Waste Specific Generation- kg/T of Production			Specific Recycle- kg/T of Production			Specific Reuse- kg/T of Production			Specific Disposal, kg/T of Production		
		French Steel Industry	Corus Group	Kawasaki Japan	French Steel Industry	Corus Group	Kawasaki Japan	French Steel Industry	Corus Group	Kawasaki Japan	French Steel Industry	Corus Group	Kawasaki Japan	French Steel Industry	Corus Group	Kawasaki Japan
BF plant	Hot metal production	13	3.3	8.53												
	BF flue dust				10	8.79	21.02				10	8.79	21.02			
	BF sludge				21.08	7.58	8.63				5.23	5.68	8.63	15.85	1.90	
	BF slag				323.08	329.7	306.91				323.08	329.7	306.91			
BOF shop	Liquid steel prod.	12	3.125	8.06												
	BOF dust/ sludge				28.33	14.91	14.53	23.33				14.91	14.53	5		
	BOF slag				116.67	120	131.32				58.33	120	131.32	58.33		
	Spent refrs.				1.5		3.77				1.46		3.77	0.04		
	Other, if any				20.83			3.33			13.33			4.17		
EAF shop	Production	3.7														
	EAF dust				18.92			5.41						13.51		
	EAF slag				148.65						81.08			67.57		
	Spent refrs.				4.86						4.73			0.14		
	Others, if any				67.57			10.81			43.24			13.51		
Hot rolling mill	Production	14	3.031													
	Mill scale				17.86	20.39					17.86	20.39				
	Mill sludge				3.57	4.78					1.43	4.78		2.14		
	Others, if any				1.93						0.64			1.29		

Note: - e denotes estimated quantity.

Table-3.7: National Averages for Generation and Management of Solid Wastes in Integrated Steel Plants [BF-BOF-CC-Rolling Mills Route]

Shop	Name of Solid Waste	National Average (Weighted) kg/T of Shop Production			
		Specific Generation	Specific Recycle	Specific Reuse	Specific Disposal
Coke oven & by-products plant					
Coke Oven	Undersize coke	192.70		192.70	
By-products plant	Neutralized acid sludge (e)	108.36	3.26	-	105.08
	Decanter sludge (e)	0.16	-	0.16	-
Iron making Plant					
BF Plant	BF Flue dust	16.773	-	11.932	4.840
	BF Sludge	7.865	-	3.319	4.546
	BF Slag including air-cooled slag	380.381	-	240.765	139.616
	Spent refractory	0.415	-	0.235	0.180
Steel making Plant					
BOF shop	BOF dust + Sludge	14.87	-	6.28	8.60
	BOF Slag	172.73	-	68.64	104.09
	Spent refractory	3.50	-	2.02	1.48
Refractory Materials Plant	Limestone + dolomite fines (e)	198.92	-	198.92	-
	Lime + Calcined dolomite fines (e)	205.495	-	205.486	0.009
	Spent refractory	1.43	0.13	0.82	0.48
	RMP Sludge	5.02	-	3.61	1.41
Continuous casting plant	Caster scale (e)	2.88	-	2.88	-
	Caster Sludge (e)	0.75	-	0.75	-
	Spent refractory	1.15	-	0.88	0.27
Hot rolling mill	Mill Scale (e)	18.23	-	18.19	0.04
	Mill sludge (e)	1.37	-	0.68	0.69
	Spent refractory	0.23	-	0.14	0.09
Acetylene Plant	Lime sludge (specific quantity in kg/Nm^3)	5.63	-	5.63	-
Captive power plant	Fly ash (specific fig in kg/MWh)	323.08	-	19.17	303.92
	Bottom ash (specific fig in kg/MWh)	154.35	-	20.66	133.69
	Coal mill reject (specific fig in kg/MWh)	2.44	-	2.44	-

Note: - e denotes estimated quantity.

Table 3.8: Generation and Dumped Quantities of Steel Plant's Solid Wastes

S.No.	Route	Description of Route	Generation - T//year	Dumped Quantity - T//year	Specific Generation - Kg/TCS	Specific Dumped Quantity - Kg/TCS
		Integrated Steel Plants				
1	A	BF-BOF-CC-ROLLING MILLS	3239390	1350582	1079.80	450.19
2	B	COREX-BOF-CC-ROLLING MILL	2151849	2002659	717.28	667.55
3	C	GAS BASED DR-TWIN-SHELL ELECTROXY STEEL MAKING FACILITY-THIN SLAB CASTING-CUM-HOT STRIP ROLLING MILL	1226125	483074	408.71	161.02
4	D	GAS BASED DR-EAF-CC-ROLLING MILL	859590	671666	286.53	223.89

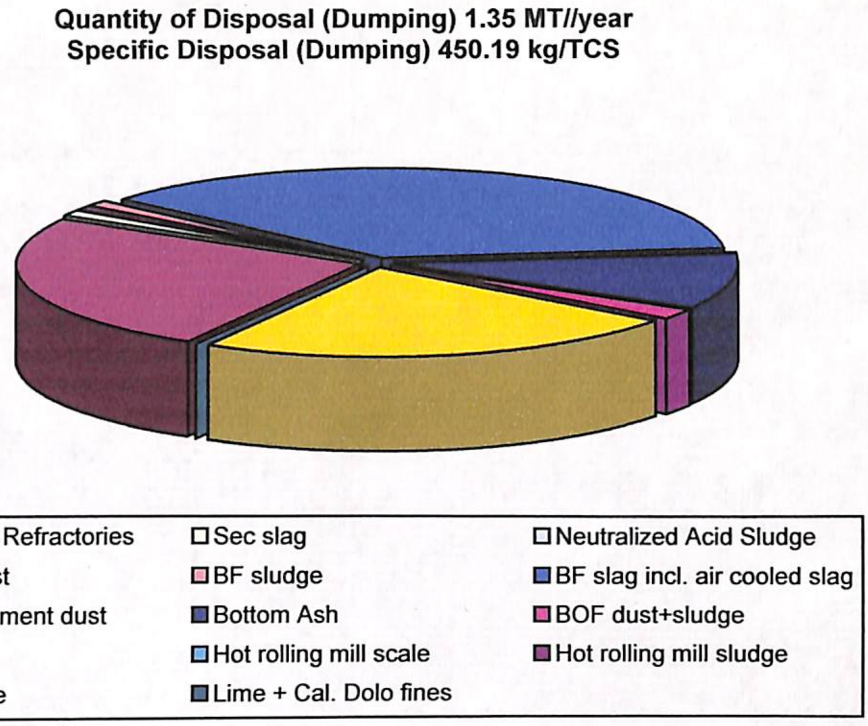


Figure 3.2: Distribution of Total Dumped Quantity for ISP-Route-A [BF-BOF-CC-Rolling Mills]

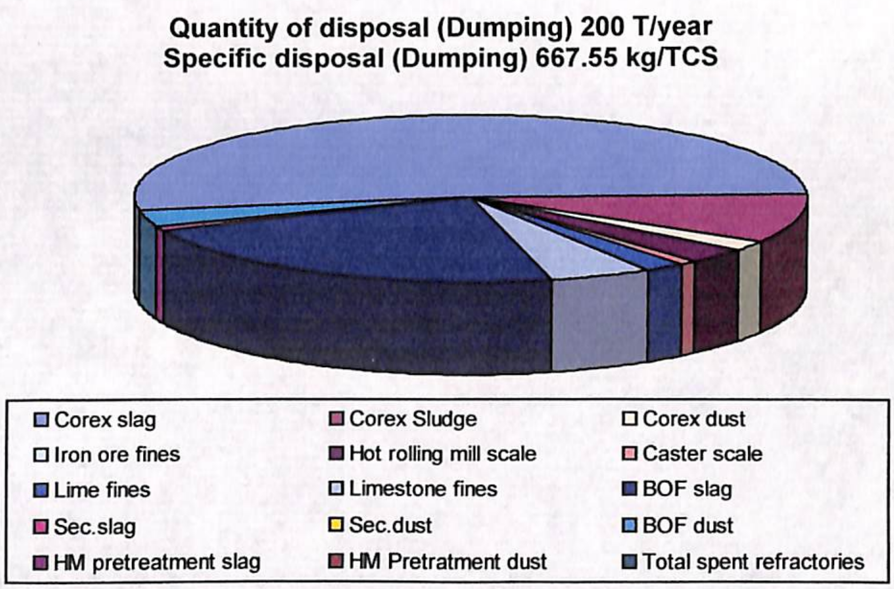


Figure 3.3: Distribution of Total Dumped Quantity for ISP-Route-B [COREX-BOF-CC-Rolling Mills]

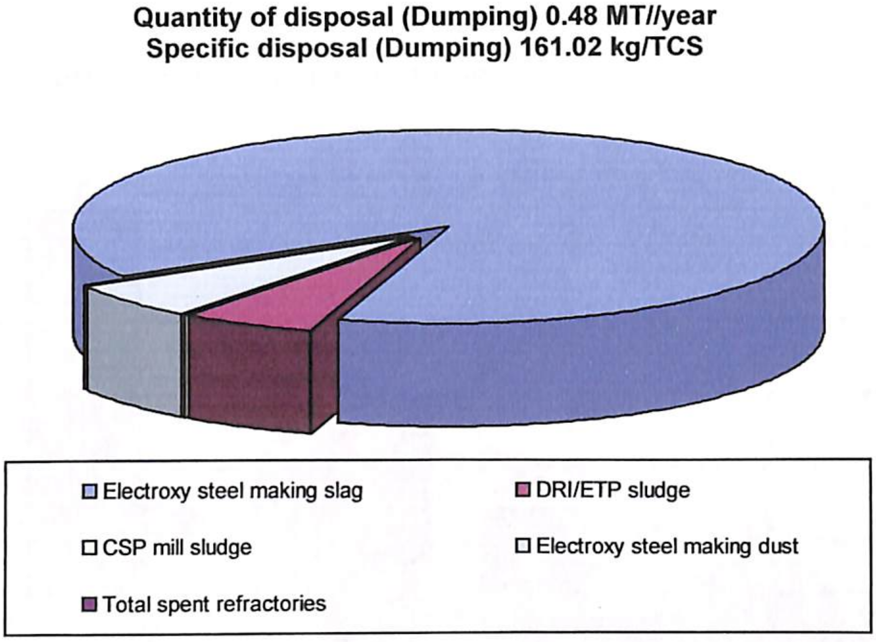


Figure 3.4: Distribution of Total Dumped Quantity for ISP-Route-C [Gas Based DR-Twin Shell Electroxy Steel Making Facility - Thin Slab Casting-Cum-Hot Strip Rolling Mill]

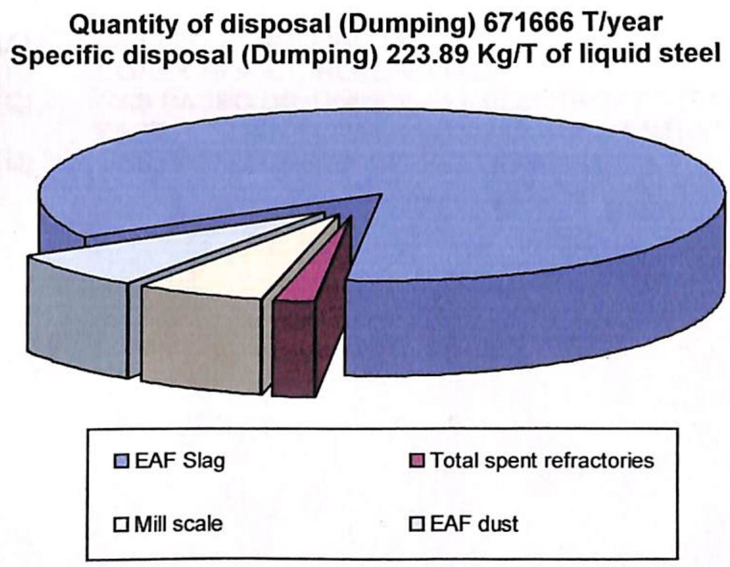


Figure 3.5: Distribution of Total Dumped Quantity for ISP-Route-D [Gas based DR-EAF-CC Rolling Mill]

INTEGRATED STEEL PLANT FOR CAPACITY 3.0 MT/Year

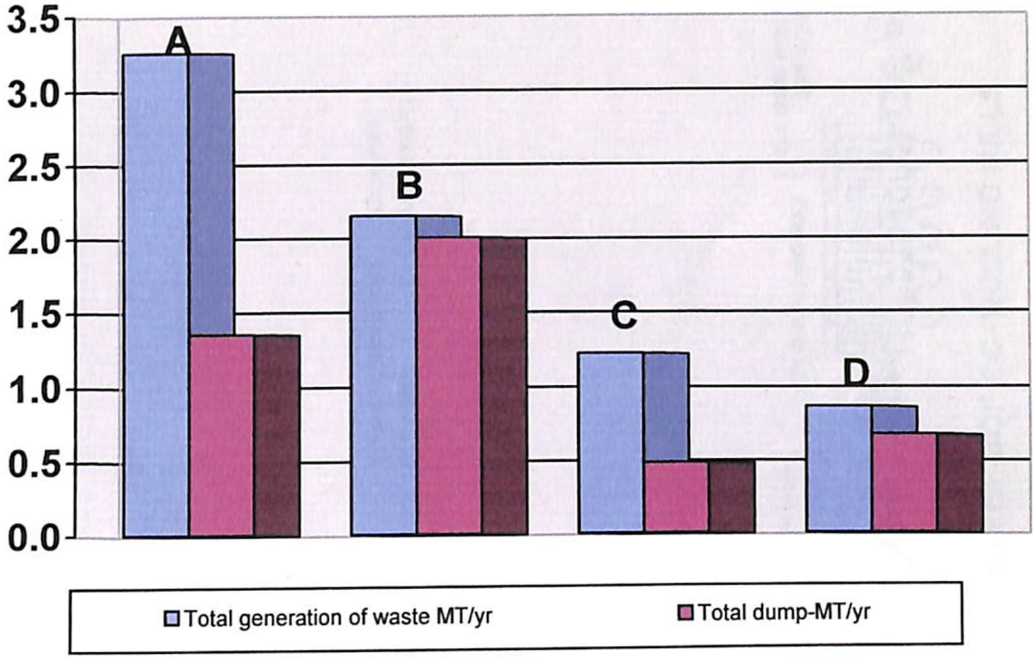
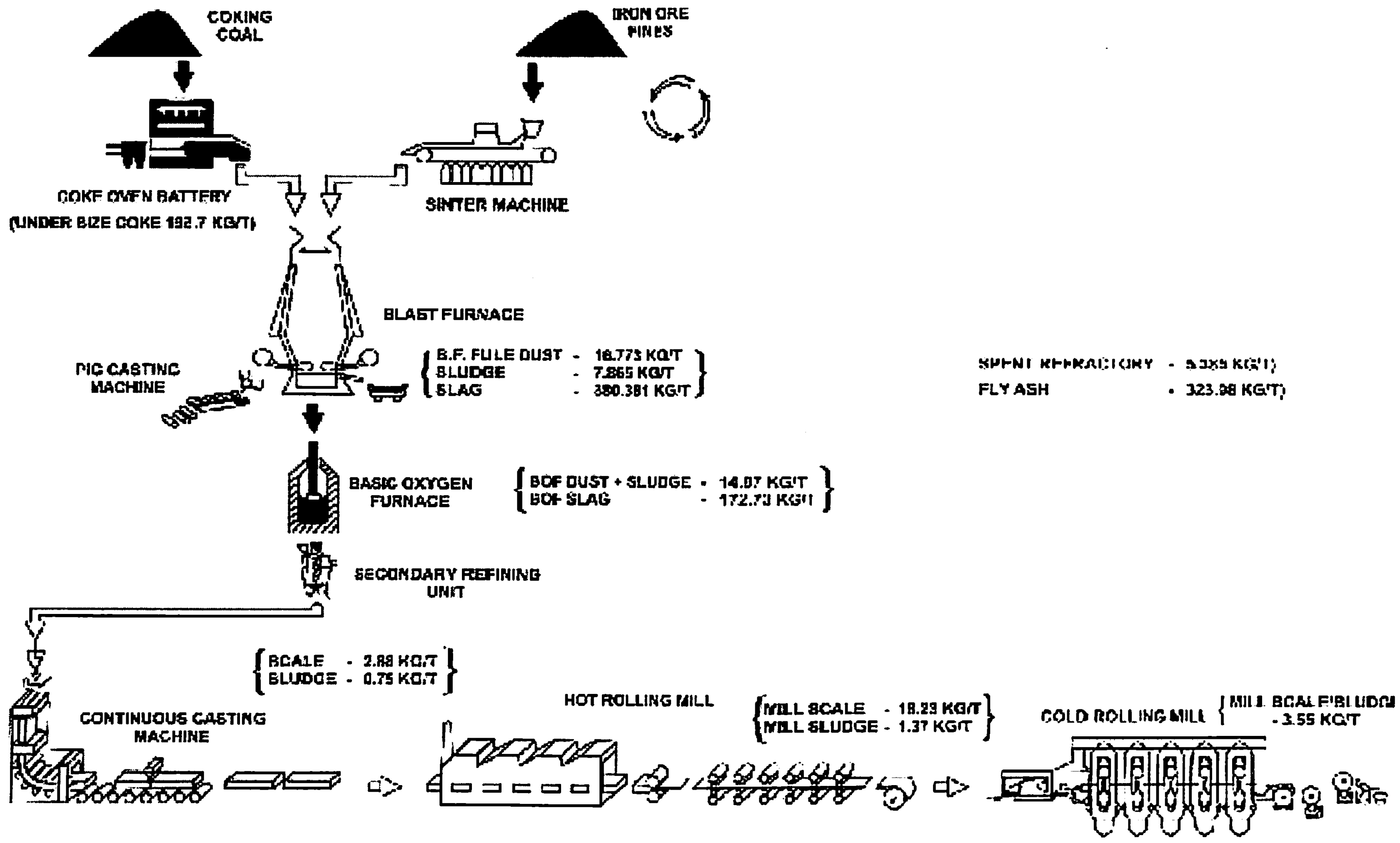


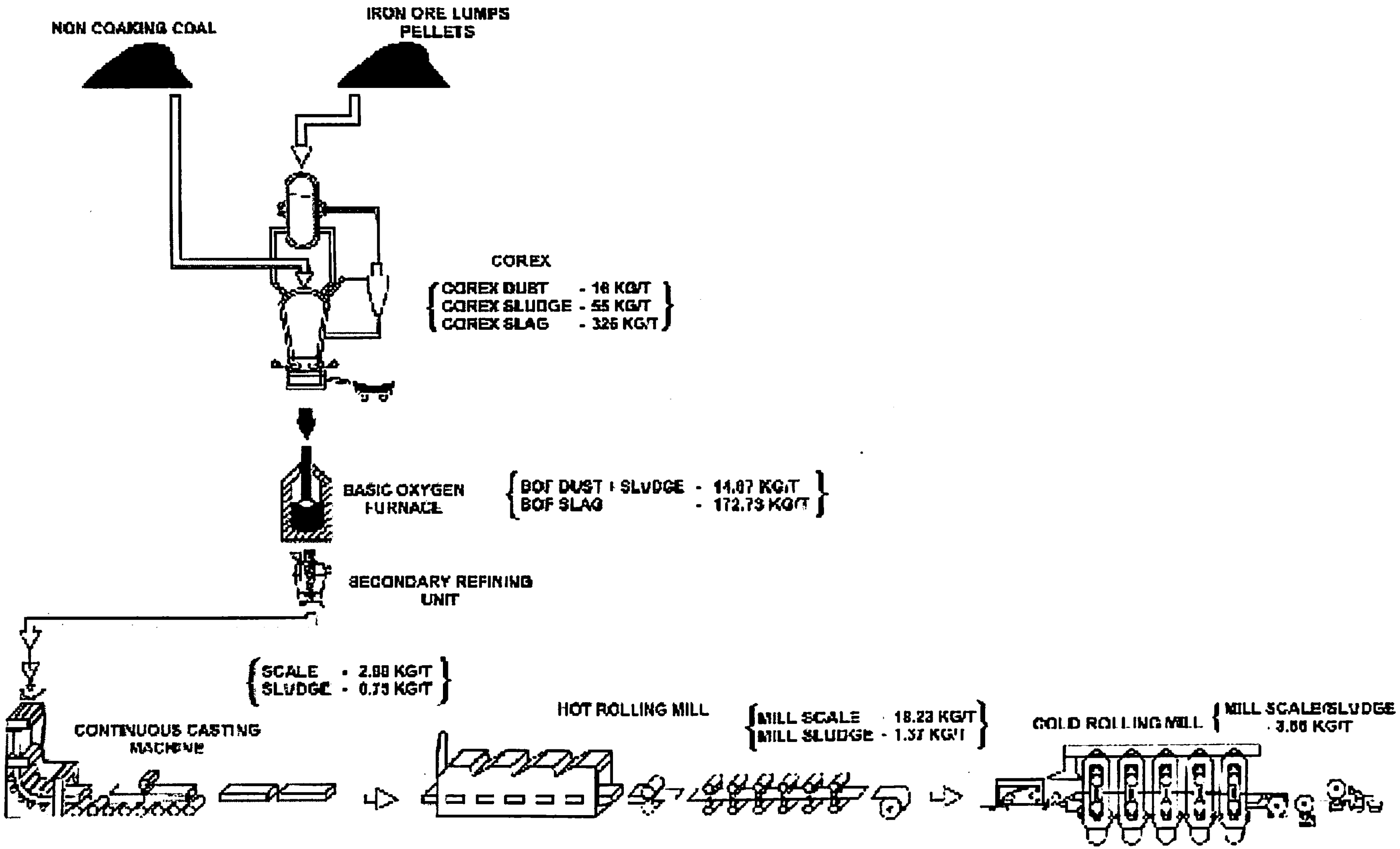
Figure 3.6: Total Generation of Waste and Total Dumping in ISPs.

LEGEND:

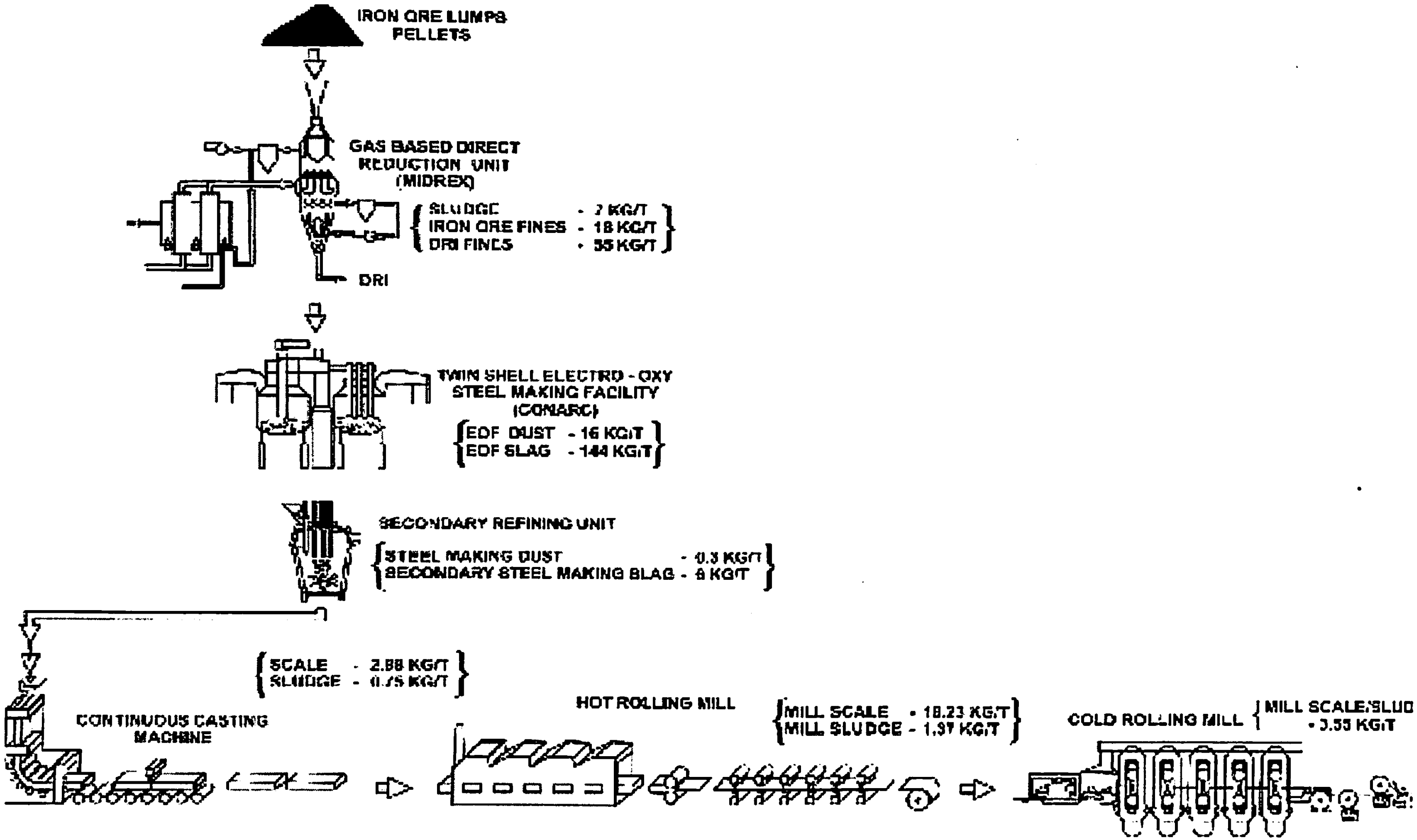
[A] BF-COF-CC-ROLLING MILLS
[B] COREX-BOF-CC-ROLLING MILL
[C] GAS BASED DR-TWIN-SHELL ELECTROXY STEEL MAKING FACILITY-THIN SLAB CASTING-CUM-HOT STRIP ROLLING MILL
[D] GAS BASED DR-EAF-CC-ROLLING MILL



DRG NO. RKA/04/BITS/01 AVERAGE GENERATION OF SOLID WASTE IN BF-BOF-CC- ROLLING MILLS



DRG NO.RKA/04/BITS/02/AVERAGE GENERATION OF SOLID WASTE IN COREX-BOF-CC-ROLLING MILL ROUTE



DRG NO. RKA/04/BITS/03 AVERAGE GENERATION OF SOLID WASTE IN GAS BASED DR - TWIN SHELL ELECTRO - OXY STEEL MAKING - CC - ROLLING MILL ROUTE

CHAPTER 4

SOLID WASTE MANAGEMENT PRACTICES IN STEEL PLANTS

4.1 Introduction

Practices and technologies of steel plant solid waste management have been classified into three groups as follows:

i. Minimization of wastes
ii. Recycling of wastes
iii. Reuse (including sale to outside parties) of wastes

For minimization of wastes, minimization measures have been indicated. For recycling/ reuse, the technologies have been briefly described with the name of the developing agency and the commercial status in. Cost data for implementation of the technologies could not be made available, because, normally, foreign parties reply only to queries about specific projects. It is suggested that research proposals may be made for the technology packages involved for indigenous development through technology absorption, engineering and commercialization and then exemplary facilities based on cost-effective technologies may be set up for other entrepreneurs to follow suit. Problems and prospects of managing key by-products which are substantially dumped at present like steel making slag, BOF dust/sludge, fly ash and spent refractory have been dealt with at length.

Recycle of waste means utilization of the waste in the same process from which the waste has been generated. Reuse of waste means utilization of the waste in any process other than the process from which the waste has been generated. The process utilizing the waste may be within the plant or outside the plant. In case of utilization outside the plant, the waste is considered to have been sold out to the firm utilizing the waste (IISI 1994).

4.1.1 Minimization of Generation of Wastes: -

Minimisation of generation of wastes is the first step or objective of waste management. The air is to minimize generation of waste or altogether eliminate it at the generating source itself. Measures presently available and adopted for minimization of generation of various kinds of wastes in different categories of steel plants are furnished in Table 4.1. Reflection of waste minimization measures on dumped quantities may be noted for each type of ISPs in drawing numbers RKA01/BITS/2004/01, 02, and 03 in chapter 3.

Table 4.1: Waste Minimization Measures in ISPs

Shop	Type of Waste	Waste Minimization Measures
Blast Furnace Plant	BF flue dust/BF sludge	Improved burden preparation, including use of higher proportion of agglomerate, charging and blast furnace operation help reduce the amount of top gas dust generation by over 90%. Metallurgical measures like top pressure, control of gas distribution, replacing coke with

Shop	Type of Waste	Waste Minimization Measures
		Other carbon bearing materials.
	BF slag	With adoption of base blending technology, improving burden preparation like, use of low – ash coke, use of higher proportion of agglomerate and intensification of the areas like, oxygen enrichment, coal dust injection, higher blast temperature and use of level-II automation and adoption of artificial intelligence, significant reduction in the amount of BF slag can be achieved.
DR plant	DRI fines	Adoption of HBI (Hot Briquetted Iron) process, adoption of Hot Link process and Hytem (High Temp.) process.
BOF shop	BOF dust/BOF sludge	Avoidance of over blown metal, minimization of fines in flux-mix, avoidance of late addition of fluxes, elimination of zinc-coated scrap in the burden, use of optimum top blowing rate, pressure and time in conjunction with bottom blowing rate and time, use of low silicon hot meal, use of low – SiO_2 lime
	BOF slag	Use of low SiO_2, high reactivity and low – LOI lime, use of low-silicon and low-sulphur hot metal, if necessary, through hot metal pretreatment, computerized charge balance or process control
EAF shop	EAF dust	Minimisation of wastes at source through improvement in process, operation and maintenance such as, continuous charging (Consteel process, Contiarc process, Finger shaft furnace; it reportedly reduces the volume of dust discharged by as much as 40%). Lime addition as a part of the bucket charge contrary to addition by pneumatic injection. Adoption of foamy slag practice to the optimum extent. Minimisation of carbon blowing by maintaining not so high carbon opening in the bath. Providing adjustable speed derives (ASD) bag house fan to reduce dust emission by 2 to 3% over the whole tap-to-tap cycle. Provision of computerized process control. Use of UHP (Ultra High Power) in all solid charge operation to reduce tap-to-tap time.
	EAF slag	Improved charge-mix preparation, cost-effective optimization of charge-mix, maintaining of minimum basicity by controlling low opening of \`S\`&\`P\` in the bath through optimized charge-mix, betterment of flux quality.
Continuous casting plant	Caster scale/ sludge	Air mist cooling.
Hot rolling mill	Mill scale	Computerisation of reheating furnaces, hot charging practice to the optimum extent, obviating normalizing through thermo-mechanical control process (TMCP).

4.1.2 Recycling and Reuse of Wastes: -

Present practices and technologies of recycling and reuse of steel plant solid wastes generated in different process of steel making have been indicated in Chapter 3.

For indigenous technologies, sourcing of the particular technology has been indicated in this Chapter and those technologies are available from RDCIS, SAIL, Ranchi, NML, Jamshedpur, RRL, Bhubaneshwar and RRL, Bhopal. Technology packages available from the above research centre/laboratories are furnished at a glance in Para 4.3.

4.2 Foreign Technologies: -

The foreign technologies indicated have been briefly described in the following paragraphs as per the following format: -

- Name of developer
- Process description in brief
- Commercial status

4.2.1 Flame Reactor Process: -

This technology is developed by Horsehead Resources Development Co. (HRDC), USA.The dry EAF dust is pneumatically injected into the hot flame in a water-cooled cyclone reactor at a temperature exceeding 2500^{0}C, achieved by firing of natural gas with oxygen-enriched air in a water-cooled burner at the top of the reactor. Dirty zinc oxide containing virtually all the lead, cadmium and halides in the raw dust is generated after reduction; volatilization and re oxidation processes in the reactor and collected finally in bag house, leaving non-hazardous iron-rich molten slag at the reactor. The zinc oxide thus produced is used for extraction of zinc in a smelter.

The Flame reactor process is in commercial operation at North Star Steel's Beaumount Texas works.

4.2.2 ZTT Ferrolime Process: -

This has been redesigned and re-engineering from the former ZIA process by Babcock International. Raw EAF dust is palletized and treated in a rotary kiln with coke and coal as reductants. The fumed zinc oxide containing lead, cadmium and halides thus generated after reduction and re oxidization process in the kiln, is collected following the afterburner and washed to remove the halides to produce an upgraded zinc oxide for sale to primary zinc smelters (Zunkel and Schmitt1995, Zunkel 1996, Zunkel 1997).

The process is now in commercial practice at Caldwell, Texas.

4.2.3 MRT Process: -

Metal Recycling Technologies has been developed this process. EAF dust is leached with hot ammonium chloride to dissolve most of the zinc, lead and cadmium oxides in the dust. Leach slurry is filtered. The unleached iron oxide containing zinc ferrite is washed and recycled to the steel mill or stockpiled. Leach solution is treated with zinc dust to precipitate the dissolved lead and cadmium as cement, which is further, separated into metallic lead and metallic cadmium for sale. Clean solution is passed to crystallizer where high purity zinc oxide crystals are produced for sale.

The MRT process at Nucor was commissioned in 1995 and is operating reasonably well after the start up problems associated with adoption of any new technology.

4.2.4 Laclede Steel Process: -

Laclede Steel modified the former Elkem sealed electric arc furnace process. EAF dust and reductant are directly fed to the sealed electric furnace in which zinc/lead/ cadmium vapours are evolved due to oxide reduction reaction. This vapor is finally condensed to zinc metal in a zinc splash condenser preceded by several proprietary gas handling steps. The iron-rich slag is suitable for disposal.The process is in commercial operation in Laclede, but the quality of the zinc metal is reported to be poor.

4.2.5 Ezinex Process: -

Engitee Impianti, Italy developed this process. EAF dust is leached in ammonium chloride solution to dissolve the zinc oxide, lead oxide and cadmium oxide. Leach solution, after filtering, is treated with zinc dust to cement the lead and cadmium for sale. The clean solution is heated in an electric oven to produce hot dip grade zinc for galvanizing or high-grade zinc metal for sale. The iron-rich zinc ferrite containing leach residue is dried, palletized with coal and recycled to the EAF.

A 10,000 T/year EAF dust plant at Ferriere Nord in Osoppo, Italy was commissioned in early 1996 and is reported to be operating well.

4.2.6 Super Detox Process: -

Bethlehem Steel Corpn, USA has developed this process. EAF dust is mixed with alumino-silicates, lime and other additives. The heavy metals are chemically altered to their least soluble states through precipitation and oxidation/ reduction, followed by being physically bound in the alumino-silicate matrix. The material solidifies to become concrete-like and is relatively impermeable (Zunkel and Schimtt1995).

Super Detox has been in commercial operation since 1989 at Northwestern Steel and Wire Co. Sterling Ill, USA.

4.2.7 Coreco Process: -

College Research Corp (Coreco), German Town, Wisconsin, USA developed this process. Oily rolling mill scale containing 2-12% of oil and normally 15% of water is heated up to 480°C under controlled conditions in a rotary kiln equipped with an after burner, hot cyclone indirect cooler and bag house. The end product thus obtained is clean iron oxide of iron content between 70 to 75%, suitable for recycling in sinter plants.

Tuscaloosa Steel Corporation, a wholly owned subsidiary of British Steel, installed this technology in 1994. To date, the gas-fired Coreco unit in Tuscaloosa Steel Corporation has been used to remediate stockpiled and current rolling mill scale at a rate of 1000 to 2000 T/month.

4.2.8 Velco Injection Technique: -

Velco GmbH, Germany developed this process. Injection of pulverized or granulated coal into the blast furnace through tuyeres is done under coal dust injection process. Plant residues like BF dust, etc.can also be pneumatically injected through tuyeres based on Velco injection technique (Wolf *et al* 2000). For injection, the bulk material needs to have good flow characteristics. This requires a high degree control on particle size. A higher fuel input must be provided through the tuyeres. Thus it is necessary to add carbon carriers. Depending on the condition of the residue, some preparations, such as drying, sieving, sorting and comminution may also be necessary. Velco GmbH has designed two injection machines, the EKS for quantities up to 150 kg/min and the UNIDOS for quantities up to 500 kg/min for pneumatic transportation of plant residue into BF (Ameling 2000).

Noteworthy results have been obtained at blast furnace 'A' at Voest Alpine Stahl in Linz, Austria with the introduction of Velco Injection Technique.

4.2.9 Carbofer Process: -

Allied Steel & Wire (ASW) and Heckett Multiserv, UK developed this process. The Carbofer process consists of two stages. The first stage is to handle the by-products (EAF dust, oily mill scale etc) and blend them with additives to prepare a consistent mix (Carbofer mix), which can be used by the furnace operators by replacing carbon as the slag foaming agent. The second stage is to pneumatically transport the Carbofer mix to the molten EAF bath. The mixture is delivered to the furnace using clean, dry compressed air at between 4 to 5 bars via water cooled lance which is introduced through the slag door. The lance manipulator system is automated so that the furnace operator can control the injection operations automatically from the furnace control room(Cartwrite and Clayton 2000).

M/s. ASW Sheerness, UK has obtained good results (good furnace yield) by adopting this process in more than 3000 heats.

4.2.10 Microwave Treatment of Steel Mill Sludge: -

This process was developed by Carnegie Mellon Research Institute (CMRI), Carnegie Mellon University and supported by the EPRI Centre for Materials Production (CMP). Steel mill sludge can be recycled or reused, provided its water and oil content are totally separated out. The common process to separate oil and water emulsions in emulsion cracking process, which typically needs the addition of heat and frequently requires demulsifying chemical agents. This process often takes 4 to 24 hours for more than 90% separation using gravity settling method. But microwave emulsion cracking system is 30 times faster and requires 90% less space compared to the common emulsion cracking system. In this process, as the heat is delivered by microwave, separation is greatly accelerated. It is believed that the microwave energy catalyses the process not just by adding heat but by coupling energy into separate species at differing absorption rates. Efficient microwave processing requires only a 20°C temperature rise and uses power at the rate of 2.1 to 3.2 kW/liter/minute.

EPRI/CMP is now proceeding to license and commercialize this technology.

4.2.11 Injection of DRI Fines: -

DRI fines can also be used for the melting process in the electric arc furnace. Like coal dust injection, DRI fines are pneumatically transported to the EAF through lance manipulator. Contrary to the coal dust injection, DRI fines are injected to the bath through the slag and duration of injection is only a part of the total heat period. For DRI fine injection technique, some safety measures are to be taken as DRI fines behave clearly more abrasive than coal and fresh DRI fines have high ignitibility (To counteract this characteristic, inert operation is required). The injection rate of DRI fines is 400-1000 kg/min, depending on the furnace capacity.

It is a regular practice in Hamburger Stahlwerke to utilise DRI fines in steel making by injection technology.

4.2.12 Romelt Process: -

This is an oxy-coal iron making process (Smelting Reduction process) developed by Moscow Institute of Steel and Alloys (MISA), Russia in association with Novolipetsk Iron and Steel Works (NLSW), Russia. Romelt process is a single stage Smelting Reduction (SR) process where all metallurgical reactions take place in a single reactor using liquid slag bath. The charge consists of measured quantities of iron bearing material, non-coking coal and fluxes is continuously fed into the molten slag bath of the Romelt furnace. Oxygen and air are injected into the molten slag bath through a row of bottom tuyeres. Heat is produced in the furnace by burning a part of carbon in the slag phase where reduction of iron oxide as well as slag formation takes place. Liquid metal and a portion of slag are taken out from the furnace bottom at regular intervals. Additional heat is generated inside the furnace by post-combustion of flue gas, which is achieved by injection of oxygen through an upper row of tuyeres. The furnace operates slightly below atmospheric pressure. The temperature of the outgoing gas ranges from 1600°C to 1700°C, which is used for generation of steam/electricity through waste heat boiler. It is reported that iron ore lumps/fines, micro fines, mill scale, sludge and any other iron bearing material can be used in this process for production of low-silicon hot metal. The viability of the process largely depends on cost of oxygen plant as well as recovery of heat from the flue gas.

A semi commercial plant of capacity 0.3 MT/yr was installed at NLSW, Russia in 1985, which is operating intermittently till date. A commercial plant of similar capacity is under installation in the Bastar District of Chhattisgarh, India.

4.2.13 Sumitomo Kawasaki Ageing Process (SKAP): -

Sumitomo Metal Industries Ltd (SMI) and Kawasaki Heavy Industries Ltd (KHI), Japan jointly developed and constructed this process. The process requires an autoclave, a slag transportation wagon, a loading deck, a shunting deck, two slag baskets, etc. The basket filled with steel making slag is transported to the autoclave by the transporting wagon. The autoclave is then exposed under 0.6 MPa pressure of saturated steam for ageing. The ageing of steel making slag is essentially a hydration reaction of free time (CaO). Steam ageing process takes minimum time (2 hours) compared to natural ageing process (2 years) because molecules of steam intrude more quickly into the grain of the slag to reach free lime than molecules of water which are larger than those of steam (Shigeru *et al* 1997, Morishita *et al* 1997).

A commercial SKAP plant has been built at SMI's Wakayama works with a processing capacity of 12,000 T/month in April 1995.

4.2.14 Hamborn Shaft Furnace: -

This process has been developed by consortium of German Steel makers; including Thyssen Krupp Stahl.It is an oxygen cupola furnace, called 'Hamborn Shaft Furnace'. It has a hearth diameter of 2.4 m and is equipped with 6 tuyeres. Its design capacity is 15 T/h of hot metal from waste materials. For the reuse of Zn, Pb, alkali bearing dusts and sludge from blast furnaces and steel plants which cannot be charged into blast furnaces via sinter plant, those materials are mixed together with coke breeze and a binder and compressed to bricks. Those bricks as well as skulls and other metallic revert materials are processed in the cupola furnace to yield hot metal. This avoids land filling of Zn, Pb, and alkali bearing wastes.

A consortium of German steel makers commercially operates the furnace.

4.2.15 Cold Briquetting of BOF sludge: -

Developed by National Recovery Systems Inc, USA and consortium of three US steel makers have developed this process. In this process cold briquetting of BOF sludge is done to produce waste oxide briquettes (WOB) and recycling the same into BOF. The recycling system may be classified into three steps as follows: -

a) Generation of BOF sludge cake
b) Cold Briquetting of BOF sludge as waste oxide briquettes
c) Recycling of WOBs.

The dust-laden slurry is passed through thickener. Thickener sludge is dewatered by centrifuge to form BOF sludge cake having about 30% moisture of sludge cake is blended with mill scale in desired proportion. The blend is then dried in a rotary drying kiln to a moisture level of 0.5-1.0%. Dried material, hydrated lime as one binder and molasses as another binder are mixed in a pug mill. The mixture is then briquetted in a roll-press briquetter. Green briquettes thus formed are screened through a vibrating screen. Screened briquettes are cured (naturally weathered) for about 48 hours to improve physical strength (Landow *et al* 1998). The waste oxide briquettes thus obtained are then recycled into BOF (Fleichaderl *et al 1999*).

The technology is commercially well established in USA and also in UK.

4.2.16 Dry Slag Granulation Process: -

Kvaerner Metals, UK developed this process. Dry slag granulation is based on molten slag atomization using a variable speed rotating cup or dish. Slag is delivered on to the centre of the cup from a slag runner via a vertical refractory line pipe. The rotation of the cup forces the slag outwards to the cup lip where it is atomized. Slag droplets cool and solidify in their flight towards the water-jacketed chamber wall. The droplets do not stick to the wall, as they are sufficiently solid before they reach the wall. The solidifying granules fall into a mobile bed, which is cooled by flow of air. Thus granulated slag is settled at the bottom of the bed, avoiding any agglomeration (Featherstone and Holliday 1998).

4.2.17 Top-layer Sintering Process: -

Voest-Alpine GmbH, Austria developed this process. Oily mill scale containing oil up to 3% can be used as a sinter mix in top layer sintering process in which a second ignition hood has been provided. This hood ignites the second layer on top of the main sinter bed. In this process, organic materials mainly from oil are completely oxidized by carrying out four separate reaction steps, namely, evaporation, cracking, gasification and combustion (Kinzel *et al* 1997). The conventional sintering process does provide sufficient thermal energy only for evaporation but not for cracking, gasification and combustion. As a result, a part of the organic material condenses in the following ductwork, ESP and is responsible for the formation of the blue haze.

4.2.18 Hydro-cyclone Process: -

This process has been designed by Shorts Brothers (Plant) Ltd., British Steel Technical and Richard Mozely Ltd., UK. Recycling of BF sludge is limited primarily due to its zinc content. However maximum recycling is possible if sludge is treated by hydro cyclone process. In a hydro cyclone process, coarser particles due to high centrifugal effect migrate to the wall of the cyclone and finally exit through the spigot located at the bottom of cyclone as the underflow fraction and on the other hand very minute particles of zinc dust remain in the water and exit from the top as the overflow fraction. The overflow is collected as thickened slurry in a small classifier for further recovery of zinc. The underflow is recycled by depositing a layer on the bed.

This process has already been established at British Steel Plc's Teesside Works, UK.

4.2.19 Injection of Oily Mill Scale Sludge into BF: -

British Steel, UK has developed this process. Recycling of oily mill scale sludge (up to 15% oil) is not possible through the sinter plant because of associated problems in the waste gas cleaning process. A process for injection of oily mill scale sludge into blast furnace is a solution for it's recycling. The oily mill scale sludge is injected through the tuyeres owing to which both the oil and iron content in the sludge are fully utilized. The oil acts as a reductant in the process, whereas iron content in the sludge contributes some iron value to the process.

British Steel, UK is successfully operating this process in their Teesside works.

4.2.20 Glassification Process: -

Oregon Steel Mills Inc, Mr.Roger B Ek and Associates & Issaquah, Washington, USA has developed this process. The glassification process is very similar to typical glass melting process. Glass forming materials and modifiers, together with EAF dust are blended in the blending system. Spent refractory, slag and other steel making by-products may be used with EAF dust, provided these are properly crushed into minus 20 mesh. The blend material is charged in a glass furnace. Glass melting takes place at approximately 1400°C. Molten glass discharged from the furnace is then quenched to form glass granules for end products; alternatively the glass may be cast into moulds or formed to produce tiles, sheets and other architectural shapes (Buddemeyer and O'Donnell 1996, Bray 1999, Griscom *et al* 1999a,Koen *et al* 1995).

The first glassification plant began test runs in November 1992 at Portland, Oregon Melt shop. It has been engineered to process well over 12,000 T of EAF dust per year.

4.2 Indigenous Technology: -

4.2.1 Technologies Developed by RDCIS, SAIL, Ranchi: -

The following technologies on reuse of solid wastes have been developed by and are available from Research and Development Centre for Iron & Steel [RDCIS], SAIL, Ranchi: -

A) Quality Road Making Using Steel Plant Wastes: -

RDCIS has jointly developed with CRRI, New Delhi, and a mixture of superior quality, for road making, consisting of air cooled BF and BOF slag, granulated BF slag, fly ash and activator. Mixture is containing; BF slag varies from 50 to 65%, BOF slag from 20 to 30% granulated BF slag from 13 to 20%, fly ash from 0 to 10% and activator from 0 to 4%.

Based on the results of laboratory studies, 12 experimental road test sections, each of 2.5m x 2.5m x 15 cm, were constructed on each of the test sections, each of the test sections with a 30 cm diameter plate in accordance with the requirements of IS: 9214,1979 (reaffirmed 1997). The results of the plate load tests were satisfactory.

Fully weathered BOF slag, therefore, has proved to be a good base or sub-base material in road pavement with or without BF slag, granulated BF slag and activators etc. It can be compacted to form a strong matrix and its skid resistance properties can be used to advantage for bituminous surfacing. BOF slag has excellent affinity for bitumen and asphalted concrete mixes, with BOF slag, as one of the constituents. This is also very durable under extremely heavy traffic where conventional mixes exhibit rutting, distortion and distress.

B) Fly Ash Brick Making: -

a) Clay-Fly Ash Brick Making: -

Clay-fly ash burnt brick/block manufacturing process developed by RDCIS is very similar to that used by the conventional brick kiln operators. Depending on the quality of clay fly ash, a certain amount of fly ash is mixed with clay and green bricks are cast in the mould after mixing appropriate amount of sand or cinder ash and water. Bricks are heat hardened in the kiln after they are dried. The bricks obtained thus are lightweight and smooth on the surface and meet all the requirements of the Bureau of Indian Standards. The RDCIS process has been studied extensively with fly ash from Rourkela, Bokaro and Bhilai Steel Plants and can use upto 60% of fly ash. The cold crushing strength (CCS) and water absorption data indicate that the requirements of BIS are met by the technology developed by RDCIS.

b) Lime-Fly Ash Brick/Block Making: -

RDCIS process for manufacture of lime-fly ash-sand/cinder ash brick/block uses conventional type of manual brick/block making and compaction technologies. All the three curing techniques autoclaving, steaming or moisture curing – have been successfully developed. Before curing, green bricks/blocks are air dried for about 24 hours. Depending on the quality of fly ash, the ratios of the input materials, type of activators, curing technique and time have been optimized as follows: -

i) Autoclaving at 15.5kg/cm^2 for 3-8 hours

ii) Steam curing at 90-95°C for 15-25 hours

iii) Moisture curing under a plastic cover for 4 to 8 weeks (ambient temperature or sunlight also influences) with water spraying once a day.

Selection of technique depends on the availability of land resources with the entrepreneurs and other infrastructure facilities.

Cold crushing strength (CCS) of all these products was measured. CCS was also measured in wet condition for the bricks/blocks kept fully under water for 7 days and then oven dried at 100°C for 48 hours. The CCS in all the cases was found to be around 110 kg/cm^2 on an average. Once the bricks were fully cured, wetting or drying did not affect the variation.

c) Aggregate Making: -

Fly ash aggregate making technology has been developed on the basis of existing pellet making technology. Using a laboratory scale disc pelletiser, various parameters like compaction, density, angle, disc speed, charging location, moisturizing location, quantity of binders, curing time and temperature have been optimized on the Bokaro, Rourkela and Bhilai fly ashes. By changing the disc pelletiser variables, the pellets of required size could be produced. All the three curing techniques, autoclaving, steaming and moisture curing as explained earlier were studied. The C.C.S. is reported satisfactory. For using the pellets in concreting the cured pellets of larger sizes of 15-30 mm could be broken to required size and used as a substitute for stone aggregate.

d) Aggregate Brick Making: -

Pellets of minus 10 mm size have been used for brick/block making. They (35-40%) are mixed with fly ash (45-55%), lime (5%) and sand (10-12%) and water about 20% of the weight of the solid, is added and thoroughly mixed. Bricks/blocks cast by conventional manual method, taken out of the cast immediately and air dried for 24 hours as detailed above attained an average C.C.S. value of 66 kg/cm^2. Moisture cured bricks/blocks for 50 days could attain only around 45 kg/cm^2. Such bricks/blocks could not be broken or sheared during compression and can be used, therefore, for the construction of non-load bearing walls.

e) Utilization of Fly Ash in Agriculture Sector: -

RDCIS conducted a detailed study on the impact of fly ash incorporation in soils (acidic red loams) on the growth, yield and trace metal content of agricultural crops, vegetable crop, flowers and tree species. Pot studies followed by field trials conducted in the control farms and farmer's fields have provided enough evidence of its possible use for flower cultivation in large areas and for a forestation purposes. In agricultural crops such as rice, soyabean or wheat where crop growth duration is over 100-120 days and in vegetable crops such as Okra, Colocasia, Potato, Tomato, Faraz bean and Red radish, application of fly ash has shown promise. However, accumulation of some of the trace metals (Pb, Ni) in edible parts is a matter of concern. With a proper quality monitoring and control of vegetables, fly ash can be a cheap source of mineral nutrition for the poor population. Amendment of soil, with fly ash, for cultivation of flowers such as Marigold, Gerbera, Sunflower and Gladiolus resulted in high growth, yield and financial returns. Tree species like Akashi, Black Siris, Chakundi, Gamhar, Karanj, Shisham and Subabul grown on 50 and 100% fly ash were also helped in their growth. Positive and beneficial effect of fly ash incorporation in soil was evident in growth and quality of flowers and growth of tree species. The application of measured and controlled amount of fly ash, a solid waste of captive power plants, for amendment of soil for cultivation of flowers and tree species resulted in higher growth, yield and financial return from horticultural crops and tree species. The conclusion of this study is that utilization of fly ash for soil amendment may help in growth of floriculture.

Therefore, application of fly ash in production of food grains, vegetables, flowers and tree species are acceptable to the farmers due to higher yield and financial returns. However, presence of heavy metal in eatables prohibits its use in production of food grains and vegetables.

C) BOF Slag: -

a) Cement Making: -

RDCIS and National Council for Cement & Building Materials, New Delhi have jointly developed technology for utilization of BOF slag up to 10% as: -

i) Raw material for production of ordinary Portland cement

ii) Blending material in Portland slag cement.

It has been observed that CaO/SiO_2 ratio in LD slag cement is the same that of Portland cement and is about 3 and the BOF slag does not have any deleterious component. In spite of the fact that BOF slag is a hard material to grind, the cement produced with BOF slag may be cheaper by about 20% (value of BOF slag is taken as zero). Therefore, it is a techno-economically viable proposition.

b) Utilization of BOF Slag as Rail Ballast: -

BOF slag aggregate is an excellent material for track ballast. It has the following advantages:

i) High resistance to wear and abrasion

ii) High resistance to lateral movement on curves and washout protection in areas subject to flooding due to its heavy weight

iii) It provides on interlocking stable road-bed due to its rough angular pieces

iv) High resistance of degradation

v) High electrical resistance and it does not interfere with the conductivity of rails when used with interlocking signal systems

vi) It contains no organic substance and is an exceptionally clean ballasting material.

BOF slag has been included in the specification of American Railway Engineers' Association [AREA].

This use of BOF slag has also been established. RDCIS, SAIL, Ranchi and RDSO, Lucknow, Ministry of Railways has jointly evaluated and found suitable for rail ballast technically and commercially.

c) Auto Grinding of BOF Slag: -

This grinding technique uses the principle of crystallo-chemical transformation during cooling. BOF slag contains di-calcium silicate, which has γ-form as the only stable phase at room temperature. During cooling of the molten slag, β-di-calcium silicate in solid form changes to γ-di-calcium silicate which is accompanied, by 10% volume increase due to difference in specific gravity of the two. The volume change is accompanied by shattering of the slag mass into dust.

Based on the characteristics of BOF slag and various lime bearing additives, heat balance calculations of suitable mixture was designed, melted in a furnace and poured out. Different rates of cooling were applied. Intensity of smell of acetylene gas was observed for the molten slag under different humidity conditions. The product thus obtained with varying degrees and rates of powdering were also characterized.

In BOF slag glassy phases comprise about 34%. A minimum of 10% additive is required for auto crumbling of the slag during cooling. However, if the additives are added in the raw form they consume a lot of heat due to endothermic reaction during dissociation. With lime less than 10%, no crumbling was observed, whereas with higher quantities of lime of C_3S in the slag is increased. Presence of FeO inhibits crumbling because a good part of added CaO forms calcium ferrite. Presence of free lime gets hydrated and forms [Ca $(OH)_2$], which causes decrepitation. Higher the humidity faster is the rate of crumbling. Melting of lime mixed BOF slag in graphite crucible leads to the formation of calcium carbide and reduction of FeO to metallic iron. CaC_2 under humid environment causes the formation of acetylene (C_2H_2) gas as given below:

$$CaC_2 + 2H_2O = Ca(OH)_2 + C_2H_2$$

Melting the slag under reducing conditions helps in recovery of metallic iron along with crumbling of the slag.

Therefore, the mechanism of crumbling of lime added BOF slag during cooling is as follows:

i) β -phase to γ -phase transformation of C_2S

ii) Hydration of free CaO

iii) Formation and hydration of calcium carbide

Due to the use of lime-bearing additives in the auto grinding technique, the lime content of the slag goes up and it becomes a richer source of lime than the BOF slag.

D) GCP Sludge/Fines: -

The GCP sludge/fines generated in the sintering plant, blast furnace, steel melting shop and raw material handling plant are disposed off in varying amounts in Bokaro Steel plant to sludge compartments, and in other steel plants in dry form. In Bhilai and Durgapur, GCP sludge/dust of sintering plant and SMS, and in RSP, part of the sludge of sintering plant is recycled. They contain about 48% iron and about 10% lime and magnesia on an average. The amount of dumped ferruginous waste is different in different steel plants. The rate of yearly dumping of ferruginous waste in SAIL plants is also different.

RDCIS has developed technologies for utilization of the ferruginous wastes of integrated steel plants through micro pelletisation-sintering route. In the particular case of Bokaro, addition of about 100 kg pellets/T of sinter increased yield 3-4%, sintering speed by 4-5%, productivity index by 8-10% and tumbler index by 2-3%. This has also reduced flux and iron ore consumption by 13 kg/T of sinter and 87 kg/T of sinter respectively. Since the basic nature of the waste is the same, the results in the case of other plants are similar.

Based on the RDCIS technologies, CET has prepared feasibility report for BSP and Mecon has prepared feasibility report for RSP.

E) Salvaged Refractory: -

Development of magnesia ramming mass from salvaged basic material & conversion of salvaged MgO-C into fresh MgO-C bricks.

In a steel-making vessel, Mag-carbon bricks are used as lining material and the cost of these bricks is around Rs.32000/T. SAIL consumes about 30,000 tonnes of these bricks for production of 10 MT of Steel. By taking into account of carbon additives and bonding agents, the magnesia grains consumed is about 25,000 T. Considering 25% as the rejection amount, the amount of Magnesia grains available for recycling is 6,250 T.

RDCIS has already developed the technology of salvaging magnesia brickbats into ramming mass. This needs facilities like crushing, screening and mixing with suitable additives like tar, pitch, chromates, phosphates, etc. The graded material was mixed with the bonds, and packed for use as ramming mass. Manufacture of Mag-carbon bricks needs high capacity press (at least 400T), It requires crushing, grinding, blending and high pressure mixing facilities. These processes also require on-line quality assurance systems.

Process know-how has been developed at RDCIS and transferred to a private party for commercial manufacture.

Salvaging of Al_2O_3-C slide gate plate for use as mortars

Slide gate plate is used as flow controlling system in a steel ladle. For production of 10 MT of steel approximately, nearly 175 T of slide gate plates are consumed in SAIL plants. These are contaminated with steel and slag. So sorting out the effective portion and considering the carbon content in the plate, the actual reclaimable slide gate plate comes out to be 120-130 T.These are then crushed and ground, demagnetized and screened and graded into different fractions.

Refractory mortars are powdered materials used for joining refractory bricks. They must have, therefore, properties similar to the refractory blocks. The mortars are generally applied in paste form and contain 20-25% water; high alumina cement and plastic clay are added to the grains thus produced acting as bonding agent and plasticizer.

Steel plants are using this technology for production of mortar in-house and thereby salvaging the alumina-carbon slide gate plates.

4.3.1 Technologies Developed by NML, Jamshedpur: -

The following technologies on reuse of solid wastes have been developed by and are available from National Metallurgical Laboratory, Jamshedpur (NML Tech. Handbook 1999): -

A) Ceramic Floor and Wall Tiles Using Fly Ash: -

NML has developed the ceramic floor and wall tiles using fly ash as main raw materials. The product conforms to all the EN standards for the tiles and has better strength of >300 kg/cm^2 and scratch hardness of >7. This can be used for industrial applications also. These tiles can be produced in glazed and unglazed form, various colors and designs and in matte and glossy finishes. 10-15% cost reduction is the salient feature of the technology.

B) Synthetic Granite Tiles from Fly Ash: -

The technology has been developed to synthetically produce the imitation granite tiles from fly ash. After polishing, it looks similar to polished granite. These tiles are very dense, show excellent mechanical properties and are free from any micro defects. These can be produced in many colors and designs. Improved properties are the major highlights of this technology.

C) Wear Resistant Ceramic Liners Using Fly Ash: -

The technology has been developed to produce wear-resistant ceramic liners for the material handling equipment. The products are very hard (equal to corundum) and dense. These liners have better abrasion and erosion resistant properties than basalt and hard steel and can substitute the high alumina ceramic liners. The products cost around 15-20% less than high alumina ceramics liners.

Major raw materials required for the production are fly ash, technical alumina, alumino-silicate minerals and additives.

The raw materials are wet mixed in proper proportion. After drying, the dry powder is hydraulically pressed to get different shapes. The pressed products are finally sintered at high temperatures. The sintered products are then ready as tiles for lining.

<u>Commercialization status: -</u>

The process has been transferred to a party. A plant with 500 TPA capacity costs Rs.250 lakhs. ROI is about 40% at a selling price of Rs.50, 000/T.

D) Heat and Sound Insulation Sandwich Panels Using Fly Ash and Other Waste Materials: -

Fly ash in combination with other waste materials has been used to develop the technology of producing heat and sound insulation sandwich panels. These panels are heat and sound insulative, light and very strong. These panels can be used as false ceiling, partition walls, etc in building industry. Achievement of better strength properties is the major advantage. (Tifac 2000)

E) Mullite-Fly Ash Aggregate for Refractory Castables: -

Mullite is a high performance refractory mineral used in bricks and castables. Mullite has been synthesized using fly ash and was used in castables for medium to high temperature applications. These aggregates have low apparent porosity and show excellent refractory properties upto 1400°C. Energy saving is the major advantage of this technology.

F) Low Pressure Briquetting of Sponge Iron Fines: -

This is a process for the agglomeration/briquetting of sponge iron fines (-3 mm) with suitable binder for use in melting furnaces. The agglomerates/briquettes can be produced using the sponge iron fines with the addition of indigenously available additives. Briquettes/agglomerates find better utility than the parent sponge iron due to high bulk density and specific gravity in addition to decreasing tendency of rusting and oxidation.

A major application is in the production of iron and steel making in different melting furnaces such as (a) EAF, (b) Cupola, (c) induction furnace, (d) for making special grade liquid iron in SAF.

Commercialisation of the process is under negotiation.

The cost of conversion from fines to briquettes will be about Rs.125/T.

4.3.3 Technologies Developed by Regional Research Laboratory [RRL] Bhubaneswar: -

The following technologies on reuse of solid wastes have been developed by and are available from RRL, Bhubaneswar.

i) Sintered lightweight aggregate from fly ash and metallurgical solid wastes (Sengupta 1999).

   Lightweight aggregate pellet ranging from 4-20 mm size for constructional use has been produced.

ii) Iron-rich hydraulic cement for metallurgical use in briquetting and pelletisation of iron oxide fines.

   Ferrite clinker produced by this process is used to make iron rich hydraulic cement binder.

iii) Plasma smelting studies of steel making process toxic dusts and sludge for recovery of metal values like Zn, Pb, Cd, etc.

   This is the process for recovering the toxic heavy metals from the dusts and sludge of steel plants by thermal plasma technique. This process is effective for dusts and sludge enriched with toxic metals. The slag produced by thermal plasma is safe for land filling.

4.3.2 Technologies Developed by RRL, Bhopal: -

Various technologies developed using fly ash by RRL, Bhopal based on the traditional methods so that one can follow easily without changing the existing infrastructure facilities available at RRL are as follows: -

i) Clay-fly ash bricks
ii) Fly ash polymer composites for panel and door shutters
iii) Sisal fiber cement corrugated roofing sheets
iv) Cement concrete solid/hollow blocks
v) Paints using fly ash as filler

A) Clay-Fly Ash Bricks: -

Good quality bricks are obtained with uniform shape, good strength and reduced water absorption as per BIS specification. Characteristic of clay-fly ash bricks are given below: -

Properties: -

- Compressive strength 70-140 kg/cm^2
- Water absorption less than 18%
- Linear shrinkage less than 10%
- Bulk density – 1.28 to 1.68 g/cm^3
- Novel features
- Improved properties
- Good shape and size
- Use of waste materials
- Less breakage
- Less shrinkage
- Helps in improving environment

Clay-fly ash bricks are now manufactured on commercial scale.

B) Fly Ash Polymer Composite Door Shutter/Panel: -

Wood is a traditional and most extensively used building material in the form of many components e.g. doors, windows, partition walls, etc. With the increasing environmental hazards due to cutting of wood in forests, the use of wood is being restricted in India. RRL, Bhopal has developed a new wood substitute using fly ash and natural organic fibers. A number of full size door shutters were made and tested to evaluate the performance. The results were found satisfactory. All the tests were carried out according to CPWD requirements.

The results of 3 ft x 1 ft and 0.15" thick sheet: -

1. Water absorption - 0.46 to 1.5%
2. Density - 0.40 to1.6 g/cm^3
3. Impact strength - 0.40 N/mm^2

Novel features: -

- Promising material for door shutter
- Energy saving process
- Use of natural fibres

- Termite and fungus resistant
- Reduction in environmental hazards, health hazards, deforestation and maintenance cost.

C) Sisal Fiber Cement Corrugated Roofing Sheet: -

Use of asbestos fiber in roofing sheets has been banned due to its carcinogenic nature and health hazards. Therefore it is necessary to study the substitution of asbestos fibre with other natural fiber. RRL, Bhopal has developed a corrugated roofing sheet using sisal fibre with chicken mesh as reinforcing substance in cement matrix. The properties of this sheet achieved only 80% of that of AC sheets. The cost of the sheet is 20% cheaper than AC sheet. The sisal fiber corrugated roofing sheets have been used in many low cost houses constructed at RRL, Bhopal in 1990. The performance of the sheets is found to be satisfactory. In this technology, about 5% of fly ash have been used which improved the workability, finishing etc of the roofing sheet.

D) Cement Concrete Solid/Hollow Blocks: -

Bricks and stones are the potential wall materials commonly used in building construction. Bricks available in many parts of the country are low in compressive strength having more than 20% moisture absorption and thus they are not of good quality. Stonewalls consume higher cement mortar and have thicker joints and required skilled labour. To replace the bricks and stones, RRL, Bhopal has developed precast concrete blocks from 6 mm aggregates; waste stone dust and fly ash. The blocks can be made both manually and mechanically. These precast concrete blocks have shown good engineering properties.Some of these is mentioned below: -

Compressive Strength: -

1.	Manually made blocks	40-60 kg/cm^2
2.	Machine made blocks	80-130 kg/cm^2
3.	Water absorption	5-10%
4.	Seepage	No seepage observed

The unique features of these blocks are: -

- Cost effective
- Consistent quality
- Speedy and easy construction
- Plastering in wall is not essential
- Good appearance

E) Paints Using Fly Ash: -

The fly ash obtained from thermal power stations has been studied as an extender pigment emulsion paint formulations at RRL, Bhopal. The results show satisfactory performance when applied on external surface of components. This paint has been formulated with addition of wider range of pigment binder ratios. It has been found that the brush ability and the performance of the paint are good. The properties of fly ash contributing to its usefulness as extender are its chemical inertness, low oil absorption and specific gravity values. This paint has shown improved abrasion properties without any adverse effect on other properties like drying time, thickness, brush ability and glossiness. The use of fly ash does not affect dark color shades of enamels but lighter shades like white may be affected by whitish gray color of the ash. The use of fly ash in this paint leads to partial replacement of conventional extenders.

4.4 By Products Needing Emphasis in Effective Management: -

Iron making and steel making slag constitute the bulk of total generation of by-products. This is followed by fly ash in ISPs having captive power plant. But with regard to utilization, though granulated BF slag is an established marketable commodity, uses of steel making slag and fly ash are not significant. For a life period of 25 years, requirement of land for disposal of fly ash is 1.3 acre/MW if dumped openly and 0.7-0.8 acre/MW, if dumped in pond/lagoon. However, a lot of R&D efforts and initiatives in the recent past are likely to substantially improve utilization of steel making slag. But fly ash is yet to get adequate attention from steel producers. BOF dust/sludge is another by-product for effective management of which adequate emphasis is necessary. Again, spent refractory, though not yet a cause of alarm with regard to the quantity generated, it will be a stumbling block if adequate attention is not paid to effective management of this by-product.

In view of the foregoing, it is considered prudent to deliberate on the problems and prospects of effective management of BOF dust/sludge, fly ash and spent refractory, which follows in the following paragraphs:

4.4.1 BOF Dust/Sludge: -

The conventional practice is that the dust/sludge is dumped in an open yard and allowed to weather for natural drying before it is charged into the sinter plant. The problems associated with this method are building up of zinc (not significant in Indian practice) and alkali contents in blast furnace and the method cannot be continued during rainy season. While the latter may be overcome by charging sludge at higher rate than its generation to make up for accumulation during rainy season, the former problem persists. But a more effective method developed by National Recovery Systems Inc. USA, is now commercially well established in USA and also in UK. The method consist in recycling BOF sludge into the BOF after its drying and cold bonded roll briquetting using hydrated lime and molasses as binder. The briquetted product is known as waste oxide briquette (WOB) (Balajee *et al* 1995). This method thus bypasses blast furnace. When zinc builds up upon multiple recycling beyond a certain limit, the sludge may be sold to entrepreneurs interested in economically extracting zinc from it. The method can be continued even during rainy season. But the main economic advantage, which makes it attractive, is that higher value addition of the waste is effected due to its direct conversion into liquid steel.

The above case clearly brings out that the objective of management of solid waste should not be just utilisation of the waste, but utilisation of the waste in the most cost-effective manner (Griscom *et al* 1999b).

4.4.2 Fly Ash: -

Fly ash is one of the most abundant residues of coal combustion. Its indiscriminate disposal requires large volumes of land, water and energy.

It is refractory in nature and very fine (150 µm to less than 1 µm), typical surface area being 4,000-10.000 sq.cm/gm. Its chemical composition and fineness of particles brings it within the specifications of siliceous or aluminous materials with pozzolanic properties. Its versatile nature facilitates its application in areas ranging from agriculture, cement, concrete, and bricks to high value added applications like extraction of alumina.

The major application areas for fly ash in the country are the following: -

a) Brick manufacturing
b) Cement constituent
c) Part replacement of cement
d) Roads and embankment construction
e) Dyke raising
f) Structural fill reclaiming low lying areas
g) Stowing material for mines
h) Agriculture and forestry
i) Other medium and high value added products (tiles, wood, paints, extraction of alumina, light weight aggregate etc.)

A) Fly Ash Bricks: -

A number of technologies have been developed and demonstrated successfully for use of fly ash as a building material. Thrust is required to have more demonstrations of these technologies in the field to build confidence in their techno-economic viability (Prabhakar et al. 1999). Towards this a number of efforts are on, including the focused thrust being provided by Fly Ash Mission of the Government of India.

Advantages of fly ash bricks over burnt clay bricks are given below:-

- Better bonding with mortar and plaster
- Provide good resistance to weathering
- Plastering over brick surface can be avoided
- Controlled dimensions and edges, smooth and fine finish
- Bricks and blocks can be made in different shapes, sizes and forms
- Can be made in different colors by using pigments

4.5 Spent Refractory: -

A number of complex materials issues as follows have limited the recycling/reuse of spent refractory material. Besides those issues, reuse is influenced by the philosophy of individual companies towards recycling and changes in technology. Applications or possible uses for spent refractory material can range from reuse in refractory to uses that require developmental research.

Specific issues must be considered for the successful recycling/reuse of spent refractory (Bennett and Kwong 1996): -

- The type and quantity of refractory
- The location of users and refractory producers

- Regulations
- Health concerns
- Contamination
- Age of materials
- Lining life
- Value of materials and
- Economics of beneficiation

4.5.1 Type and Quantity of Refractory: -

Several thousand types of refractory are used in the steel industry. They have been classified by ASTM and ISO based upon chemistry, but they also can be classified based on installation method, forming method, grain structure, bonding mechanism, porosity or whether the material is shaped or unshaped. Each type of refractory material is used in varying quantities depending upon requirement. They also may be custom-tailored with different additives to meat performance requirements.

Steel producers and refractory manufactures are located at different places. The use of recycled refractory materials as refractory is at a disadvantage compared with refractory made from mined raw materials. This is because of the high shipping costs, changed material chemistry, low mineral value and unknown performance of the recycled refractory. Only a limited number of refractory producers currently recycle spent refractory materials from steel production.

4.5.2 Regulations: -

Consideration of these regulations is important in determining how a material is classified (hazardous or no hazardous), the length of time and the quantity of waste that can be stored on-site, and how a material can be handled or land filled.

4.5.3 Health Concerns: -

Refractory materials may have health issues that must be addressed upon removal and/or processing for reuse. These concerns include the possibility of hazardous materials, such as a hexavalent chrome (carcinogenic) or refractory ceramic fibres (possible carcinogen), existing in the spent refractory. Another concern might be whether respirable silica (silicosis) is generated during beneficiation. Additional health concerns may arise from process contamination in the spent refractory.

4.5.4 Contamination: -

Refractory contamination is the largest single obstacle to reuse. Refractory can become contaminated while in service, as a result of different furnace lining materials being mixed upon removal, or through material storage after removal. Contamination during refractory use includes slag and metal penetration within and on the refractory, salt or vapor deposition within the refractory pore structure, and chemical changes that occur in the refractory structure caused by process attack.

During tear out a used lining, a variety of refractory materials become combined. This is caused, in part, by the use of different refractory materials to meet service requirements (called zoning) in a steelmaking ladle. Separation of different materials during refractory removal may help lower future beneficiation costs. Added contamination of the spent refractory can occur during storage from dust, moisture or other materials in the surrounding environment. Any of these sources of contamination can affect the physical properties of a material in the new application.

4.5.5 Age of Material: -

Two age groups of steelmaking refractory exist – old and new. Refractory stored on-site (old materials) may be a variety of materials collected under different environmental laws. Contaminants can vary throughout the storage pile, based upon refractory use patterns. If old wastes are being processed that were land filled long ago, material in them now may be classified as hazardous that once was not, raising beneficiation costs.

New material is defined as spent refractory currently being removed from an application. Different priorities and beneficiation schemes may be necessary for old and new materials. Spent dolomite refractory, for example, will begin to hydrate upon removal from a furnace. They may need to be specially stored for applications, such as slag conditioning.

4.5.6 Lining Life: -

Refractory service life depends upon the application, type of material utilized and lining maintenance. Service life can range from hours to years. This can result in cyclic material availability or in storage problems, depending upon the frequency and quantity of material removed from an application.

Spent refractory typically are removed from service continuously, producing many small quantity lots of material. The quantity of spent refractory material removed from service typically is less than that of material installed because of wear and corrosion during use.

4.5.7 Value of Materials: -

The value of a spent refractory is determined by two factors – the worth of its components and any other costs associated with disposal. Refractory materials, such as natural flake graphite or fused MgO, have high material value. Meanwhile, refractory containing hazardous materials, such as carcinogenic chrome, incur high waste disposal costs.

Hazardous or no hazardous, landfill cost varies. Disposal costs can vary for non hazardous materials, depending upon whether disposal is conducted on-site or at an industrial landfill.

Either material value or disposal costs may justify recycling/reuse. Contaminants removed from the spent refractory during the recycling/reuse process, such as iron may help to lower beneficiation costs.

4.5.8 Economics of Beneficiation: -

The economics of beneficiation have been and will continue to be an important determinant as to whether recycling/reuse occurs. The final beneficiation costs will be determined based upon the complexity and costs associated with beneficiation, the amount of material being processed, the consistency and purity of the desired processed material, and the shipping distances involved (Griscom et al.1999).

Typically, beneficiation involves sorting, primary crushing, again sorting, and separation, screening, secondary crushing, screening, storage or water treatment, flotation, leaching, drying and storage. Different stages of the beneficiation cycle may be eliminated, depending upon the desired purity and particle size of the finished material and the condition of the starting material. Recoverable material, such as iron, must be separated to hold improve beneficiation economics. If hazardous waste is present, beneficiation may be used to concentrate this material, reducing the amount of material requiring treatment or costly disposal. Keeping the spent refractory clean during removal and storage before beneficiation is important in helping lower beneficiation costs.

4.5.9 Company Philosophy: -

The commitment of a steel company to recycling or finding alternative uses for spent refractory materials is important, since the primary goal of a steel producer is metal production, not waste recycling. A strong commitment by company management to the reduction or elimination of waste materials, such as spent refractory may help to facilitate waste reduction and/or reuse.

Management can do several things to promote waste recycling/reuse. It can encourage the utilization of more environmentally friendly refractory whenever possible, the consideration of refractory waste disposal in all phases of plant production and the implementation of plant policies to keep refractory clean during and after removal. Management also can promote in-house reuse of spent material such as refractory, slag conditioners or in other areas of production. Management's tracking and assignment of refractory waste disposal costs to different areas of production, and the setting of waste reduction goals, also are important steps in helping to reduce waste disposal costs.

4.5.10 Changes in Technology: -

Changes in technology have had and will continue to have a pronounced effect on reducing refractory wastes. Refractory producers have strived to improve the performance of refractory, which has resulted in longer refractory life and less refractory used per tonne of steel produced.

Efforts to recycle spent refractory materials have resulted in some high value refractory components, such as natural flake graphite, being reused in steel making refractory. They also have resulted in ladle shrouds and slide gates being repaired for reuse. Entire or partial ladle linings may be reused many times by mechanically removing thick surface slag or metal from the refractory lining, then reapplying a new surface lining over the old lining by vibration casting. New techniques, such as slag splashing, have helped reduce refractory wear and costs. Refractory repairs constantly are made to extend lining life during service. The subcontracting of refractory installation and use of monolithic linings, such as castables and gunning mixes also have meant a lower refractory inventory and a reduction in the quantity of obsolete material available for disposal.

An example of the effect of technology on decreasing the amount of material disposed is shown by the pronounced decline in the consumption of chromite ore used in refractory manufacture. The large decrease occurred because of many factors, including the displacement of the open-hearth furnace by the basic oxygen furnace, the use of water-cooled panels in electric arc furnaces, substitute materials being developed in industries, such as cement and by general concerns over the toxicity of hexavalent chrome. All have led to the elimination of chrome-containing refractory lining from many operations.

Refractory manufactures should give future consideration to shifting long-range research goals from performance to developing refractory that are more environmentally friendly or more recyclable. If done, this probably would adversely affect refractory performance during the development cycle of these refractory. Research of this type has been very successful in the glass industry, in which recycling is more prevalent.

4.5.11 Uses for Spent Refractory: -

A) Reuse as Refractory

Reuse of spent refractory materials, as refractory is limited. Before refractory reuse occurs, consideration must be given to appropriate utilization areas, possible compromises in material performance and the cost and case of manufacture of the targeted products.

Depending upon the beneficiated refractory chemistry, particle sizing and impurities, applications may be similar to or less severe than, the original application. Research may be needed to determine whether complete substitution or use of small percentages of spent material in refractory formulations has merit. Reuse of spent refractory as refractory have the potential to be one of the largest areas of refractory reuse. To reduce refractory waste stream, steel makers should have closer involvement with recycles of spent refractory, subcontractors and installers utilized in the plant, and refractory producers.

B) Alternative Uses: -

Alternative uses for spent refractory material include processing into ferro-alloys, a raw material in cement, or an aggregate in concrete. Basic and alumina silicate refractory can be used as slag conditioners or for slag splashing in metallurgical processes. Both conditioning and splashing applications would prolong refractory life, as well as utilize spent refractory material.

C) Dumping: -

If dumping is used for refractory wastes, care must be taken with some materials like, BF refractory, which contain cyanides, which need to be placed on land disposal areas with impermeable lining at bottom. Tar bonded bricks and lining from EAF with hexavalent chromium are subjected to dumping restrictions. If the pH value is higher than 12, refractory material may also cause some difficulties in landfill.

4.6 Costs Involved in Implementation of the Technologies: -

While communications were made to many foreign technology developers, there was no response from them. It has been found from the previous experiences and the present experience that foreign technology developers respond only to queries on specific projects.

But indirectly, one may rest assured that all the technologies covered in this study are, prima-facie, economically viable since only commercially established processes or processes due for commercialization have been covered in this study and the technologies specified permit, prima-facie, `sustainable development`.

One key factor, which swings economics either way, is the cost of handling and transportation of the wastes for dumping. Some of the costs reported in literature are furnished below.

Transportation of non-hazardous wastes to a landfill may cost \$20/T (Hoffman 2000). Handling of hazardous wastes like EAF dust and its transportation to a landfill may cost \$150/T (Hoffman 2000).

With opening up of economy in the country, corresponding costs in India will not be much less than the above costs.

With regard to capital cost involved, an on-site waste processing facility may be allowed to be build, owned and operated by a third party, allowing steel makers to conserve capital funds for more priority facilities in production chain and avoiding responsibility of another hot end operation.

Moreover, economics is very much specific to region, location, local conditions, capacity involved, etc. Therefore, tailor-made economic study only will be the effective tool for decision-making.

In view of the above, it is suggested that research proposals may be made for the technology packages involved for indigenous development through technology absorption, engineering and commercialization and then exemplary facilities based on cost-effective technologies may be set up for other entrepreneurs to follow suit.

4.7 Research Gap: -

From literature survey and practices developed by National and International organizations it is evident that enough solutions are available for recycling of blast furnace slag and steel making slag. Therefore these items were not considered for evolution of any methodology for its recycling or reuse. Emphasis was given to those wastes for which recycling technology does not exist or available technology is exorbitantly costly. The wastes selected in Indian context are as follows:-

a) Blast Furnace Air Cooled Slag
b) Blast Furnace Granulated Slag
c) Basic Oxygen Furnace Slag
d) Coke Breeze
e) Iron Ore Fines
f) Mill Scale/sludge
g) Lime Fines
h) Dolomite Fines
i) Blast Furnace Flue Dust
j) Fly Ash
k) Gas Cleaning Plant Sludge
l) L.D. Converter Sludge
m) Refractory Waste
n) Poly Chlorinated Bi Phenyl

Steel Plants are continuously generating large amount of waste, percentage of slag being maximum, creates utmost problem. Now slag is being used for soil improvement, road construction, and sinter production, hot metal production and as a binding, insulating and paving material (Sahay *et al* 2000).

High lime content it becomes excellent additive in cement industry. Adding similar amount of granulated slag during grinding can save 50% of clinker, in early days, slag granulation unit was quite far from blast furnaces and molten slag temperature was dropping, in granulation as a result vitreous content was also reducing. In order to preserve vitreous content, slag granulation units are now integrated with cast houses. Cement plants are consuming 100% of granulated slag. Granulated slag increases productivity of cement plants by 8 To 10% and saves 10 to 15% of energy that is usually derived from coal or gas. Cement industry produces CO_2 gas proportional to cement production and half of it is generated from limestone calcinations and rest from fossil fuel used for production of clinker. By substituting limestone partly with slag, it is observe that 10-12% CO_2 emission is reduced.

LD slag, after cooling and quenching, is crushed and metal particles are removed by magnetic separation.

SIZE 0-2 MM: It is used for soil improvement. Plenty of vegetation has been developed in Slag dump area. Use of air-cooled slag is showing encouraging results in slag-wool production. 3 to 5% of air-cooled slag is now used for slag wool production, well known for its "Thermal Insulating Property". Iron recovery from air cooled granulated slag is done by magnetic separation. Recovered iron is sold in the market, as this does not find use unless it is further processed for steel production. BF slag & BOF slag when mixed in 30:70 ratios, it forms good soil improvement agent. This is how plantation has been taken-up at the top of slag dump & a mini forest has been developed by planting and maintaining 20,000 saplings. These slag dumps are still active.

SIZE 2-10MM BOF SLAG: Rich in lime, magnesia & Fe content, 2 to 10 mm size has been successfully used for production in sinter making thus saving costly ore and coke in sinter making.

SIZE 10-40MM BOF SLAG: This has been used for road constructions after natural aging.

SIZE 40-60MM BOF SLAG: Some portions of 40-60mm have been used as ballast in internal rail track thus replacing mined rock. The high strength and abrasion values and good bitumen adhesion property makes it suitable for road aggregate for sub-base and surface layers. The roads inside the steel plants are being laid using this slag. Another very important use is as a flux in blast furnace due to high percentage of lime & magnesia present in it. This can neutralize siliceous & acidic constituents in blast furnace burden.

STEEL SCRAP RECOVERY: During magnetic separation in slag-dump, enormous amount of metallic are recovered. Last year 0.15 million tones of metal could be recovered. Smaller size is sold in market as these needs further processing whereas larger ones are used in twin hearth furnace.

It is evident that there exists a clear cut gap between utilization and generation. For blast furnace air cooled, granulated slag and basic oxygen furnace slag already enough cost effective recycling means are available; hence excluded from this study. In chapters 5, 6, 7 the economical methods developed would be narrated one by one excluding blast furnace slag and steel making slag.

4.8 Summary: -

The recycling of steel plant waste generated from involved process is proven one and is a cost effective method of disposal and reuse. But there are some pit falls. Problems of waste disposal will not be solved by others from outside the steel plant but solution is available with steel plant operators only. Since throughout the world, the disposal is a problem, hence several methods are developed and adopted in practice with the existing operating practice. These operating practices are thoroughly described here and also brought into notice about waste minimization measures adopted, mentioning type of wastes generated and its practical application of use in various units of steel plant.

Fly ash generation was almost 100% left out without any use of it, with present statutory strict regulation of Government, fly ash is being used at Cement Industry, various other innovation materials developed, also in-house, brick making is also described here. Critical mention has been made about beneficiation of raw materials supplied at steel plants and recycling, reuse of generated waste will continue to be important determinant for the improved economics of the plant operation and its survival in the competitive field of steel productions though it is apparent that primary goal of steel industry is to produce steel, not waste reduction. But with proper planning, the waste material can be turned into a valuable product, which is a source of income. Very often, one industry's waste material can be another company's raw feed material.

CHAPTER 5

INNOVATIVE USES OF PROCESS WASTE IN INTEGRATED STEEL PLANTS

5.0 Introduction

Steel industries, world wide and India in particular is trying to utilize natural resources and conserving energy requirement during production process of steel making while strictly adhering to set guidelines and policies enforced by local government. Steel makers are committed to maintain environmentally clean climate and condition in and around the work sites and adjoining localities to protect human health condition. In the last 30 years, world steel industries, invested about $7 billion to combat the challenges of environmental issues so as to comply with national health standards.

Companies engaged in steel industry spend about 15% of their annual capital expenditure on environmental projects and the appreciable result obtained can be seen from the data, which points out those pollutants discharges have been reduced by 90% since the year 1970.

Yet the further reduction of the pollutants emission is the demand of the day. To meet the demand, the cost effective pollution control technologies need to be adopted by integrated steel industries.

Use of steel products defines country's industrial economy and growth potential. Steel material are fully recyclable after use but the crux of the problem is huge quantity of waste generation, during the process of steel making which is not easily recyclable.

Hence it has become imperative for the steel plants that they should find the newer methods for controlling the waste generation, maximize recycling of the generated waste and finding the cost effective disposal methods (Riemer and Kristoffersen 1999b).

In some countries, solid generation has been pruned down to 200kg/TCS and recycling rates have reached to about 95% (Ghal and Noseworthy1998).In India solid waste generation is about 600 to 1000kg/TCS and recycling rate is hovering around 50%. This comparison shows the existence of a major performance gap in Indian Steel Industries (Chowdhary 2003 and Smithyman *et al* 1997).

One of the main objectives of plant management is to control generation of fines in mines and works and control on dumping by devising suitable schemes to integrate, reuse, and recycle effectively with some investments on innovative project of agglomeration process viz. Pelletising, Briquetting and Sintering.

In ISPs variety of waste is generated and a general break up is shown as follows: -

i. Process Wastes
ii. Waste Collected From Pollution Control Equipments
iii. Process Rejects

Waste according to above category is shown in Table 5.1: -

Table 5.1: Waste Generation during Steel Production

S. No.	Description	S. No.	Description
I	**Process Waste**	II	**Waste Collected from Pollution Control Equipments**
1.	Blast Furnace Air Cooled Slag	9.	Blast Furnace Flue Dust
2.	Blast Furnace Granulated Slag	10.	Fly Ash
3.	Basic Oxygen Furnace Slag	11.	Gas Cleaning Plant Sludge
4.	Coke Breeze	12.	Refractory Material Plant Dust
5.	Iron Ore Fines	13.	L.D. Converter Sludge
6.	Mill Scale/sludge	14.	Blast Furnace Sludge
7.	Lime Fines	III	**Waste Rejects from Process**
8.	Dolomite Fines	15.	Refractory Waste
		16.	Poly Chlorinated Bi Phenyl

S. No. 1 to 8 is waste generated in the process, while S.No.9 to 14 is waste collected from pollution control equipment. S No.15 and 16 is waste reject from process. In this chapter innovative ways developed for utilisation during research is described in respect of waste generated in process.

This chapter describes the ways process waste can be utilized in ISPs. As it is evident from literature survey and world practices being followed enough work has been done for gainful utilization of blast furnace air-cooled slag, blast furnace granulated slag and basic oxygen furnace slag, and hence no work has been done for these wastes.

5.1 Coke Making: -

Metallurgical coal is heated to high temperatures (900°C to 1200°C) in an oxygen deficient atmosphere to remove the volatile components. The remaining residue is coke; an efficient reductant for blast furnace iron making. In coke making the basic inputs are coal, heat electricity and water. Coke is prime product where as by products are many viz. coke oven gas, coal tar, light oil and ammonia liquor. Ammonia phenol cyanide and hydrogen sulphide are generated in addition to SO_2 NO_2 CO and particulate. BTEX i.e. benzene, toluene, ethylene and xylene are other by products.

5.1.1 Coke Making and its Bye-Products: -

Coke-making process produces primarily -

a) Coke for blast furnace burden: -

- Pearl Coke (10-25mm size)

- Fines and mixed breeze (Used generally as fuel in sinter plant operation)

b) By-Products: By distillation of unpurified foul gas evolved during coking process are: -

- Coal Tar
- Pitch
- Creosote
- Benzol
- Clean desulphurised coke oven (CO) gas
- Ammonia Liquor
- Ammonia Sulphuric
- Sulphuric Acid
- Certain intermediate fractions

The by-products from coke ovens and by-products shop of a BF based integrated steel plant are spent refractory, neutralized acid sludge and decanter sludge. Any other by-product from this shop, say nut coke or coke breeze, is either used in the plant or sold out. Neutralized acid sludge is produced after neutralization of acid sludge obtained from acid washing of benzol in benzol plant. This generation may be minimized and gainfully utilized, if acid regeneration plant is provided. In that case, whatever neutralized acid sludge is generated is recycled into crude tar processing unit. This is the practice with Bhilai Steel Plant and should be followed by other steel plants also. Decanter sludge is basically coal dust mixed with tar. This by-product finds immediate market outside as a fuel and is completely sold out (Sukul and Chakraborty 2002). Spent refractory are presently partly reused and partly dumped. This will be deliberated subsequently along with spent refractory from other production shops. Therefore, in today's context, coke ovens and by-products plants may be considered to yield only by-products, which are gainfully utilized.

In modern sinter plant of a BF based ISP, all by-product arising are recycled and it operates as a closed circuit system. It also acts as a scavenger to the steel plant as a whole (Yadav 2002).

In view of the above, coke ovens and by-products shop and sinter plant of a BF based ISP are not deliberated further with regard to management of solid by-products. However some experiments were conducted to utilise coke breeze in a gainful way is described below: -

5.1.2 Coke Breeze: -

BF does not use coke of (-) 25mm size, called as coke breeze. This is being sold in the market and recycled to meet sinter plant fuel requirement partially. However for gainful utilisation screening in two fractions 0-10mm and 10-25mm was done and were utilised totally. The earlier one was agglomerated and utilised in small furnace for enhancing carbon component. The later one is straight utilised along with sinter in blast furnace.

A) Experiment I: Coke Breeze Agglomeration: -

i) COKE DUST: -

During pushing process, 0.5 to 1.0 kg of coke dust per tonne of coal charged in coke oven is recovered which is suitable for sinter plant use. The dust after screening is collected in two different fractions: -

a) 0-10mm

b) 10-25mm

ii) MATERIAL AND METHOD: -

Experiment was conducted to use the screened coke dust 0-10mm size by agglomerating along with pitch. 5 tonnes of such dust was mixed along with 4 tonnes of iron ore fines & 1 tonne of coal tar pitch. The suitable percentage of all these were thoroughly mixed and pressed in a hydraulic press at a pressure of 100kg/cm^2. The composition of coke breeze was assayed and following results were obtained:

Carbon	Ash	Volatile Matter	Moisture
57.3%	29.2%	13.5%	11.2%

iii) RESULTS AND DISCUSSION: -

The agglomerates so generated were found suitable in handling strength, as it was not getting disintegrated. Drop test was conducted and it was confirming the requirements for charging in small furnaces. The so prepared Sample 2 was found more suitable from economic point of view, considering cost of coke breeze as Rs.2, 000/T, cost of iron ore as Rs.500/T and cost of pitch as Rs.7, 000/T and the other processing costs to be considered as Rs.100/T. It was found that the samples produced were cost effective compared to the cost of coke. However these samples were also containing iron ore, which improved yield in iron making. This has given added advantage of iron ore fines present in the composite mixture. Sample 2 was selected for use in cupola furnace for iron making. The samples are further being tried in electric arc furnace for sponge iron making (Table 5.2).

Table 5.2: Composite Samples of Coke Breeze and Iron Ore

S.No.	Material	Sample 1	Sample 2	Sample 3
1	Coke Breeze	50	55	60
2	Iron Ore	40	42	35
3	Pitch	10	3	5

The tumbler Index of these samples were tested and found 40, 35 and 25 respectively, the coke breeze agglomerates thus produced were used in small furnaces like Cupola and it has substituted the carbon requirement for the melt. Photo and microstructure of coke breeze agglomerate is shown in fig. 5.1.

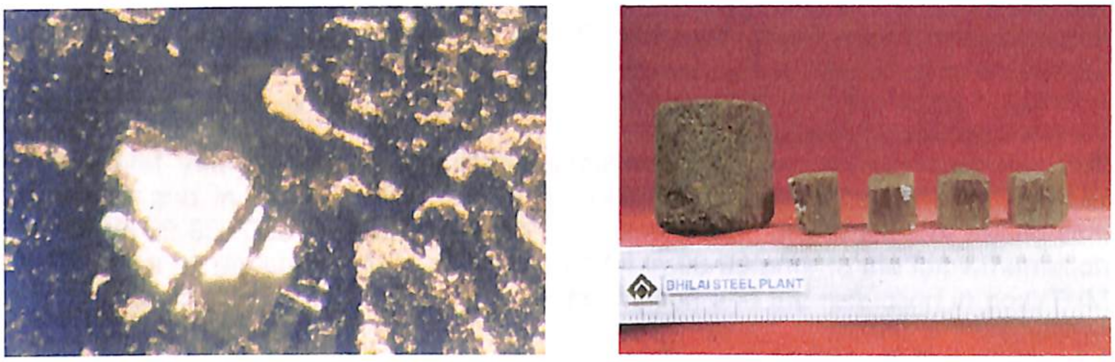


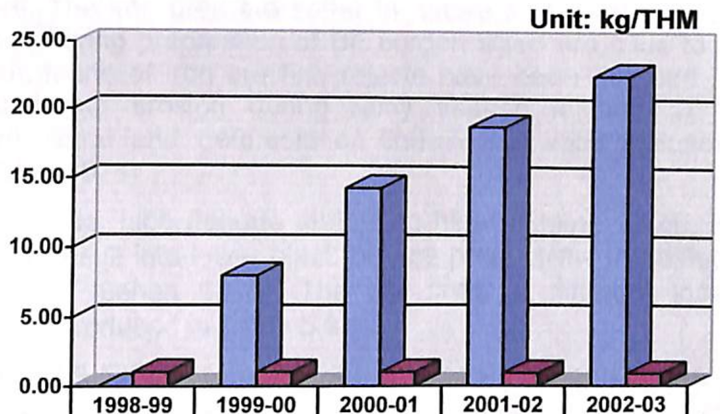
Figure 5.1: Photo and Microstructure* of Coke Breeze Agglomerate

(*Magnifacation: 200 times, Optical Microscope - Jenapol, Camera –Contax 167MT)

B) Experiment II: Nut Coke Utilisation: -

i) NUT COKE

Nut coke is the 10 to 25mm size coke left over after meeting the requirements of BF (+25mm size) and sinter plant (-10mm size). These coke arising at coke ovens and the coke screens at blast furnace were identified as a source of carbon that can reduce the +25mm coke requirement (Murthy and Gangopadhyay 2000).



	1998-99	1999-00	2000-01	2001-02	2002-03
Nut coke	0.00	8.00	14.30	18.80	22.60
Dry Coke	1.04	1.03	1.01	0.93	0.89

Figure 5.2: Nut Coke Utilisation and Dry Coke Consumption

ii) METHODS AND MATERIAL: -

In this experiment the nut coke was fed along with the sinter product to blast furnace and this was implemented in two phases. In the first phase, the 10-25mm coke was screened and fed through a combination of road transport and belt conveyors. In the second phase the system was totally mechanized avoiding transportation of the nut coke by road.

iii) RESULTS AND DISCUSSION: -

In the first year (8 months) of implementation, the nut coke consumption was 8kg/THM and in the second year it was 14kg/THM and it was 22.6kg/THM per annum in 02-03. This has benefited BSP in reducing the consumption of coking coal to 0.897 tonne dry coal/THM in 02-03 from 1.04 in 98-99 prior to the implementation of the project. The pattern of nut coke consumption and the reduction in coal/THM are depicted in Fig 5.2 above.

5.2 Utilisation of Iron Ore Fines: -

Blast furnace route for producing liquid iron is an established, efficient and economic route and is responsible for bulk of hot metal production worldwide. Raw material viz. iron ore from iron ore mines generate large scale iron-bearing material. In this study, a process has been experimented to utilize large volume of undersize ore fines by agglomeration. This method is projected to achieve a better utilization of the useless iron ore fines in most efficient manner (Degel and Metermann 2000, Dickerson *et al* 2000).

5.2.1 Iron Ore Fines in Bhilai Steel Plant: -

In the iron ore captive mines of Bhilai Steel Plant, large amount of fines are generated during the process of mining. These fines are being accumulated continuously and have no buyers nor have any gainful use. The arising of iron ore fines is much more. The iron ores are softer in nature and mingled with high clay; generate more fines during preparation of BF burden sized ore. Due to this reason, more than 8 million tonne of iron ore fine rejects have been dumped haphazardly which has resulted into erosion during rainy season leading to large scale degradation of agricultural land, deforestation and air and water pollution (Box *et al* 1999, Villar and Dawe 1975).

Fines are of lower grade, high gangue attributing high alumina which, if used after agglomeration would result into lower blast furnace productivity in addition to higher energy consumption (Fruehan 1998). The ore fines of different locations were assayed and report is produced in Table 5.3: -

TABLE 5.3 Characteristics of Iron Ore Fines and Slime

Sl. No.	Source	Physical Analysis %					Chemical Analysis %			
		+10 mm	-10 to +5 mm	-5 to +3 mm	-3 to +1 mm	-1 mm	Fe	SiO_2	Al_2O_3	LOI
1	M.M.G.F. Dump	12.5	11.1	8.4	15.7	52.3	63.96	2.3	2.13	4.15
2	Jharan Dalli bottom	4.8	13.0	12.7	20.8	48.7	63.5	3.5	2.65	3.05
3	Jharan Dalli top	10.8	12.5	9.0	15.9	51.8	63.53	4.33	3.22	1.72
4	Waste rock Mayur Pani	4.4	10.1	7.9	18.7	58.9	61.82	3.19	3.41	4.84
5	Mayur Kanan	7.4	18.3	14.0	19.0	41.3	60.86	6.2	4.0	2.74
6	Yellow clay MMGF Dump	16.3	13.9	12,7	21.2	35.9	4.3	40.8	34.93	10.46

5.2.2 Experimental: Iron Ore Fines Agglomeration

Agglomeration was done of the iron ore fines for its utilization in iron making. The fines with different granulometry were agglomerated along with low temperature and high temperature binders with different composition as shown in Table 5.4.

The preparation was equal and granulometry was not moderated. It was used on as collected basis. The desired quantity was taken and thorough mixing was done. It was put in cylindrical mould of 5.0 cm diameter and compacted manually. The green briquette so obtained was strong enough to handle (Sastry1977). During experiment, it was found that strength of agglomerate depended on following factors: -

i. Granulometry
ii. Compression load
iii. Time of compression
iv. Amount of water
v. Setting time
vi. Rate of vibration

Table 5.4: Iron Ore Fines Agglomeration with Different Binders (# Cost in Rupees/T)

S. No.	Material	%	Cost #	%	Cost #	%	Cost #
1.	Binder low	5	100		-	4	80
2.	Binder high	5	250		-	5	250
3.	Iron fines 0-6mm	60	-	70	-	15	-
4.	Iron ore coarse 6-10mm	30	-	23	-	35	-
5.	Portland cement	-	-	7	40		
6.	Coke breeze	-	-	-	-	41	-
7.	Cost/T of material		350		40		330
8.	Processing cost/T		100		100		100
9.	Total cost/T		450		140		430

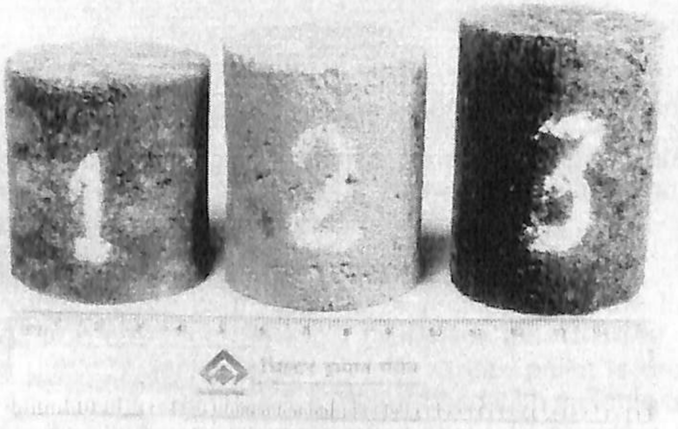


Figure 5.3: Iron Ore Agglomerates

These iron ore agglomerates (Figure 5.3) although were of low grade but could be used directly in small furnaces, as green strength was very good. Sample III could be used where fuel savings is desired as the unburnt carbon present in it could give additional benefit. If these agglomerates are used in small furnaces as a part of charge, improvement in yield is possible at nominal cost.

A) Tests Conducted: -

Shatter Test:-

• Sample No.	1	2	3
• Percentage of+10mm Fraction Survived	95%	92%	93%

B) Discussions & Recommendation: -

For the application of the developed product 5 T of such agglomerate was prepared and used in small furnaces viz for production of sponge iron & cast iron in electric Arc Furnace. Based on this application, it was seen that the addition of this agglomerate achieved about 2% increase in yield. These advantages could be summarized as below: –

a) 2% improvement in yield.
b) Fewer burdens on environment.
c) Utilisation of coke & iron ore fines in sample
d) Reduced carbon requirement for iron making.

The green briquettes so obtained were tough and have enough handling strength. The disintegration of agglomerates at higher temperature needs further study. Low-grade iron ore agglomerates can be used directly in small furnaces, as handling strength is good. It can be used as coolant in L D Converters. Converter vessels are charged primarily with steel scrap, hot metal from blast furnaces, flux and iron ore. The later is used to trim final temperature and adjust hot metal / scrap consumption ratio. Sample 3 experimented with coke breeze can be used where fuel savings on account of unburnt carbon present in it will give additional benefit.

C) Scheme: -

The strength of briquette was good. A semi automatic scheme can be installed for

trouble free operation for agglomeration. As recommended one such scheme is shown for implementation in Fig 5.4.Its further evaluation and long-term use to qualify benefits need to be studied further.

This scheme of utilization of the iron ore fines is particularly useful and is being attempted in various other countries. For example, using the low cost purchased steam coal and iron ore fines the Steel Dynamics Inc. (SDI) of USA is seeking to produce about 0.5 MT/year of liquid pig iron. Green pellet is produced from waste iron ore fines and steam coal fines & agglomerated with suitable binder. The pellet is placed in rotary hearth furnace, where after about 15 minutes; it is converted into high strength iron pellet.

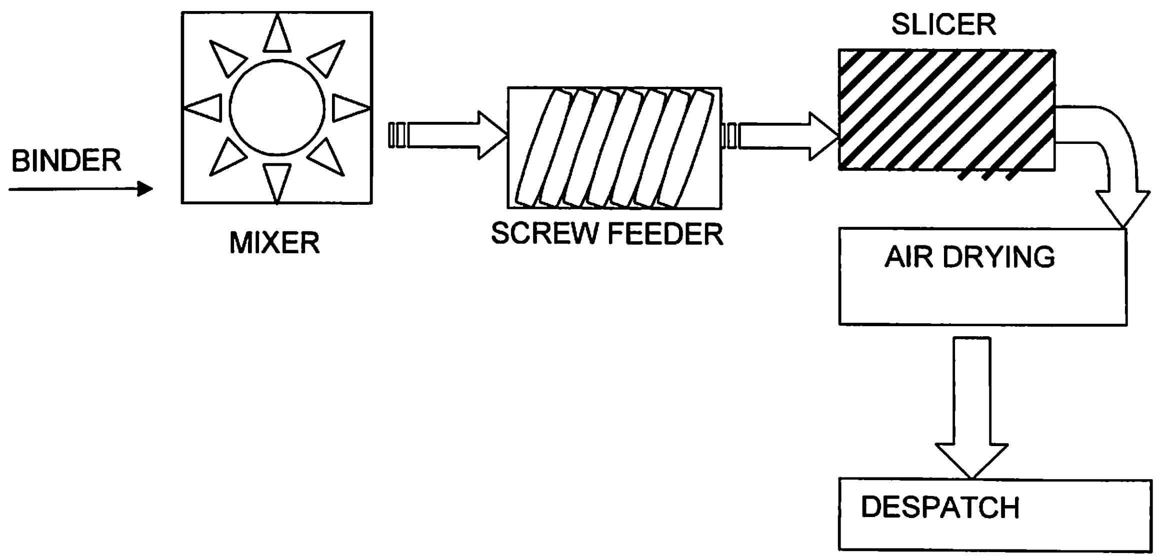


Figure 5.4: Scheme for Agglomeration

These pellets are charged into electric arc furnace thus converting them into liquid pig iron. The combination of rotary hearth furnace to reduce green pellets or iron bearing fines and submerged arc furnace to melt the complete reduction of DRI formed, offer a flexible hot metal supply at an operating cost of US $ 90 to $130/T and a low load on the environment. In the area of alternative iron making processes, Demag offers the rotary hearth furnaces (DRHF) for hot DRI production and Demag's Submerged Arc Furnace (SAF) to convert DRI to hot metal.

D) Conclusion: -

Iron ore agglomerates are low cost, in-house generated valuable byproduct and eco friendly solution to the huge wastes and consequently prevent environmental degradation. Its further evaluation and long-term use to qualify benefits need to be continued.

5.3 Utilization of Mill Scale and Sludge: -

In steel industry the scrap are already being recycled at close to 100%, and therefore offer little opportunity for increased recycling. In contrast, only half of the iron units potentially available from by-products are currently recovered, and just over three quarters of those potentially available from obsolete scrap are now recycled. In absolute terms, by-products offer the opportunity to potentially recycle a huge amount of iron units. With further research, development, and demonstration, the industry should be able to fully exploit this opportunity and recover 100% of these additional iron units. One advantage to focusing on this source is that most aspects of by-product generation and treatment are under the control of the steel industry. In addition, many technologies are already under development that may assist in this effort. For these reasons, byproducts are considered the best near-term opportunity for increasing iron unit recovery in the industry

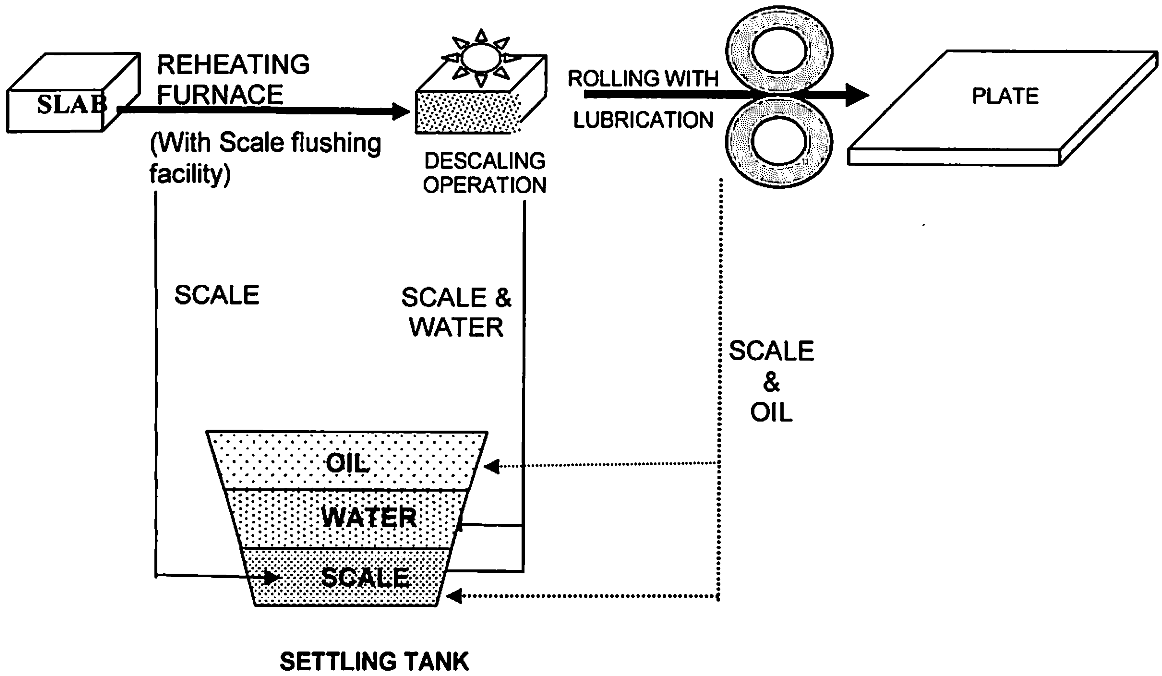


Figure 5.5: Plate Mill Sludge Generation

Hot rolling mill scale, sludge and cold rolling mill scale and sludge are such by-products or process wastes which are produced in large volume, yet no work has been done to enhance their recycling rate in Indian ISP's. The generation of mill sludge is shown in Figure 5.5. The scale is usually sold or recycled and reused within the ISP (Sintering Plant Unit). But the recycling of oily scale without de-oiling causes variety of problems ranges from opacity and pollution to the quality of the finished product. Hence an urgent need existed for the technology, which can de-oil these wastes. This work has developed a technology for the removal of oil from the mill scale sludge

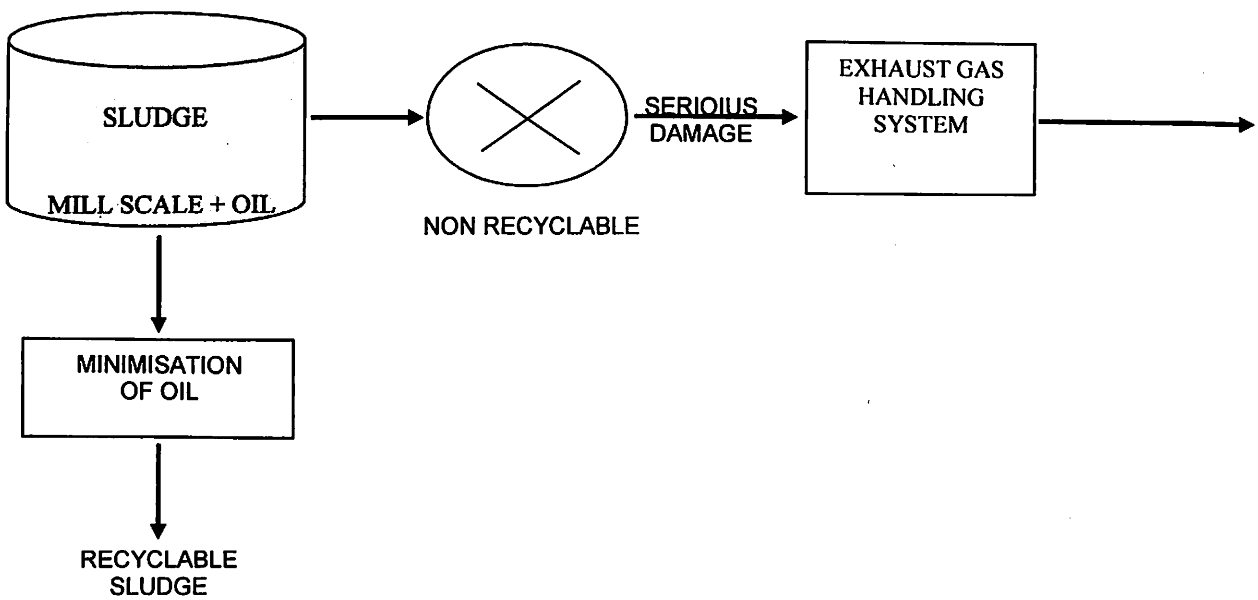


Figure 5.6: Scheme for Recycling of Sludge

Mill sludge contains about 2 – 15% oil. Most of it is land filled in foreign countries. The situation in India is about half of the mill sludge is reused through sinter plants though it is established that, it is unsafe to use mill scale containing more than 3% oil in sinter plant due to problems in electrostatic precipitators of gas Cleaning system. The Scheme for recycling of sludge is shown in Figure 5.6.

5.3.1 Utilization of Plate Mill Sludge: -

Disposal of sludge is one of the most difficult problems in the management of oily waste in steel plants especially from the rolling operations. Firstly, the presence of oil and grease in the effluent or process water stream in the form of emulsions can cause immense difficulties in treating other pollutants by subsequent process. Hence it is desirable and necessary that these pollutants are removed before the wastewater is discharged to watercourse or the process water re-cycled. Secondly, emulsified oily waste pollution/ disposal are an acute problem. There are only two known ways of disposing this type of sludge i.e. either in a water body viz. river or sea (older practice) or to store them in specially constructed pits/ ponds.

Disposal in a water body is no longer permitted today as the stringent government regulations, which emanated after public outcry against it. Storage in specially constructed tanks is becoming very difficult day by day because of two counts. One is due to large space requirement and the second is the destruction of nearby fertile land and pollution of the environmental segments.

Very little is known about its latest treatment methods to deal with these myriad problems. The objective of this investigation was to explore the available technical know-how to recover most of the material for recycling. In this work the pollution aspects of in-plant recycling of the material along with their usability characteristics has been studied. At the same time a close view in the environmental significance of the project has been kept in mind.

5.3.2 Existing Approaches towards the Problem: -

The literature survey shows the acknowledgement of the problem as evinced by following excerpted accounts: -

A) Source of Emulsified Waste: -

During steel manufacturing, the ingots, slabs, blooms are rolled into desired phases in either hot or cold rolling mills. Oily wastes from hot rolling mills contain primarily lubricating oil and hydraulic pressure fluids that are not usually emulsified. The cold rolling of steel strips obtained from hot rolling mills comprises three main operations, acid pickling of hot strips, the strip is pre-oiled so as to prevent scratching, when it is uncoiled. Then the mill rolls are sprayed with an emulsion of water and soluble oil. In addition to the rolling mills, oil losses from lubrication system or hydraulic mechanism get mixed with the emulsion. The emulsion or more precisely the base oils, contain anti-oxygen or algaecide additives. After shaping, the steel is rinsed to remove the adhering oils. The rinsed and coolant waters from the rolling mills oily sludge are very stable and difficult to separate from wastewater. Treatments of emulsified water mixtures are complex and costly and represent a secondary phase of treatment after the primary separation of free oil. Unlike primary treatment, which consists of only gravity separation plus skimming, several processes are directed towards breaking the oil-in-water emulsions (Sripriya 1999, Scope of Project 1999, RRL Bhubneswar).

The associated oil and grease from the rolling process, is the main problem with these materials, which may omit undesirable compounds during sintering. The high and unstable oil content of mill scale is undesirable. If added to the sinter mix the oily compounds condenses in the electrostatic precipitator, reduces its efficiency and has a danger of subnormal burning such that the electrostatic precipitator can glow fires.

Moisture in the waste to be recycled is also a major problem, besides there is a limit on the amount of moisture that can be in the material recycled through the sinter plant. Too much moisture requires additional fuel to evaporate and thus can slow down movement of the flame front resulting in incomplete sintering. In order to overcome this challenge the materials removed by descaling water, wet scrubbers' wastewater treatment must be appropriately done before being used in the sintering process. A significant obstacle to increasing recycling rates is the difficulty in routinely dewatering sludge to the appropriate moisture level in a cost-effective manner.

B) Possibilities of Secondary Settling Tank Sludge Utilization: -

The main alternative recycling possibilities available in literature for recycling of oily mill scale within an integrated iron and steel works are: -

a) Spraying of oily mill scale on sinter belt as practiced in Bethlehem steel.
b) Oily mill scales onto the sinter strand using top-layer sintering process.
c) Normal use as scales after recovering oil through ultrasonication
d) Directly through BF route by tuyere injection (Young 1999).
e) Biological de-oiling of the rolling sludge.

i) INJECTION OF OILY MILL SCALE IN SINTER PLANT: -

Burns harbor division of Bethlehem steel developed and patented an innovative and low cost technology for recycling oily mill scales and sludge to sinter plant without opacity problem in the sinter plant stack or operating sinter quality problems. (Lean1999). The process involves injection of the sludge directly in the annealing zone of the sinter plant. The oily sludge is sprayed on top of the bed immediately after ignition using high-pressure spray nozzles to form a fine mist, which is then drawn through the flame front of the sinter bed. As the spray is drawn through the red zone of the bed complete combustion occurs.

This results in the complete combustion of contaminated oil as opposed to the vaporization of the oils contained in the sinter bed, eliminating any stack opacity problems. (Kinzel *et al* 1997). The scheme is shown in Fig. 5.7.

A typical example suggests that recycling of mill onto the sinter strand is only permitted if the oil content is very low; even there is the risk of hydrocarbon entrainment into the off gas and therefore the formation of dioxins/ furans. Additionally essential effect on sinter quality and sinter strength occurs and therefore recycling is also limited to a certain percentage of the sinter.

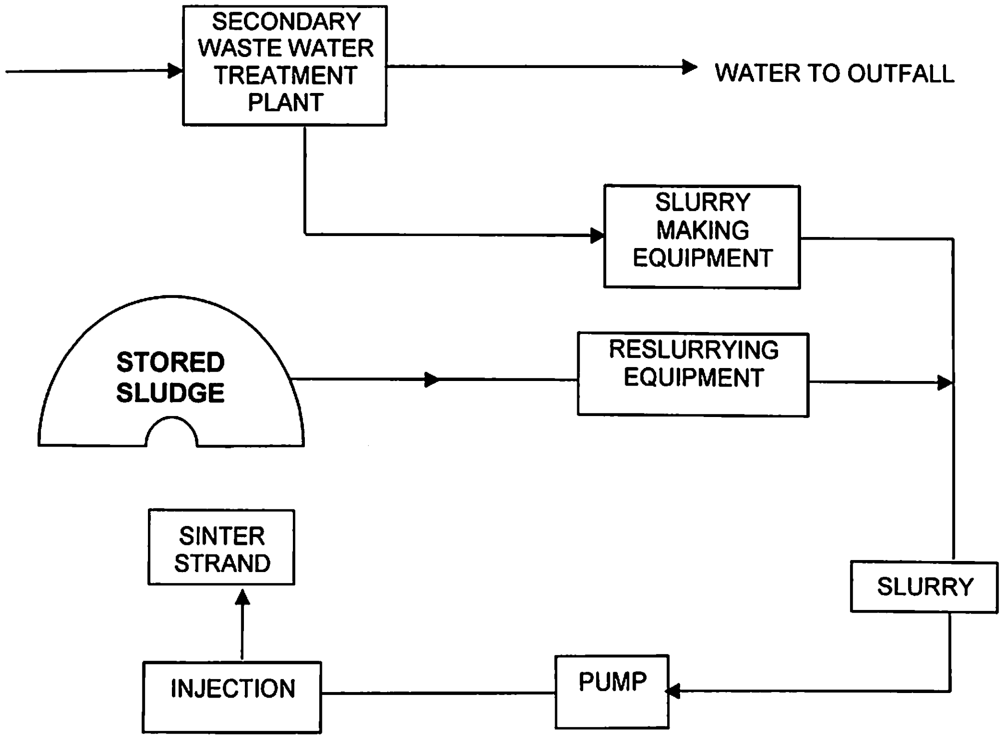


Figure 5.7: Burns Harbour Oily Sludge Recycling Facility

ii) MILL SLUDGE AS BLAST FURNACE FEED: -

In few instances to explore the possibility of utilization of mill sludge as a substitute for iron ore in blast furnace feed, briquetting tests were conducted. For these tests briquettes were made with sludge using different percentages of molasses and hydrated lime as the binders. In one case where experimental data is given, the mill sludge was air dried to 4.5% moisture. The percentages of molasses and hydrated lime varied at 1.3 and 5% and 1 and 3% respectively. The prepared mixtures were-compacted in a cylindrical mould briquettes were formed. After the briquettes were produced, various physical property strength tests were performed. Green strength and cured drop strength were determined by dropping the briquettes from height of 1 meter onto a steel plate. The total drops of catastrophic failure were taken as measure of green and cure drop strength. (Waste Management Japanese Steel 2000; Fleischanderi *et al* 2000).

The drop strength was measured after 24 hours and 120 hours. The crushing strength of the briquettes was also determined at this time. Cost has mostly been the prohibitive factor for this process.

In a typical instance, two blast furnaces in Belgium have been equipped to inject an oily sludge, composed of 30 to 40% of water, 20 to 50% of oil and 10 to 20% of solids through on tuyere. Reportedly, the main problems arising from the procedure are related to fine mill scale becoming trapped in the filters and settling tanks. Bethlehem steel corporations composting tests at Burns Harbor, Indiana and Sparrows point, Maryland showed that naturally occurring micro-organisms could be used to achieve a 50% reduction in the oil content of waste water treatment plant sludge. Further pilot tests on oily rolling mill sludge showed that even greater reduction in oil content (13%

reduced to 1.3%) could be achieved in a process using bio treatment as one part of a multi-stage process.

iii) MILL SLUDGE FOR USE AS HEAVY MEDIA: -

Since mill sludge basically contains iron oxides and magnetite being one such oxide, the possibility of utilizing the mill sludge as heavy media in coal washery has been explored in few instances and its properties were compared with that of magnetite obtained from coal washeries. (Lochan *et al* 2000).

5.3.3 Summary of Approaches: -

The alternatives available in literature for recycling of oily mill scale are:

a) Processing through sinter route
b) Directly through BF route by tuyere injection
c) Recovering oil from scale through ultrasonication and then use in BF (Muhammad *et al* 1999).
d) Biological de-oiling of the rolling sludge.

Out of these the possibility of use of oily mill scale through sinter route felt to be most promising from technological and logistic point of view in the context of BSP. Therefore this experiment centered on possibility of utilisation of this material through sinter route. To achieve it this study set the methodology of investigation as follows: -

i. Qualitative and quantitative evaluation of the sludge.
ii. Literature survey on appropriate methodologies of sludge treatment and dispersal system to facilitate recycling.
iii. Detailed information gathering on recycling in sinter bed/ sinter mix.
iv. Study of the effect of plate mill sludge recycling on environment, sinter process equipment and sinter quality.
v. Study of the possibility of industrial scale utilization of the sludge.

5.3.4 Experimental: -

A) Flowablity Studies: -

Major stumbling block of using the material was sticky nature of the sludge. Literature survey revealed that all the conventional methods of oil removal would be cost-ineffective. Therefore, the main thrust was given on heating process. The mill sludge was heated in muffle furnace to different temperatures (250^{0}C, 300^{0}C, 400^{0}C & 450^{0}C) to find out the variation in oil content.

<u>Heating of Oily sludge</u>

Amount of sludge	1.5 T
Size of furnace	2m x 3m
Heating material used	Iron Plate

Gas used	CO Gas
Temperature	1600° C
Duration of heating	8 hrs.

Since the developed material was to be ultimately used at integrated steel plant-scale, the heating experiment was carried out in the heating furnace at BSP Tar Bonded Dolomite Brick Shop in process conditions optimized through a series of experiments. Sludge characteristics obtained after the heat treatment is given in Table-5.5.

TYPICAL CHEMICAL COMPOSITION OF THE MILL SLUDGE: -

Sludge Characteristics before Treatment: -

Oil Content : 11.6% LOI : 42%

Granulometry : Very Fine Material Conglomerated Mass.

TABLE 5.5: Chemical Composition of Sludge after Treatment

Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	S	Mn O
77.45%	5.77%	1.20%	o.14%	2.31%	0.12%	0.023%	0.45%	0.27%	1.18%

Sludge Characteristics after Treatment: - Oil Content: 5.8%, LOI: 10.73%.

B) Oil Content Determination by Solvent Extraction: -

The Process consisted of a low temperature multi stage extraction using petroleum ether, flowing countercurrent to the oily solids. This extracted the oil and the water attached to the solids. The solvents were then settled and filtered Evaporation of the volatile content provided the percentage of the oil content in the mill scales.

C) Pot Sintering Investigation: -

Pot sintering investigation was carried out to study the effect of using mill sludge on sintering parameters i.e. strength index, productivity, reduction degradation index, reducibility index and meltdown characteristics. Sinter Plant-II sintering process parameters were considered for investigation i.e. bed height = 450 mm, suction = 700 mm wc, ignition time = 2 min, mixing and balling time = 3 min, moisture content of sinter mix = 6.2%, specific coke consumption = 90kg/T, degree of stabilization for calculation of yield = 5 drop from 2 m height and percentage sinter return including BF sinter = 30%, mill scale = 15 kg/T. Dalli and Rajhara ore in blend = 80:20. Since mixed flux was supplied, MgO content of the sinter could not be maintained constant. The charge calculation was made for conducting the experiments. The chemistry of the raw materials, specific consumption of the raw material and target chemistry of sinter is given in Tables 5.6, 5.7, 5.8.

Table 5.6: Chemistry of Raw Materials

Raw Material	LOI %	Fe (%)	SiO_2 (%)	Al_2O_3 (%)	CaO (%)	MgO (%)
Iron Ore (Dalli Mines)	2.5	63.28	4.35	2.52	-	-
Iron Ore (Rajhara Mines)	3.0	63.00	4.41	2.65	-	-
Blend Ore	2.6	63.22	4.36	2.55	-	-
Mixed Flux	42.43	-	5.53	2.53	33.8	10.43
Mill Scale	-	71.44	1.26	-	-	-
Coke Breeze	-	9.78	50.36	24.45	3.76	1.25

Table 5.7: Specific Raw Material Consumption

S. No.	Iron Ore kg/T	Mix Flux kg/T	Mill Scale kg/T	Coke Breeze kg/T	Sludge kg/T
1	749.16	416.02	15	90	0
2	742.11	419.87	15	90	5
3	733.95	426.08	15	90	10

Table 5.8: Target Chemical Analysis of Sinter

S. No.	Sludge kg/T	Fe %	SiO_2 %	Al_2O_3 %	CaO %	MgO %
1	0	49.59	6.44	3.36	14.12	4.35
2	5	48.41	6.45	3.39	14.25	4.40
3	10	48.17	6.49	3.57	14.46	4.46

After carrying out the tests for basic parameters as above the sludge charge calculations were repeated with treated sludge being added in different proportions up to 10 kg/T of sinter to find out its impact on environment and sinter properties. Sintering experiments were carried out with the charge consisting of ore fines, fluxes, ferruginous wastes and coke breeze, in desired proportions, to get particular basicity, SiO_2 and MgO in sinter etc. Ignition of the bed was done by spreading a layer of about 650 gram charcoal on top of the charge bed and igniting it at low suction of 500-millimeter water column for duration of 1-2 minutes.

All sinter were produced using the above facility and then subjected to shatter test and tumbler tests. The sinter produced from pot grate furnace was dropped five times from a height of 2 meters on to steel plate and the fraction of a size of +5.0mm was taken as usable sinter (yield) and balance was treated as return sinter. The material for hearth layer was drawn from usable sinter.

a) Shatter Test: -

20 Kg of 10-40mm sinter was taken for the shatter test. The material was allowed to fall five times from a height of 2 meters on to a steel plate, the fraction with a size of +5mm, which survived after the test, is reported as shatter index.

b) Tumbler Test: -

15 kg of 10-40 mm size sinter was taken for the tumbler test. The material was subjected to tumbling in a drum having 1000 mm diameter and 500 mm width. The drum was provided with two shifters of 50 mm height on opposite ends. The drum was rotated at 25 rpm for 8 minutes. The fraction with a size of + 6.3 mm was reported as tumbler index. (TI)

5.3.5 Environmental Studies: -

Environmental studies were carried out after digging a porthole at the gas outlet pipe of pot sintering unit. Simultaneously the flue gases generated during sintering process were monitored to assess the concentration of CO, SO_2, NO, H_2S and NO_2. Stack gas analyzer was used to study the emission level. Although gas monitor shows results on a continuous basis, the peak value of each parameter during whole process stage has been noted to take care of the worst-case scenario.

5.3.6 Results and Discussion: -

Remarkable improvement was observed in the flow ability characteristic of the sludge after medium-high temperature heating (around 200^{0}C). Properties of the sludge before and after treatment are given in table 5.5. A scheme has been suggested in the recommendation section to convert the sludge into sand like flow able material.

Investigation and interpretation of the sludge characteristics revealed that all methods of oil removal except high temperature heating for making the material flow able would be highly cost-ineffective. Chemical processing of oil removal would involve high speed mixing with some organic solvent. As the oil content is not very high, the driving force of the separation process involved will be low and consequently efficiency of operation will be low. At the same time, separation of oil from this organic solvent would also pose a major problem and therefore would reduce the possibility or re-use of the solvent. Because of low oil content of the sludge most commonly used in the case, driving force of the operation would cut down oil content to almost half the initial value (5-6%). This happens probably because of breaking of oil water emulsion. After shredding and screening the material becomes highly flow able.

It has been found that use of this sludge has some impact on sintering process. In all the experiments carried out marginal decrease in strength of the sinter has been observed when the treated sludge is used at high proportions (10kg/T of sinter). Strength of sinter increases till utilization of sludge is restricted to 5 kg/T. Specific productivity of sinter increases at all levels of utilization. It has been noticed that the material helps in slightly reducing sintering time. Besides, sinter also gets richer in iron content. The results of sintering studies have been given in Table 5.9.

Table 5.9: Experimental Result of Tests

Sludge	T.I.	Y+5%	P+5(T/m^2/hr)
0	73.10	73.10	1.14
5	73.30	76.62	1.24
10	72.67	78.68	1.27

- Y+5 = Yield of +5mm sinter after subjecting to 5 no. of drops
- B.D. = Bulk Density (T/m^2)
- T I. = Tumbler Index + 6.3mm min %
- P+5 = Productivity T/m^2/hr

Total use of mill scale in sinter plant is 15-17 kg/T of sinter. Total mill scale generation in the plant is, in an average, 80,000-tonnes/ annum and in that contribution of plate mill primary scale is around 10,000-tonnes/ annum or around

12%. Therefore if this primary scale mixed with treated secondary sludge in a ratio of 1:6, the contribution of secondary sludge would be nearly two percent. However, on transportation and logistics ground, such ideal mixing is not always practical. To make care of worst-case scenario, i.e. only primary and secondary sludge being added to sinter, for experimental purposes the dried free-flowing material has been used at a ratio up to 10 kg/T of sinter to find out firstly, the optimum level of mixing and secondly, whether this material has any impact on environment and sinter-quality.

Environmental studies have shown that notable increase in Carbon-monoxide (CO) content takes place when treated sludge is added to the sinter in high quantity (10 kg/T of sinter). During experiment it was observed that initially CO content was high and reached up to a level of 3200 ppm for maximum amount of treated sludge used (10 kg/T). This value of CO is nearly 50% increase from what obtained during base studies (average value 2,000 ppm). At this time the concentration of other parameters were very low. After some time when the metallurgical reaction started the CO concentration also reduced to level of below 200 ppm, H_2S, SO_2 NO and NO_2 concentration also reduced to less than 10 ppm. Addition of up to 5 kg/T of sinter does not have pronounced effect on emitted gas. Other parameters show little or no variation. Typical results of environmental studies are given Table 5.10.

Table 5.10: Stack Emissions (ppm max.)

Mill Sludge kg/T.	**CO**	**CO_2**	**O_2**	**N_2**	**S_2**	**H_2S**	**NO**
0	1850	0.3	20.9	90	130	10	90
5	2050	0.3	20.9	100	136	200	100
10	3000	0.4	20.9	105	239	110	22

Environmental data obtained need to be viewed along with sintering process in the plant in a holistic manner. In sintering process coke breeze and iron ore fines are mixed and charged on sinter bed. A set of burner is used to ignite the sinter mix. Air is sucked under high pressure, support the ignition and help in increasing temperature. Initially the coke breeze provides the heat required for the sintering. After a lapse of time reduction of iron ore starts and coke breeze acts as the reducing agent. Once metallurgical reaction has started the CO concentration reduced drastically, to a level of below 200 ppm. In pot sintering it was possible to collect flue gas in different process conditions. But in actual process while on one end of the sinter bed raw material is being charged, at the same time sinter cake is being discharged into sinter breaker. All the wind legs are connected to one common wind main. Thus in actual practice flue gases being discharged from the chimney are mixture of gases sucked from each wind leg and thus would result in lower CO concentration in the flue gas being emitted from the chimney.

5.3.7 Techno-Economic Evaluation: -

The basic aim of waste recycling is to recover its mineral value. The wastes having high mineral value are potent for recycling. Compared to other environmental measures in-plant, waste-recycling offers a notional techno-economic advantage.

- Secondary settling tank sludge available = 3,000T/annum
- Minimum quantity available for utilization/ efficiency of utilization = 1,500 Tonnes/annum.
- Iron content of treated mill sludge =54.39%(as Fe)
- Since mill scale is internally generated, its cost is not available. On the basis of liner relationship between iron content and the cost of procured raw material the price of this treated mill sludge can be taken as RS. 450/T of material.
- Notional cost of material used = 1500 * 450 = Rs. 6,75,000

5.3.8 Cost of Processing: -

The prime cost of processing of the sludge is heating cost. Heating cost can be determined by taking into account that 40% of the material contains moisture and some oil (around 5%). Since oil content is less, the specific heat of the material can be approximately taken to be that of water. Therefore heat required is calculated as: -

$$Q = m \times C_p \times \Delta t \times t$$

$$= 1200 \times 1000 \times 1 \times (200-25) \times 8/10^6 \text{ G.Cal}$$

$$= 1680 \text{ G.Cal}$$

Average cost of BF gas, coke oven gas and LD gas is taken as. Rs.300/G.Cal.

Total heating cost is = 1680 X 300 = Rs. 5, 04,000

(However, heating cost can be saved if batch heating is carried out in the plate mill-reheating furnace)

Considering that material processing cost after heating would be approximately same as material processing cost of per tonne of sinter produced.

Electricity cost = 1,500 X 40 = Rs. 60,000

Other operating cost = 1,500 X 20 = Rs. 30,000

Total approximate cost of processing: 5, 04,000 + 60,000 + 30,000 = Rs. 5, 94,000

Benefit = 6, 75,000 – 5, 94,000 = Rs.80, 000

This offers an economic justification of sludge processing cost, in addition to offering environmental benefits.

Following assumptions have been made while deciding on the techno-economic impact of the proposed scheme.

(a) Spare Equipments are available within the plant will be used.

(b) Manpower is available in the plant and may be redeployed, if required, from other areas.

(c) All costs have been calculated on the basis of average cost data of BSP operations.

Therefore in addition to offering environmental benefits, utilization of the material would result in net notional economic benefit of approximately Rs.80, 000/annum.

Notional economic benefit would be much higher if batch heating can be arranged. And it is to be carried out in spare areas of plate mill reheating furnace.

5.3.9 Conclusion: -

Total mill scale utilization of BSP is around Rs.80, 000Tonnes/annum of which contribution of plate mill primary scale is approximately 10,000 Tonnes/ annum. With reference to Plate Mill secondary settling tank sludge whose generation is approximately 3,000 Tonnes/ annum. It is concluded that to utilize about 50% of the material generated i.e.1,500Tonnes/ annum, this figure has been arrived at by taking into account that the sludge has high moisture content and also the fact that any methods of utilization would result in some handling losses.

No norms are available for Carbon Monoxide (CO) emission in sinter plant. However, the norm of CO emission in coke oven is 3 kg/T of coke produced. The measured values of CO in the gas is much lower that these values and is likely to fall further once this is added with primary mill scale after processing. Therefore if secondary settling tank sludge, after treatment, is mixed with primary scale at a ratio1: 6 oil content of the mix from plate mill zone will come down to below 1% and oil content of the overall mill scale will be below 0.2%, much lower than the safe limit of utilization.

Hence it is concluded that the treated sludge can be added to the sinter that the sludge first be proposed limit to take care of any ensuing norm. It is also proposed that the sludge first be processed as recommended in the scheme and then added to the sinter mix along with primary mill scale at a ration of 1: 6 which may be mixed up to a ratio of 1:3 (5 kg of treated sludge/Tof sinter).

5.3.10 Recommendation: -

The cost and quality of hot metal plays an important role in determining the cost of steel produced in the integrated steel plant. Reutilization of wastes generated as substitutes of original raw materials would not only help in preserving the resources but would also save the cost of raw materials by reducing their specific consumption. With respect to laboratory results the yield of sinter productivity will be higher, sinter strength will increase and sintering time will reduce fractionally. Therefore the following scheme is recommended for treatment of secondary settling tank sludge before mixing it with primary scale. To care of the marginal increase in Carbon Monoxide (CO) content, a safe limit of utilization of treated sludge (5 kg/T sinter) is recommended.

5.3.11 Secondary Settling Tank Sludge Utilization Scheme: -

Considering total generation of 3,000T/ annum and also considering that three shift operations can take place minimum 300 day/ annum material need to be processed is 10 tonnes/ day. Therefore taking transportation and other losses into account, the capacity of the furnace should be approximately one tonne per plate for a 3 plate-heating chamber. One chamber needs to be kept for reheating purposes (return from shredder and ball mill). Capacities of other chamber should be such that they should handle the output of heating chamber and would also depend on the spare equipments available inside the plant. The scheme is shown below in Figure 5.8.

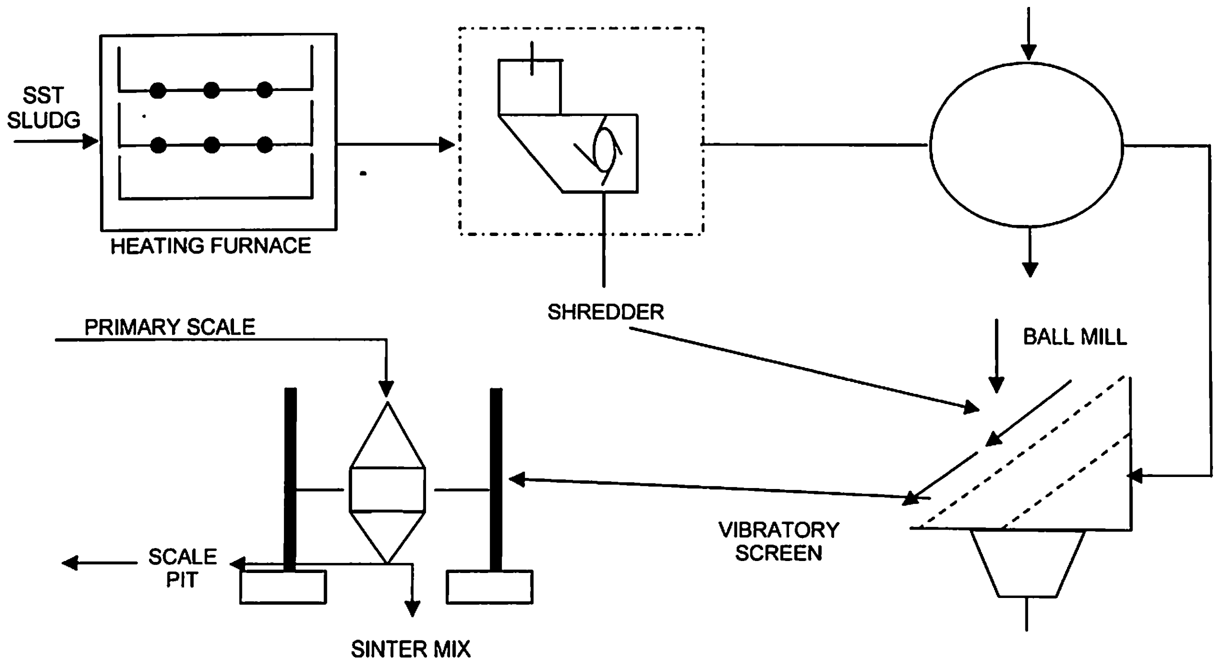


Figure 5.8: Secondary Settling Tank Sludge Utilisation Scheme

5.4 Lime Fines: -

The lime produced at refractory material plant is first screened through 10mm Screen and the lumps are sent to converter for steel making. The –10mm known as lime fines is a waste material. This material has been utilized successfully in many areas covering many objectives as stated below: -

5.4.1 Lime enhancement in sinter: -

A) Method: -

The lime fines can be added to the sinter that is being produced for consumption in blast furnace. This has multidimensional benefits. Firstly, this makes the sinter as self fluxed sinter and hence the consumption of limestone in blast furnace decreases. This apart, the very nature of the sinter as homogeneous nature of the iron oxide and lime makes the lime, iron ore reaction chemically and thermodynamically much more efficient. The heat required in the blast furnace for the calcinations of limestone comes from the coke. The charging of self fluxed sinter results in the saving of precious coke.

B) Advantages of Lime fines in sinter: -

a) Sinter production improved.

b) Helped in reducing coke rate in blast furnace due to presence of lime in sinter.

c) Reduction in consumption of limestone in blast furnace.

5.4.2 Using as Briquettes: -

Lime briquettes are almond shaped material made by compacting lime fines with special mechanical molding equipment. Their advantage over other forms of lime is that they are usually of uniform size and help in effective utilization of lime fines (Agrawal and Bajpai 2000). The briquette plant at Bhilai Steel Plant has resulted in following advantages: -

a) During kiln maintenance, relining and in exigencies, supply of lime can be supplemented by briquettes.

b) Briquettes are used in RH degasser and VAD for special steel production.

c) It helps in slag formation in converter at a faster rate.

Associated disadvantage is that it is very fragile and may get crushed during transit if precautions are not taken and may cause unbalancing of gas cleaning plant fan blades.

5.4.3 Ladle Covering Compound (LCC): -

LCC is a material used to form an insulating layer over the liquid steel to prevent heat loss during one-hour duration of casting. This material was being purchased from the market at @Rs.27, 000/ per tonne. Ladle covering compound was developed using waste material like BOF slag and lime.

A) Material and Method: -

The basic ingredient for producing LCC is converter slag, which again is a recycled product. This is used after drying and grinding. Slag is ground to -1mm size.90% Dried and ground slag is mixed along with 10% lime powder. After steel is tapped 800kg. of this mixture was dispensed on the top layer of molten steel in steel ladle. Then the steel was sent for casting in continuous casting shop.

B) Observation: -

Steel ladle temperature drop was recorded. It was found that the temperature drop has reduced by 5^0C, which helped caster operation and reduced the fear of metal getting cold and subsequently termination of casting. The temperature drop recorded is shown in table 5.11: -

Table 5.11: Drop in Temperature on 2/2/03 of Steel during Casting

	Temp. Drop	Temp, Drop	Temp. Drop
L.C.C. (from waste)	17^0C	16^0C	18^0C
Purchased L.C.C.	22^0C	23^0C	22^0C

C) Discussions and Recommendation: -

The following advantages were noticed: -

a) Temperature drop reduced by 5^0C.

b) The cost was 80% cheaper.

c) Less load on environment

d) However there is a danger of rephosphorisation and resulphurisation and to prevent it, lime fines is used as an ingredient for the production of LCC.

5.4.4 Fly Ash Bricks: -

As per government gazette, no person shall within a radius of 50 km from a coal or lignite based thermal power plant, manufacture clay bricks, tiles or blocks for use in construction activities without mixing at least 25% of fly ash, bottom ash or pond ash with soil on weight-to-weight basis. Hence, the idea of producing bricks by non-conventional materials is gaining importance day by day. Producing bricks with the help of fly ash generated in power plants in huge amounts require lime as binder.

The lime fines generated can be effectively utilized for this purpose. Lime fines, fly ash, sand and ash pond slurry was mixed thoroughly and moldable mix was prepared, which were formed in the shape of bricks upon pressing in hydraulic press. These bricks were treated in steam chamber and then cured to 800° C. These bricks were cheaper, higher in crushing strength and were having lower water absorption values.

Bricks made in this way are superior in quality, consume less fuel due to unburnt carbon present in it and incur low labor cost due to less digging. The bricks so made have smoother finish require less mortar for jointing and require no plastering material. These bricks are still to be popularized. This is described in detail in pollution control collected waste utilisation in subsequent chapter.

5.4.5 Coolant in Converter: -

The converter sludge is a mixture of GCP sludge and ventilation unit dust. This is being generated at the rate of 5,000T/year .It was being dumped. A product was developed by mixing the converter sludge with lime that could be used as a coolant in the converter. In the converter the bath temperature, sometimes, go beyond the required temperature limit. In such cases, it is required to bring down before it is suitable for tapping.

A) Material and Method: -

The lime fines-sludge briquette can be charged onto the converter to serve the purpose. To make these briquettes the converter sludge was first dried in the furnace fired with coke oven gas. This was then mixed with lime fines in proper proportions and was briquetted. The resulting briquette was a product that could be charged into the converter for cooling the bath. This has proved to be an effective substitution for iron ore. These briquettes have reduced oxygen and lime consumption in addition to landfill. It has been thought of achieving a production level wherein dumping of converter sludge will not be required.

B) Discussions and Recommendation: -

Lime Briquettes helped steel making in following ways:

a) Cost effective.

b) Slag formation in converter was faster.

c) Lime consumption in converter got reduced.

5.5 Dolomite Fines: -

-3mm sintered dolomite fines were being sent for dumping. This was not being utilised in any way. This reject was tried in filling well block of steel ladles to be used as well filler compound successfully.

A) Material and Method: -

-3mm sintered dolomite reject of rotary kiln after screening was crushed in a roller crusher to a size of -1mm.The crushed material was screened through 1mm vibratory screen.

B) Results and discussion: -

The pyrometric cone equivalent was tested and it was 1770^{0}C.The physical appearance was round. These fines were used in place of well filler mass. Free opening results were shown in table 5.12: -

Table 5.12: Free Opening of Steel Ladle

Date	Purchased Well Filler Mass	*Sintered Dolomite Well Filler Mass*
15/10/02	75%	*87%*
16/10/02	68%	*92%*
17/10/02	*78%*	*89%*

The cost of well filler mass is Rs.30, 000/T where as cost of dolomite well filler mass is negligible. This in addition to cost saving has helped in reducing dumping and thus helping to keep environment clean.

5.6 Summary: -

An integrated steel plant consists of various units' viz. ore-mines and variety of production unit's viz. Coke Ovens, Blast Furnaces, Steel Melting Shops, Rolling Mills, and Captive Power Plants etc. All units work in tandem to produce rated crude steel capacity of the plant. While doing that an enormous quantity of process wastes are generated and accumulated in any ISP and which need to be utilized. In this work it has been described the methods developed for the gainful utilization of process wastes being generated in the steel plant. The methods investigated involved mostly of agglomeration processes such as pelletizing, briquetting and sintering. Special attention was focused on methods to reuse the waste viz. Iron ore fines to reuse at small furnaces, Plate Mill sludge and only mill scale as sinter feed. Methods also suggested for use of lime and dolomite fines as briquettes. Future reduction of discharge rate of pollutants is the demand of the day by society, hence the need for use of innovative process in the industry to maintain growth potential of the country.

CHAPTER 6

INNOVATIVE USES OF WASTE COLLECTED IN POLLUTION CONTROL UNITS IN INTEGRATED STEEL PLANT

6.0 Introduction: -

Iron and steel manufacturing is a pyrometallurgical process with abundant emissions of various pollutants. Hence, in every country they are being increasingly targeted for control of air emissions. In addition to a multitude of gaseous air impurities, dusts play a special role, not only because they occur in large quantities but also due to the fact that the dusts contain some hazardous substances affecting both man and the environment, e.g. heavy metals. Due to the use of coolant water and wet separation methods, problems of maintaining water purity also occur. Continuous casting plants require high specific water quantities from which the wastewater is considerably contaminated with oil. Casting without spray-water cooling relieves the load on water resources.

Emissions produced by the iron and steel industry require extensive measures and systems for air protection. Above all, dusts containing substances hazardous to health and the environment, such as lead, cadmium, mercury, arsenic and thallium, must be cleaned by high-performance separation systems. Nowadays, not only the primary emission sources, such as sintering plants, but also secondary sources such as blast furnace casting bays can be intercepted and dedusted. In the case of gaseous emissions, attention must be paid primarily to reducing carbon monoxide and sulphur dioxide, as well as nitrous oxides and fluorine compounds.

Steel is an exceptionally recyclable material because steel products and by-products are excellent in terms of the "reduce, reuse and recycle" principle. The development towards waste-free steel industry has resulted in reduction of wastes and emissions and brought to light the possibilities offered by utilization of by-products. Newer business opportunities are opening up in this field that make optimal use of by-products based on research and development. On proper refining the recycled products compete favourably with natural materials, improve recycling and preserve non-renewable resources (Hiltunen and Poylio 1998).

In spite of this fact the Indian steel industry is yet to reach the high standards achieved by its counterparts in developed world in the arena of waste minimizations and recycling. However, under the directions of management research study was taken up in Bhilai Steel Plant. This plant has taken some very bold steps in this area and very encouraging results are being obtained. One such attempt was the use of mixed pond ash for manufacturing superior quality bricks (Pandey and Agrawal 2002).

No literature or any significant paper detailing the critical evaluations and comparisons of different recycling processes could be seen in a large literature survey. Thus, there exists an urgent need of research at the world level and no such attempt has ever been reported in Indian setting. In Indian ISPs no effective recycling and final dumping facilities exist, hence, the dusts and sludge separated from the waste gas cleaning systems represent potential pollutants of the ground and water environments. The major component of these wastes is fly ash generated in various air cleaning systems and the blast furnace sludge. Dumping sites create another problem i.e. the fly ash that is composed of very light particles becomes air borne very easily. Thus the problem of air pollution remains far from being solved. Dense plantation around the dumping sites helps in lowering the problem but is not the effective solution.

In this research work the experiments were carried out to utilise the solid waste generated during pollution control activities in different zones of the plant with an idea to establish a new process or manufacturing a new product using the waste material. Due approvals were taken from the BSP Management for conducting the experiment after discussing with management representatives regarding the experiment, material to be used and necessary units help in conducting the experiment.

After elaborate discussions with the concerned authorities and the experts from RDCIS, Ranchi the trial experiments were conducted, where the representative of the sections also participated for collecting data, its updating, and wherever needed the retrials were conducted.

The aim of these elaborate exercises was to evolve the process methodology, which could be out into actual practice in Bhilai Steel Plant. Obviously, this objective encompassed all factors pertaining to the engineering, economics and the ease in adoption. Only the trials, which could satisfy the three 'E' criteria that is engineering, economy and ease, were put forward for the approval of the management for actual adoption. It is a matter of satisfaction that most of the trials being reported here have already been accepted for implementation and the rest are being adopted. Since the raw materials, manpower and the equipments used were from indigenous sources, no additional cost is involved. Further the benefits are substantial and it is proved that these wastes could be utilised gainfully avoiding the dumping of the material, which was a routine earlier.

6.1 Pelletising and Reuse of Electrostatic Precipitator Dust: -

Electrostatic precipitator dust poses serious problem in transportation and recycling. During the process of sinter making, lot of micro fines are produced. According to our estimate about 60T of ESP dust is needed to be handled every day for the production of 8,500T of sinter. The chemical analysis showed that these micro fines possess high iron (Fe) content, which makes them suitable for recycling. Hence, various experiments were conducted to reuse them for iron making since the blast furnace can accept the raw materials in the form of pellets only. This experiment was aimed in converting, these fines in the form of pellets. In these experiments it has been found that the ESP fines of sintering plant can be pelletised using binders Successful production of the required size of pellets helped in recycling and thus saved cost of similar amount of raw material.

A) Experimental: -

The chemical composition of representative ESP dust was follows in Table 6.1: -

Table 6.1: Chemical Composition of Electrostatic Precipitator Dust

Component	**CaO**	**MgO**	**Fe**	**Indeterminate**
Percentage	23%	17%	58%	2%

10T of ESP micro fines was palletised with different percentage of binder namely bantonite and molasses and pellets so formed were tested for shattering strength conducting shatter test. For the test the material was allowed to fall from a height of 2 M on a steel plate and 3 mm fraction survived after the test is considered as acceptable. Fig. 6.1 depicts photograph of pellets and microstructure of samples made out of ESP micro fines.

Figure-6.1: Photograph of Pellets and Microstructure* of Samples of ESP Micro Fines (*Magnifacation: 200 times, Optical Microscope - Jenapol, Camera –Contax 167MT)

B) Results and Discussions: -

Six representative samples were prepared with differing proportion of binders as described in Table 6.2.

Table 6.2: Preparation of ESP Fines Pellets

S. No.	**Material**	**Rate Rs./T**	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**	**Sample 6**
1	ESP fines	0	98%	97%	95%	98%	97%	95%
2	Molasses	2000	2%	3%	5%	0	0	0
3	Bentonite	3000	0	0	0	2%	3%	5%
Cost Rs./T			40	60	100	60	90	150

Sample 2, 3, 5 and 6 showed good green strength conforming suitability for transportation and good handling g strength. Based on above about 10T of pellets were produced and found to be suitable in sinter making. The BSP Management, based on the lower cost, approved sample 2 for adoption.

6.2 Management of Waste Generated During Iron Making: -

6.2.1 Blast Furnace Sludge, Flue and Filtration Dust: -

Blast furnace removes oxide from the iron ore in reducing atmosphere and produces large amount of carbon mono oxide in the process Before it can be used as a fuel, the dust in gas (fine particles of iron ore, lime stone, dolomites etc.) must be separated from the gas.

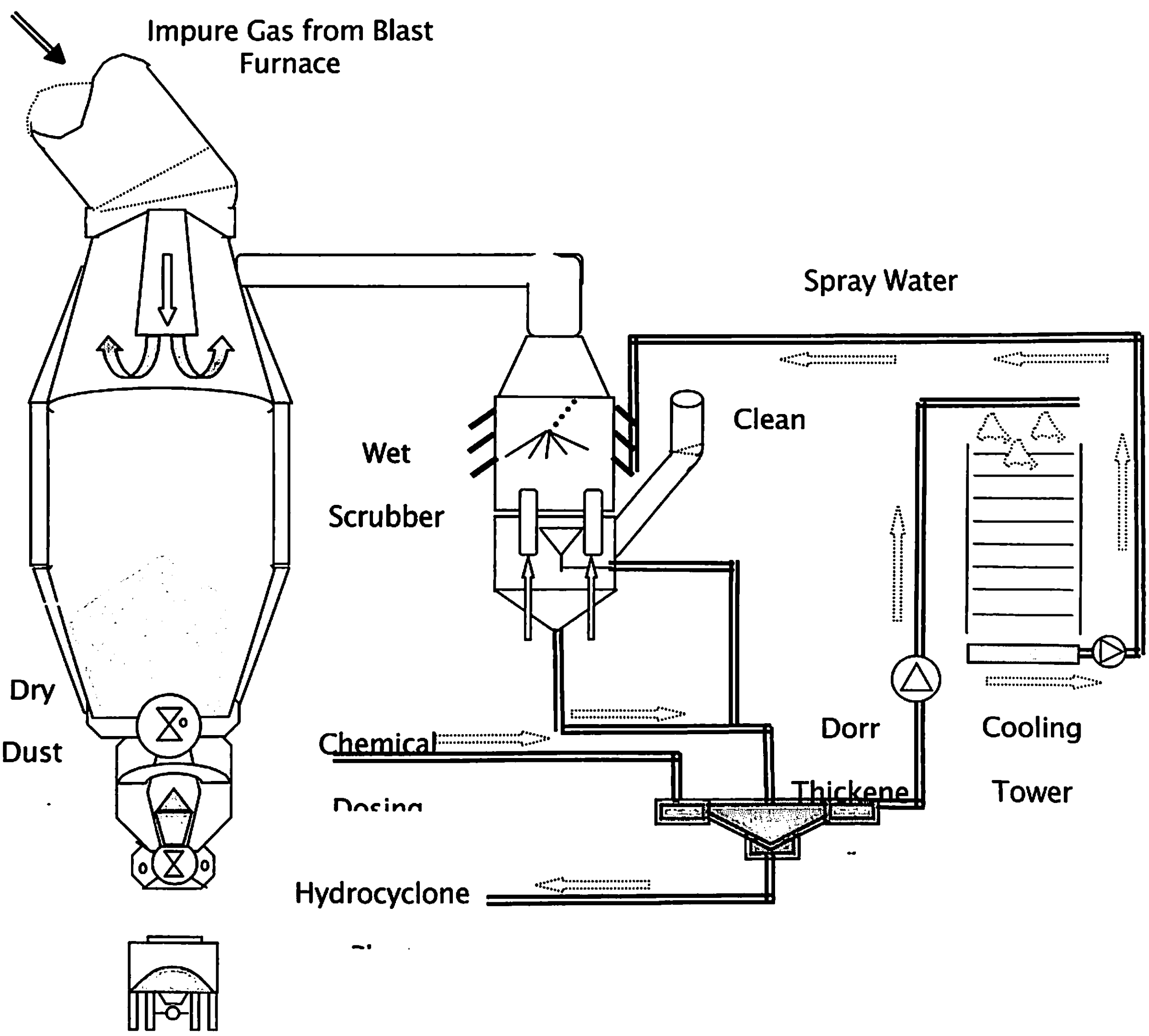


Figure 6.2: Blast Furnace Gas Cleaning Plant Schematic

Wet scrubber at the blast furnace gas cleaning system does this separation. The scrubber water is recycled continuously and the ultimate blow down water heavily impregnated with wastes goes to the wastewater treatment plant (Fig. 6.2), where coal, coke, iron and lime fines become a sludge, which is allowed to settle in ash pond along with fly ash of power plant.

Earlier this sludge was dumped in the landfill. Under this research work this sludge was dewatered and filter cake was formed which was used as excellent raw material in sinter plant.

6.2.2 Recycling Of Blast Furnace Sludge: -

The blast furnace gas cleaning plant sludge contains considerable amount of zinc, lead and alkali oxides. If this material were continuously recycled without treatment, unacceptably high levels of these oxides would build up in furnace. Studies on characterization of sludge revealed that these oxides are concentrated in the finest size. Classification of sludge may simply separate finer fraction containing high zinc, lead and alkali oxides and courser fraction with low zinc and lead levels. The size separation of sludge through use of small diameter hydro cyclones operated at high inlet pressures results in zinc reduction of 80-90% to the overflow. The underflow containing low zinc and lead and high iron and carbon can be recycled through the sinter plant after dewatering. The hydro cyclone facility is relatively simple and inexpensive.

A) Hydro Cyclone Treatment of Blast Furnace Sludge: -

The high levels of iron and carbon present in blast furnace sludge would (if it were not for the high levels of trace elements also present) make it attractive material to recycle. Experimental work has been carried out at BSP to see its applicability. The results show that processing blast furnace sludge through hydro cyclone system reduced the zinc and lead content (Fig. 6.3). This enabled large proportion of material to be recycled to the blast furnace via sinter plant.

B) Results and Discussion: -

Results indicate that levels of ZnO and PbO in the sludge can be reduced from 2.7% and 0.3% to 0.4% and 0.06% respectively. Based on recovery of 72% by weight results indicate that in the region of 88% of ZnO and 86% of PbO can be removed in only 28% of solid material. Hydro cyclone introduction includes benefits of: -

a) Overall intrinsic value of recovered material

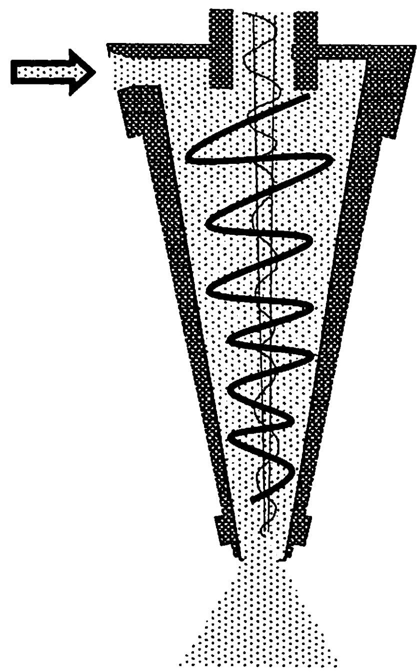
b) Reduction and dumping / reclamation costs.

c) Environmental impact. A reduction of 70 to 80% in quality of solids deposited at landfills.

d) The extension of mineral ore reserves as the product can replace raw furnace feed of iron ore and carbon recycled to blast furnace.

	OVERFLOW
% w/w	< 1.0 %
% C	18.0 – 30.0 %
% Fe	18.0 – 30.0 %
% ZnO	3.0 – 10.0 %
% PbO	0.5 – 3.0 %

	FEED
% w/w	1.0 – 6.0 %
% C	25.0 – 40.0 %
% Fe	25.0 – 40.0 %
% ZnO	1.4 – 3.0 %
% PbO	0.5 – 3.0 %



	UNDERFLOW
% w/w	60.0 – 70.0 %
% C	28.0 – 46.0 %
% Fe	28.0 – 46.0 %
% ZnO	0.2 – 0.5 %
% PbO	0.02 – 0.15 %

Figure 6.3: Typical Hydro cyclone Performance

Hydro cyclone treatment of blast furnace slurries provides a simple and cost effective method to facilitate recycling of a major proportion of previously discharged solids which contain acceptable levels of lead and zinc for recycling to the blast furnace. The values of product alone, and the low running costs associated with the process plants, has provided a pay back time of few months of capital equipments expenditure.

6.2.3 Recycling Of Blast Furnace Flue and Filtration Dust: -

A) Agglomeration of Blast Furnace Flue and Filtration Dust: -

Molten pig iron (temperature above 1500°C) is transported from the Blast furnace by ladle cars lined with refractory bricks to basic oxygen furnace (BOF) or other steel melting shop (SMS). In the process the surface of molten liquid metal comes into contact with air and releases carbon flakes and iron oxides fines. Air containing these materials are captured by hood (cast house dedusting system) and cleaned through bag-house filter or electrostatic precipitator (ESP). The recovered iron and carbon products are suitable for use in sinter plant. A general chemical composition of blast furnace dust is presented below in Table 6.3: -

Table 6.3: ESP Micro fines Chemistry

Fe	SiO_2	CaO	Al_2O_3	C	Alkalis	Zn	Pb
30-50%	5-8%	4-6%	2-5%	20-35%	1-2.5%	Traces	Traces

Blast furnace flue dust, ventilation dust converter GCP sludge and sinter plant settling tank sludge were chemically analysed and two different proportions were attempted for preparing agglomerates. The composition of the two samples and their chemical composition are presented in Table 6.4.

As these dusts are rich in iron content (~55 %+) a mixture of the dusts was mixed with suitable binder for facilitating the agglomeration. The binders used were just sufficient to improve handling strength. On heating up to 1300°C, Sample II showed good stability thus was suitable for use in either twin hearth furnace or basic oxygen furnace as a coolant with a property of non-disintegration.

Table 6.4: Chemistry of Samples

S. No	Material	Sample I	Sample II	Elements	% In Sample I	% In Sample II
1.	Flue Dust	20%	18%	SiO_2	4.94	4.47
2.	Vent Dust	20%	18%	Fe (T)	56.00	58.00
3.	GCP Sludge	20%	18%	Al_2O_3	5.10	6.63
4.	Settling Tank Sludge	20%	18%	CaO	6.40	5.00
5.	Ore Fine	10%	16%	MgO	3.00	1.80
6.	Binder I	5%	7%	MnO	1.80	2.00
7.	Binder II	5%	5%	P_2O_5	0.28	0.30
8.	---	---	---	SO_3	4.12	1.37

The microstructure and the photograph of the prepared agglomerate are presented in Figure 6.4.

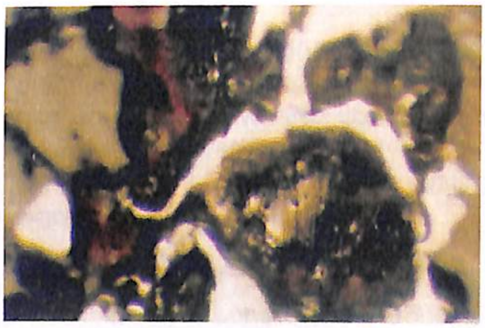


Figure 6.4: A Micro Structure* of Photo of GCP Sludge and Flue Dust-Agglomerate

(*Magnifacation: 200 times, Optical Microscope - Jenapol, Camera –Contax 167MT)

Recycling of dust with or without treatment is an integral part of waste management. Attempts have been made to use ferruginous and carbonaceous dusts as sinter feed material. It has been observed that better productivity and decrease in coke rate can be achieved by recycling these dusts in sinter plant. Briquetting of dust fines is also one of the options for reuse in steel making processes. Cement, molasses, lime and sodium silicates were used for developing cold bonded briquettes with acceptable strength and high temperature properties for its reuse in basic oxygen furnace.

B) Cost Analysis: -

As the economics always plays an important role a cost-benefit analysis was carried out and the results are shown in Table 6.5.

Table 6.5: Cost Pattern of Dust Agglomerate

S. No.	Item	Sample-I %	Cost Rs.	Sample-II %	Cost Rs.
1.	Binder-I: Low temperature @ Rs.2000/T	5	150	7	140
2.	Binder-II: High temperature @ Rs.5000/T	5	250	5	250
3.	Cost/T of material in Rs.		400	460	390
4.	Cost/Tof product @Rs.100/Tas processing cost		500	560	490

C) Test conducted: -

Shatter Test

Sample 1	85%

Sample 2	87%

D) Results and Recommendations: -

These samples were good in handling strength. Upon heating to 1350°C for 1 hr. due to partial melting of iron ore fines, it showed compactness, which proved to be suitable for use in furnace where operating temperature was high. Five tonnes of these agglomerates were used in converter as a coolant in steel making. Due to presence of CaO & MgO it has given good coating over the lining of vessel. Following advantages were seen: -

a) Lime consumption reduced to 1%.

b) Oxygen consumption reduced to 0.5%.

c) Yield improvement was seen to 0.2%.

Technologist and operating personnel appreciated these trials. It was recommended to install a suitable agglomeration equipment to avoid manpower requirement. Blast furnace flue dust and ventilation dusts can be used after agglomeration where as G.C.P sludge can be better used after hydro cycloning.

6.2.4 Recycling of Basic Oxygen Furnace Sludge: -

This study describes techniques for recycling the gas cleaning plant (GCP) sludge generated during basic oxygen furnace (BOF) steel making process. Two different experiments were conducted to gainfully utilize converter sludge in iron making and steel making. The experiments resulted in two different products namely lime sludge briquette (LSB) and dolomite sludge mix (DSM). While LSB is used as a coolant in steel making, DSM is used for sinter production. Each one is having cost effective advantages on one hand and substantially reduced dumping of waste on the other.

This research has particularly targeted the slurry from BOF for its recycling. In all major steel producing countries this slurry, which contains zinc content too high to directly recycle, is put into a settling tank and the water is pressed out of the slurry. The remaining fraction is either stockpiled or land filled. Steel companies are prospecting for the processes to economically retrieve the zinc and iron units (BHP Steel 2002). This experiment describes a breakthrough achieved which portents great savings economically and environmentally.

Slurry water from saturator, expansion chamber, elbow and baffle separator is collected in hydraulic tank guard, which is then discharged to radial settling tank through launder. Radial settling tank deposits, henceforth called 'GCP Sludge', is dumped in the landfill. Large production of this sludge has made it an environmental nuisance for the steel industry.

The solid fraction of BOF gas cleaning slurry (GCP sludge) could be a desirable by-product as it contains primarily iron oxide and free lime. Although BOF sludge is not suitable revert for use in blast furnace (BF) because of the high zinc content in other countries, this constraint does not exist in India, as the scrap used in our country is largely free from zinc. This made us to attempt for the recycling of this waste. The GCP sludge obtained in integrated steel plant of Bhilai was analyzed by X-Ray fluorescence method and the results showed presence of high Fe content. Looking to the high Fe (total) availability it was decided to recycle it. Preparation of two types of products i.e. lime sludge briquette (LSB) and dolomite sludge mix (DSM) were attempted. The major difficulty encountered when recycling sludge to Iron or Steel making is the moisture removal and material handling. It has been identified the ways in which these two problems can be eliminated, effectively.

A) Experiment I: Lime Sludge Briquette (LSB): -

Chemically the GCP sludge was found rich in iron oxides and total Fe content. This attracted to utilize it in place of iron ore. Coke Oven gas available in the Plant was used for drying. It is available as a by-product in coke manufacturing in the coke ovens. CO gas burners were installed in an in-house furnace specially designed for the purpose of elimination of the water component. Converter sludge was dried at 200°C in CO gas fired furnace for appropriate time. The dried sludge was screened and the size fraction ≤5 mm was collected after demagnetization. The ≤5mm size fraction was charged into mixer of briquette machine. Lime was used as the binder in briquette process. Lime was charged through a separate line into the mixer, and proportion was adjusted to form briquettes of adequate handling strength in briquette machine. These briquettes were used as a coolant and proved as a replacement of iron ore in converter during steel making.

B) Experiment II: Dolomite Sludge Mix (DSM): -

In the previous experiment carbon mono-oxide gas, a by-product from Coke Ovens was used to dry the sludge. In this experiment, moisture and handling problem was overcome by a unique process of dehydration. This process the sludge dehydration was achieved by mixing it with hot dolomite collected from dust chamber of rotary kiln during calcinations/sintering of raw dolomite. Calcinations of the dolomite are essential step during the sinter making operation. The process of calcinations/sintering of dolomite are carried out in the rotary kiln where the pulverized coal is supplied with a jet of the compressed air.

Large amounts of fines are carried away by hot flue gases, which is unavoidable in this process. These fines are separated from the flue gases in the dust chamber. The temperature of dust chamber is around 600^{O} C. At the time of disposal, these fines are generally at a temperature of 200°–250° C. It was envisaged using this heat energy for the dehydration of GCP sludge. These outgoing gases from rotary kiln comprise of flue gases, ash, and dolomite fines. The rate of generation of the rotary kiln fines is more than 40 T/day. Prior to this experiment, these fines were cooled and then sent to dump yard as landfills.

The composition of the rotary kiln fines and the results are presented in the Results and Discussion section. Looking to the rich composition and temperature it was experimented to mix the rotary kiln fines with GCP sludge. GCP sludge from converter was sprayed on the dolomite fines obtained from the rotary kiln.

To achieve the same, a recycling process was developed in the plant premises. BOF sludge was supplied in tippers to the dolomite plant. Blending of the hot dolomite (~400°C) with sludge was done layer by layer with the help of grab bucket crane. The sludge was blended with dolomite in a predetermined mix ratios using layering effect of sludge–dolomite–sludge and so on. The mix ratios are not divulged here in view of the commercial significance of this process.

The process uses available heat from hot dolomite to dehydrate the sludge and it resulted in a huge savings in drying costs. The treated mix is then allowed to cool for approximately 16-20 hours. The undersize mix was then transported in rail wagons to the ore handling and preparation plant where it was mixed with the iron ore fines. Care was taken that in the preparation of iron ore fines the moisture should not exceed 7% in so prepared mix. Thus, the sludge was converted to non-dusting, free flowing material suitable as iron ore fines to be used in sinter making machine for sinter production. This sinter was charged in BF for making iron.

C) Results and Discussion: -

The major issues in such a recycling effort are economy and probable effect on the quality of the steel produced. This research has addressed the both issues. It was considered to recycle more of this waste with less of investment in process. Care was also taken to recycle this product without sacrificing the quality of prime product, yield and ensuring compatibility with the process. Operationally, the final moisture content of mix is critical for proper handling and charging. Too low moisture may cause dust generation on the other hand high moisture content may cause plugging of hoppers and bins. Based on large number of actual trials it was observed that the presence of moisture may lead to the following problems: -

i. Explosion: - Explosion in the converter vessel may take place because of the presence of pure oxygen and high temperature generation of hydrogen.

ii. Disintegration:- Disintegration of briquettes will take place due to hydration of lime.

iii. Feeding problem:- Wet sludge/briquette does not flow smoothly through vibro-feeders and can cause chute jamming and lump formation in the bunker.

Experiments were conducted to find out the suitable moisture content to avoid the above problems. Series of experiments showed that sludge with moisture between 3-4% is optimum to avoid the above problems. A moisture level less than 3-4% causes excessive fugitive dust. On the other hand, a moisture level above 7% starts choking in the flow line and equipments. Hence, the sludge moisture was kept at the desired level of 3-4% in the process.

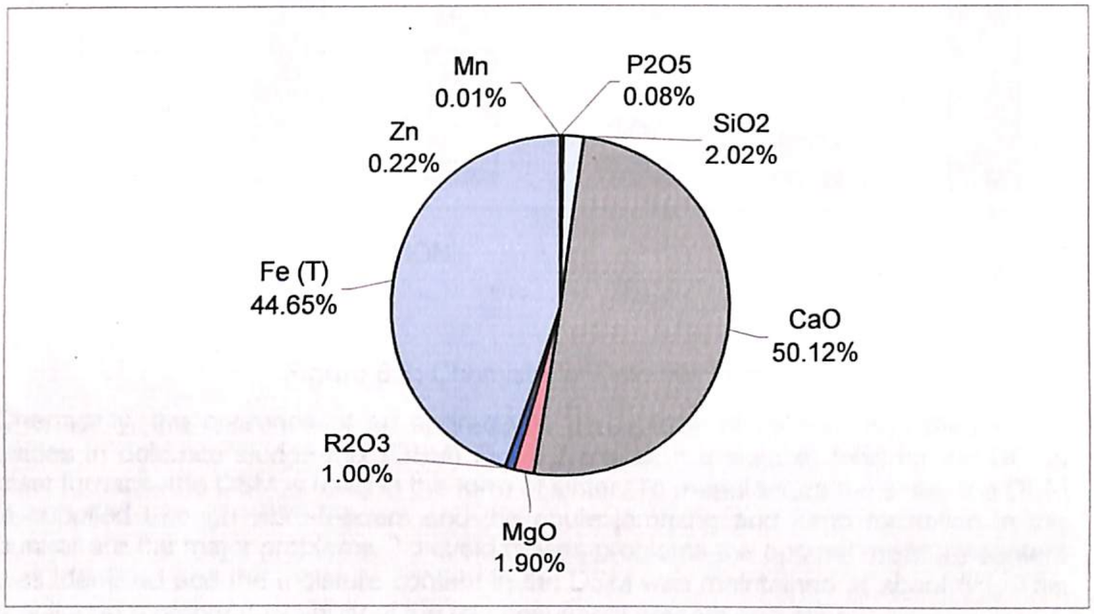


Figure 6.5: Composition of Lime Sludge Briquette (LSB)

The chemical composition of the lime briquettes so prepared was estimated using the X-ray florescence analysis and wet chemical analysis. The mean composition is presented in Fig. 6.5 above.

Initially one tonne of LSB was fed to the converter. On satisfactory performance, the quantity was increased to 2T, 5T and 10T and now 15T LSB is being supplied every day. Thus, it was possible to consume entire sludge this way. The use of iron rich GCP sludge has reduced the iron ore addition in the BOF converter. Another benefit, which has been noted, is the reduced oxygen consumption as the presence of oxides is high in the GCP sludge. Further, the converter sludge is having high percentage of lime hence; it would reduce lime consumption also. Apart from the above, the most significant engineering benefit is in the form of a good vessel coating, which was achieved in using LSB. A better coating of the BOF directly results into a longer life of the coating of the converter.

The experiments using dolomite fines have provided even better results. The composition of dolomite fines is presented in the Fig. 6.6. In this process, the sludge dehydration was achieved by mixing it with hot dolomite fines (~400^{o}C) to produce low moisture material suitable for charging in sinter machine as a replacement of iron ore fines.

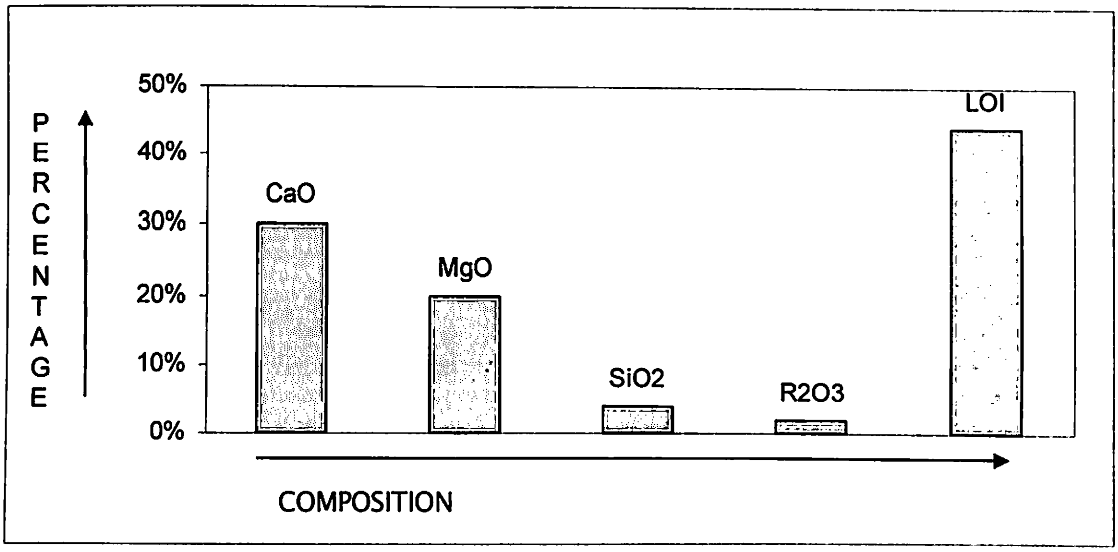


Figure 6.6: Chemistry of Dolomite Fines

Chemically, the presence of an appreciable percentage of calcium and magnesium oxides in dolomite sludge mix (DSM) Fig. 6.7 makes it a suitable feed for the BF. In blast furnace, the DSM is used in the form of sinter. To manufacture the sinter the DSM is supplied through vibro-feeders and the chute jamming and lump formation in the bunker are the major problems. To avoid theses problems the optimal moisture content was identified and the moisture content in the DSM was maintained at about 5%. This resulted in a proper flow ability of the mix ensuring a smooth operation.

Greater economy by the use of otherwise wasted heat and the chemical properties of the DSM have proved the advantages, which can be accrued by such researches. Fiscal calculation shows that a saving of more than $10/ tonne of steel produced is easily attained by this method. Thus, this research has successfully invented the method of waste recycling suitable to the Indian conditions.

Another major technological issue has also been studied through this work. This concerns the high cooling effect of the oxidized by-products of BOF. As it is already known that the dust, scales and sludge from iron and steel making processes usually have high iron content, these by-products are in oxidized form virtually without exception. Iron oxide containing material can be used as a substitutive coolant during converter blowing process. Traditionally scrap and iron ore are used as coolants. Charging iron oxide to converter may also speed up slag formation in the beginning of the process and decarburization reactions.

One of the biggest problems concerning utilization of oxidized by-products in BOF-steel making is probably a high cooling effect. This decreases the scrap melting capacity of a converter, which may reduce total amount of produced steel. Adding a reductant with the by-product charge could diminish this problem.

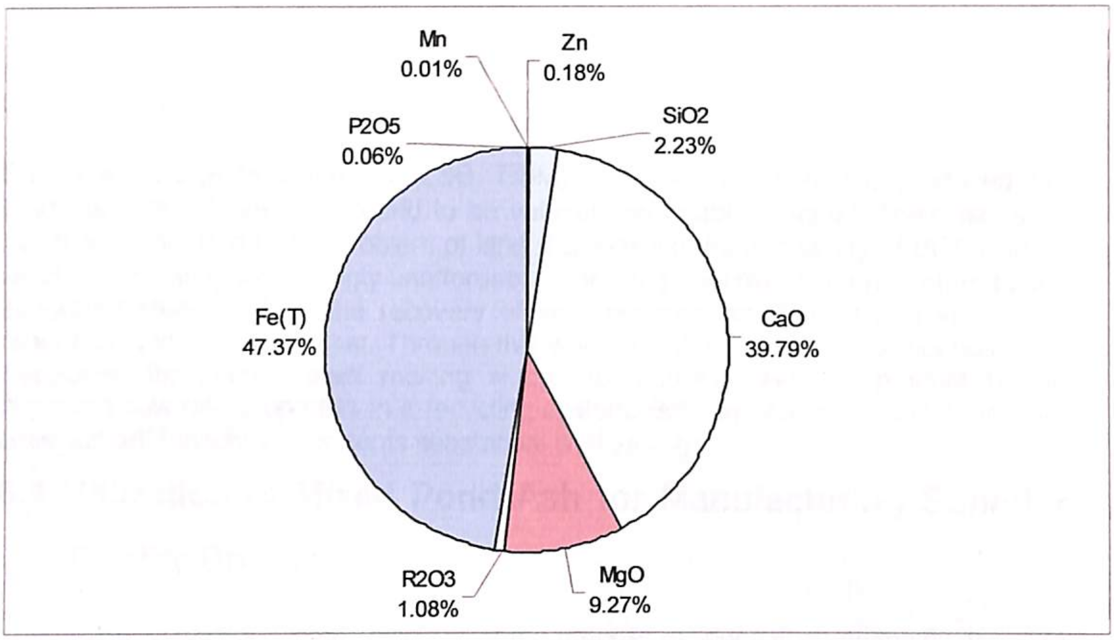


Figure 6.7: Composition of Dolomite Sludge Mix (DSM).

It is also possible to prevent oxidation of dust in some cases, when the cooling effect decreases. Anyway, at least sinter which is used as a secondary coolant, could be replaced by a by-product with a high iron oxide content. The cooling effect of sinter is close to cooling effects of several dust, scales and sludge. The amount of dust produced during converter process may be increased when by-products are added. Some elements are also enriched in the dust.

These factors may increase scaffold formation on the inner surface of the flue gas duct. Using by-products as raw material may increase content of some elements in raw steel. However, this experiment has successfully countered the problems identified as above because the actual trials in both BOF and BF have shown no adverse effect on the product quality and quantity. It is also reported that the absence of any negative cooling effect in either of the furnace following the mix proportions devised in this experiment.

Both experiments have developed a unique technology of sludge recycling in Bhilai Steel Plant in an environment-friendly way. Owing to its simplicity and visible benefits, the DSM technology has already been adopted by the BSP. Overall, the use of LSB or DSM is advantageous due to the following reasons: -

i. Iron ore use has been eliminated partially.
ii. Reduction in oxygen consumption is envisaged.
iii. Reduction in lime consumption.
iv. Good coating of converter vessel was seen.
v. Land filling is reduced.
vi. This has helped in controlling final temperature by reducing desired tapping temperature.
vii. Longer life and thus less frequent repairs of the BOF lining.

D) Conclusion: -

Converter sludge briquette/mix (LSB, DSM) are low cost, in-house produced by-products, which have been found to be valuable recyclable material. Their use is an eco-friendly solution to the problem of landfill disposal of huge quantity of BOF sludge, which is becoming increasingly unaffordable. This study will result in a net return to any integrated steel plant by the recovery of iron, reduced landfill cost and substantial reduction in steel making cost. Through this work, a viable industrial process has been developed for treating steel making sludge to produce useful by-product having improved flow rate properties in a recycling system. Both by-products (LSB, DSM) are environment friendly and portents substantial cost savings.

6.3 Utilization of Mixed Pond Ash for Manufacturing Superior Quality Bricks: -

The problem of collection and disposal of the process residues such as the fly ash (FA) and sludge from the various industrial operations has become one of the most potent environmental problems facing the entire world. Heavy metals and variety of organic constituents are almost invariably present in trace amounts in such FA and have been reported to cause abnormally high levels of inorganic and organic pollution in Indian atmosphere (Pandey *et al* 1998, Pandey *et al* 1999). Most of the combustion residues do not meet the environmental standard set for their bulk applications. The airborne ash coming from the stacks or due to the drying up of the ash ponds causes severe respiratory and other ailments, visual and aesthetic problems in almost all the major industrial cities in India. FA is also considered a hazardous waste due to the probable leaching of potentially toxic substance into the surface and ground water and soil.

Nearly 73% of India's total installed power generation capacity is thermal, of which coal-based generation is 90% – the remaining comprising diesel, wind, gas, and steam. The 85 utility thermal power stations, besides the several captive power plants, use bituminous and sub-bituminous coal and produce large quantities of FA. High ash content (30%–50%) contributes to these large volumes of FA. The World Bank has cautioned India that by 2015, disposal of coal ash would require 1000 square kilometres or one square meters of land per person (TERI 2000). The FA thus obtained has been experimented for the suitability in the applications such as ash alloys, ceramic tiles, fire bricks, insulation products, mineral wool, ceramic fibre, distemper, synthetic wood, fire abatement applications, soil conditioner, mine filling, roads and embankment, cement etc.

Utilization of FA can result not only in reducing the magnitude of the environmental problems, but it is also to exploit FA as raw material for value added products (and conserve traditional materials), and for extraction of valuable materials. Amongst many uses of the FA, its use as building materials is particularly suitable because it is anticipated, that there would be considerable shortfall in production of various building materials. According to a study, there would be a large short-fall in the production of bricks, to the tune of 25 billion bricks on an estimated demand of 100 billion bricks per year in India by the turn of the century. Considerable work has been done in various research institutions in India for utilization of FA. In spite of the recognition of the size of FA utilization / disposal problem and availability of technologies appropriate for Indian FAes and applications, India utilizes hardly about 3% of the total FA generated (TIFAC 2000, Kumar *et al* 2000). Hence, India is productively using only about 3% or 1.5 million tonne of FA. Thus, 49 to 50 million tonne of FA per year at present pose environmental threat. This figure will grow to over 87 million tonne per year by the turn of the century, if present dismal level of utilization only ash is maintained (Kumar *et al* 1978, Kumar and Sharma 1999a, Kumar *et al 1999b*, Kumar *et al* 2000).

To tackle the problem and encourage the use of FA for making building materials the Government of India has imposed restriction (Gazette notification of 14th September 1999, issued by the Ministry of Environment and Forests) on the brick manufacturers to use at least 25% of ash on weight-to-weight basis if the brick kiln is located within a radius of 50 km from coal or lignite based thermal power plants. The demand for bricks is expected to be about 100 billion per year by the turn of the century. Even if only 50% of the estimated demand of 100 billion bricks per year, is met from FA for productive use saving alternate resources, and reducing environmental hazard to that extent. In addition, it would save thousands of hectares of land from being used as pond area this still does not account for the potential of using other industrial wastes like red-mud (Kumar *et al* 1999b, Raju *et al* 1996).

Every integrated steel plant in India is having own captive power plant, which generates huge quantity of ash. This ash is often dumped along with other process wastes in dumping pits. This paper has attempted to use the various wastes in an integrated steel plant to see if they can be used to produce a superior quality ash bricks, which would be more palatable to the customer because of the quality and aesthetics. The pond ash in steel plant is different from the pure FA, since it gets mixed with blast furnace and twin hearth furnace sludge, an estimation of optimum proportion of pond ash and clay in the manufactured bricks and its strength is necessary. The results of such test will be helpful in persuading the local brick manufacturers to use the pond ash as raw material.

6.3.1 Experimental Details: -

The FA and mixed FA samples were obtained form the various ashes and sludge dumping ponds of Bhilai Steel Plant, Bhilai. The samples were analyzed to find out their chemical composition and loss on ignition (LOI). For use as a control, FA bricks and normal clay bricks were also manufactured. For the purpose, dry FA was obtained from the power plant. One part by weight of hydrated lime and sand was added to about eight parts by weight of FA. The material was then fed to a mixer for making a homogeneous mixture with the addition of water and was allowed to stand overnight. The material was then fed to a hydraulic press where it was pressed at 180 - 200 kg/cm^2 to get moulded green bricks. These green bricks were air dried for 24 hours. The green bricks were then cured in an autoclave and subjected to steam curing at 10 - 12 kg/cm^2 for 6 hours. For the preparation of mixed-ash bricks Different proportions of clay with pond-ash were mixed in a 1.5 T motorized mixer and four samples were prepared. These mixes were enriched with different proportion of water according to the plasticity of clay. No chemical binder was used in this process. As the mix contained clay, press pressure was reduced to 100 kg/cm^2. Four categories of bricks of differing proportion were made. The curing of these bricks was carried out at different temperatures viz. 200° C, 800° C and 1200°C.These bricks were tested for apparent porosity, bulk density, weight, compressive strength and water absorption.

6.3.2 Results and Discussion: -

The chemical analysis of FA and other mixed ashes obtained from various ash ponds of Bhilai Steel Plant shows that the percentage of iron is very high in the ash pond where the sludge from twin hearth furnace and fly ash from power plant is present. Silica content is less compared to other samples (Table 6.6).

Table 6.6: Chemical Constitution of the Various Ash Mix in Ash Ponds in Bhilai Steel Plant

Components	SiO_2	Al_2O_3	CaO	MgO	Fe (total)	LOI
Fly–Ash	58 %	22 %	1 %	0.8 %	2 %	8 %
Fly-Ash + BF Sludge	58 %	24 %	1.6 %	2.25 %	8 %	8 %
Fly- Ash + T.H.F. Sludge	24 %	10.5 %	1.4 %	0.5 %	33 %	11.2 %

Table 6.7: Green Strength of Bricks Made of Various Mixes.

Sample Category	% Clay	% Pond Ash	% Water	Green Strength
50	50	50	10	Poor
50 +	50	50	15	Good
60	60	40	12	Good
60 +	60	40	18	Poor

Table 6.7 shows the Green strength of the four categories of mixes and it was found that the addition of 40-50% pond ash with 12-15% of water provides good green strength.

Figure 6.8: Normal Fly Ash Brick Manufactured Using FA, Clay and Lime Binder

Mullite ($3Al_2O_3.2SiO_2$) is responsible for the compressive strength of bricks. The aim of this work was to synchronize mullite ($3Al_2O_3.2SiO_2$) generation in the bricks by sintering FA with alumina. Under appropriate conditions, the ash & Al_2O_3 react to form mullite phase during sintering while producing the ordinary FA brick. However, this does not happen normally in the case of steel plant pond-ash because the FA is mixed with blast furnace & steel melting sludge and the higher percentages of iron fouls the reaction with concomitant decrease in the silica content.

Fig. 6.8 shows that the FA brick made using lime as a binder was found to be black in colour and smooth in finish. Their crushing strength was comparable to the ordinary red (clay) bricks. Water absorption was also below the stipulated values. However, the blackish colour of these bricks is the biggest lacunae in the popularization of these bricks in spite of all other attendant benefits

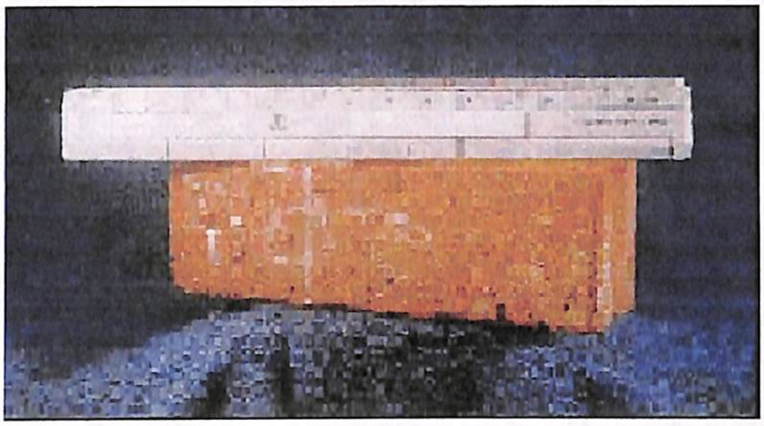


Figure 6.9: Mixed Pond-Ash Clay Bricks after Curing at 800° C

The mixed pond ash and clay bricks have provided very encouraging 'results particularly with 50+ and 60 category composition. Sample number 50 & 60+ showed poor green strength and hence discarded. The 50 + & 60 category bricks have shown good green strength. Therefore, these samples were air dried for 24 hours, which further improved the strength. These bricks were cut into three pieces and further tests were carried out by curing at different temperatures. The first batches of samples were kept at 200°C for 4 hours in an in-house built gas fired furnace. The black colour of samples changed to grey colour and crushing strength was increased. The texture and surface was smooth.

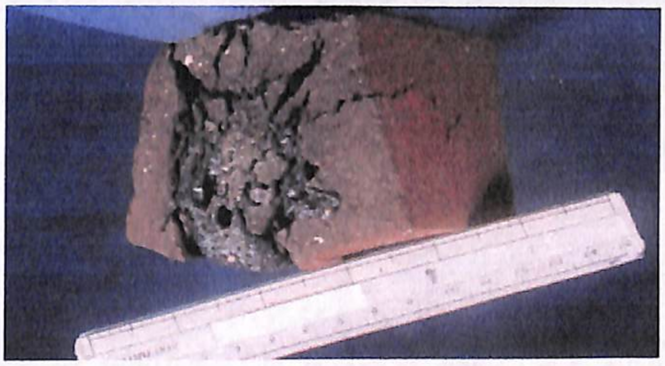


Figure 6.10: Mixed Pond-Ash Clay Bricks after Curing at 1200°C

On dropping the brick on a steel plate from 2M heights, sample did not break from any angle. The second batches of samples were heated to 800° C in a muffle furnace. Samples were slowly cured and temperature was raised to 800° C in four hours. After maintaining it for two more hours at this temperature, the furnace was allowed to be cooled slowly. This process changed the brick colour to red - brown with weight stabilization due to complete moisture removal. No crack was visible in the bricks (Fig. 6.9). The third batch was put in the hearth of muffle furnace and temperature was increased slowly to 1200° C in six hours. It was kept for two hours at 1200° C zone and then cooled slowly. The cooling time was about eight hours. This heating caused most of the samples to be cracked and it also caused patchy agglomeration of iron metal and slag in the bricks (Fig. 6.10).

Figure 6.11: Micro Structure* of Mixed Pond-Ash Clay Bricks at 800°C

(*Magnifacation: 200 times, Optical Microscope - Jenapol, Camera –Contax 167MT)

The microstructure (Fig.6.11) confirms the distribution of iron and slag in the mix, which exerts a beneficial impact on the strength of the bricks thus prepared.

Bricks cured at 800° C were tested for apparent porosity, bulk density, crushing strength and water absorption tests. On all counts, the mixed pond-ash clay bricks have been found superior to the normal clay red bricks. The cold crushing strength was higher and water absorption was on lower side vis-à-vis red bricks (Table 6.8).

Table 6.8: Structural Properties of Mixed Pond-Ash Clay Bricks

Sample	Apparent Porosity	Bulk Density g/cm^3	Cold Crushing Strength kg/cm^2	Water Absorption %
Mixed pond-ash clay 50 + category	34.9	2.14	99.2	16.3
Mixed pond-ash clay 60 category	34.3	2.1	95.2	16.2
Normal clay red brick	34.0	1.68	70	20

Based on the superior quality, strength and aesthetic merits mixed pond-ash clay bricks have a greater potential for wider acceptance of the consumers.

Table 6.9: FA Generation in SAIL Plants

Steel Plant	FA Generation in Tonnes	Generation Rate kg/T of Crude Steel
Bhilai Steel Plant	180838	91.2
Durgapur Steel Plant	120379	140.8
Rourkela Steel Plant	437834	594.6
Bokaro Steel Plant	490750	230.7
Indian Iron & Steel Co.	71131	182.2
SAIL (TOTAL)	1300932	247.9

Table 6.10: FA Recycled, Sold and Dumped In ISPs of India

Plant	FA Recycled	Sold	Dumped
Bhilai Steel Plant	-	-	100 %
Durgapur Steel Plant	-	-	100 %
Rourkela Steel Plant	25.6	-	74.4 %
Bokaro Steel Plant	-	-	100 %-
Indian Iron & Steel Co.	-	82.8 %	17.2 %
SAIL Plants (Over all)	9.5 %	4.5 %	86%

The large production of the fly ash in the integrated steel plants of India (Table 6.9) and its present mode of disposal as identified (Table-6.10) attest to the need of adoption and popularization mixed pond-ash clay bricks.

The production of mixed pond-ash clay bricks has many advantages compared to the normal bricks. First, it has low cost of production due to the fuel saving on account of the presence of unburnt carbon (up to15%) present in some pond ash. Secondly, the process is less labour intensive and thirdly the smooth surface finish and the absence of cracks provides a better construction quality with lower consumption of the cement mortar. These bricks do not even require any plastering. The only disadvantage which has been noted by us is the heavier weight of these bricks compared to the normal bricks. Still, this could be a rather beneficial feature depending on the application of these bricks.

6.3.3 Conclusion: -

Bricks manufactured by using mixed pond-ash of an integrated steel plant have been found to be cheap, superior in structural and aesthetic qualities. This experiment has established that the use of mixed pond-ash in the range of 40-50% remaining being the clay provides a very viable option of the use of huge quantities of FA now being dumped by the Indian steel industry.

6.4 SUMMARY: -

Steel plant's operational units are equipped with pollution control units. Lot of wastes are collected from these units. Land filling of such dust or sludge is prohibitive, as blast furnace sludge will contaminate subsoil water, as it contains lead, and fly ash for power generation will be air borne if dumped on land and contaminate climatic environment condition. In this chapter, keeping in view of the effect of these waste which are injurious to health and climatic condition a good number of experiments were done which are described here.

Suitable results are obtained during experiment in actual field of application and recommended for plant's regular use by recycling and reuse. Emphasis was placed more on use by recycling of blast furnace sludge, electro static precipitator, dust fines, basic oxygen furnace sludge, lime sludge, and mixed pond ashes.

Chapter 7

INNOVATIVE USE OF PROCESS REJECTS IN INTEGRATED STEEL PLANTS

7.0 Introduction: -

The major way the industrial metabolic system differs from the natural metabolism of the Earth is that the natural cycles (of water, carbon/oxygen, nitrogen, sulphur, etc.) are closed, whereas the industrial cycles are open. In other words, the industrial system does not generally recycle its nutrients. Rather, the industrial system starts with high quality materials (fossil fuels, ores) extracted from the Earth, and returns them to nature in degraded form. There are only two possible long-run fates for waste materials a) Recycling and reuse 2) dissipative loss. The more materials are recycled, the less will be dissipated into the environment, and vice versa. (Kirkpatrick 1992). The dissipative losses need to be made up by replacement from virgin sources (Ayers and Ayers 1996).

This chapter describes the ways to reduce the dissipative losses of the various process rejects. As per definition the word process rejects means any unusable parts, e.g. reject batteries, exhausted catalyst, worn out refractory etc.

7.1 Recycling and Reconditioning of Spent Refractory: -

Generation of spent refractory in a steel plant in India is 3 to 10 kg/T of crude steel. Refractory bricks are costly inputs to steel making process. The dismantling of furnaces for relining from coke ovens to rolling mills generates different variety of refractory. Removed refractory can be reused or used for less critical applications. The refractory grog arising from the fire clay, basic and other bricks are used for production of refractory mortars or can be used along with mix of new bricks for new brick production after carefully studying.

The consumption of recovered material covers up to 25% of total raw material consumption at mortar shop. High alumina refractory are recovered from slide gate plates of steel ladles and used in production of runner mass for blast furnace. The improvement in runner life along with cost advantage and waste utilization aspects are the benefits. The steel shell of slide gate is recycled as scrap.

Presently dolomite based refractory from converter and transfer ladle linings is fed after processing to sinter plant because of calcium oxide and magnesium it contains. Rejected silica bricks are being used for paving of roads. The extent of sale is around 15 to 40%. The remaining part is dumped.

Major portion of spent refractory in foreign countries is dumped. Extent of reuse varies widely from country to country. It is zero or near in some countries including USA to about 33% in Germany. The remaining part is reused as salvaged bricks for less critical applications or as a raw material for manufacture of bricks / mortars. Spent refractory contain some organic elements (such as chromium and also refractory ceramic fibres), which becomes a harmful if inhaled by human causing respiration problems.

Bhilai Steel Plant in India, set up in 1958, is producing 4MTof steel every year. Steel, as a finished product is user's friendly and is eco friendly too. It has good strength and is weldable and completely recyclable. Nevertheless during its production from mines to mills lot of pollutants viz. air pollution, water contamination and solid wastes are generated which need to be dealt carefully. Steel production without refractory cannot be imagined. Refractory constitute about 4 to 6% of total cost of steel production. These refractory are used as lining material for various furnaces and vessels required for production and handling of hot metal steel and other finished products.

After the life of refractory lining of these vessels are over they are stripped off and new lining is provided. Residual refractory is in large quantities when blast furnaces, mixers, converters ladles and others viz. hot blast stoves soaking pits and reheating furnaces are relined. This refractory material consists of mainly fire clay magnesia carbon, magnesia chrome, high alumina and castables.

Till now these residual refractory were disposed off generally by dumping in a dump yard; which have been occupying lot of dump space. Due to weathering, components from these residues are leached out and percolated into ground water leading to large-scale land degradation resulting in air and water pollution. Although consumption has been optimized, the generation of residual refractory has been a matter of concern .The focus has shifted from disposal to integrated waste management of potentially valuable resources and residues.

Steel plants world over have adopted various methods of recycling of waste. In many developed countries, it has become mandatory and dumping attracts heavy penalty by the state. The various ways in which recycling is done include crushing of used refractory and mixing it with blast furnace charge. Agglomeration of various types of sludge and waste fines and recycling them in converter or in various secondary steel-making units is another option (Sinha *et al* 2000).

Each industry dealing in high temperature product processing generates residual refractory that is recycled. The life cycle must be kept in mind and initiatives are required to eliminate the ill impact of waste being generated.

The life cycle concept imparts knowledge of recycling at every stage from raw material to finished product. The same is employed for reusing of refractory waste product, which is a source of major cost reduction program. Recycling of residual refractory is shown in Fig. 7.1.

New purchased refractory is installed in furnace vessel or stoves as per requirement. After the refractory life is over, skull breaker or pneumatic chisel dismantles it. The broken refractory are salvaged and put into different boxes (Mukherjee and chakraborty 1999, Mukherjee and Chakraborty 2000). The first one contains good ones which can be recycled straight; second one is for dumping where no amount of treatment can be exercised for its revitalization. The third one contains refractory that is fit for recycling but costly and hence sold. The fourth one is good for rejuvenation.

In the experiment these residues are cleaned and crushed to desired size. Different granulometry is prepared for required compaction and a Suitable binder was added and mixed thoroughly in mortar and pressed into required shapes in hydraulic press. This recycling of the refractory has greatly benefited the Bhilai Steel Plant as enumerated below: -

i) Refractory purchase has reduced.

ii) The regenerated bricks and mortar are cheaper and hence are economically beneficial.

iii) This recycling is environment friendly as the refractory dumping has reduced drastically.

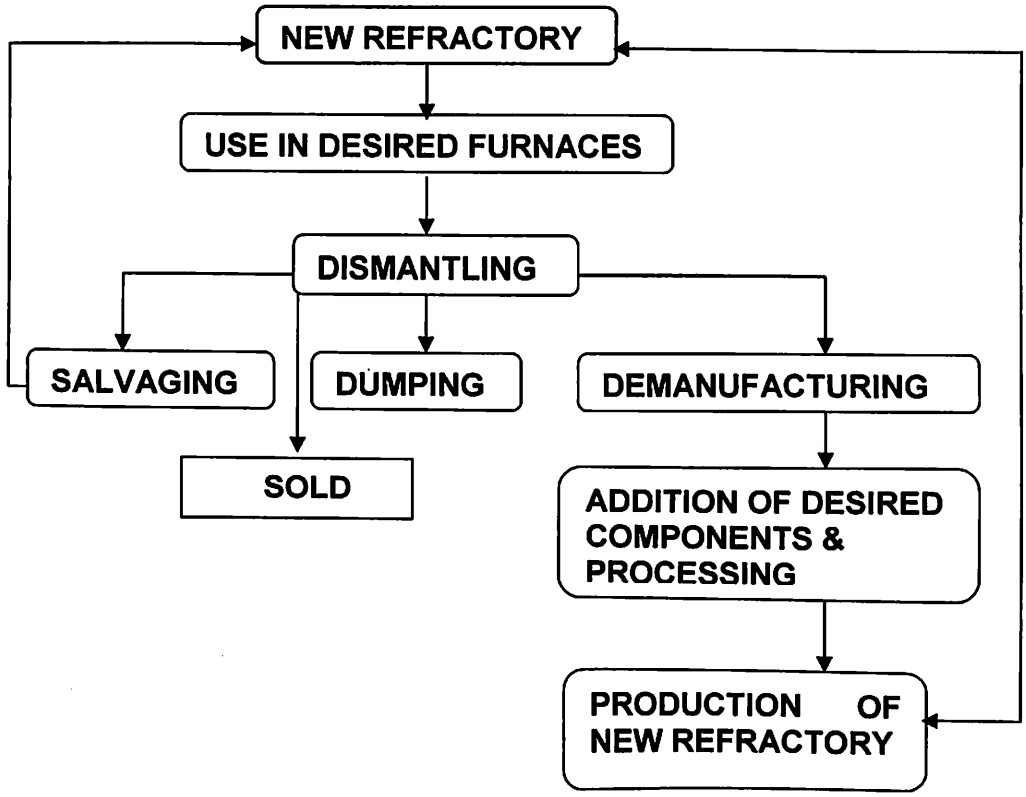


Figure 7.1: Refractory Recycling & Salvaging

7.2 Utilization of Refractory Waste: -

The various areas in which trials have been conducted in BSP and the details thereof are explained in Table 7.1.

Table 7.1: Utilization of Residual Refractory

S.No.	Residual Refractory	Rejuvenated Product
1.	Fire Clay Grog	i) Fire Clay Brick
		ii) Fire Clay Mortar
		iii) Tap Hole mass
2.	Magnesia Carbon Grog.	i) BOFVessel Bricks.
		ii) Steel and VAD Ladle Bricks.
		iii) Skimmer Plate
		iv) Rocking Runner Bricks.
		v) Coating and Ramming Mass.
3.	High Alumina Brick Grog	I) Steel Ladle Mortar.
		ii) Blast Furnace Trough Mass.
5.	Chrome Magnesite Grog.	i) Converter Coating Mass.

7.2.1 Fire Clay Grog: -

Fire clay bricks are used in soaking pits, hot blast stoves, reheating furnaces, casting platform and many other areas throughout the plant. After the refractory life is over these bricks were being dismantled and dumped. It was occupying a lot of landfill area and was causing environmental degradation. Various areas have been identified where these could be used effectively and a brief account is given below: -

7.2.2 Fire Clay Bricks: -

A) Methods & Material: -

A trial was conducted in this study wherein the fireclay brick grog was crushed in different size fractions and was mixed with suitable binders. It was then pressed in hydraulic press at suitable pressure. The bricks so made were then air dried and tempered for few hours in a tempering kiln. Properties obtained were quite encouraging and are as shown in Table- 7.2 below: -

B) Results & Discussion: -

Table 7.2: Properties of Regenerated Fire Brick

S. No.	Properties	Values of Bricks from Grog	Values of New Brick
1.	B.D.	2.1 g/cm^3 at 200° C	2.2 g/cm^3 at 200° C
2.	C.C.S.	100kg/cm^2 at 200 ° C 400kg/cm^2 at 1300 ° C	200kg/cm^{2}min.at 1300 ° C
3.	P.C.E.	1675 ° C after firing at 1350 ° C	1710 ° C after firing at 1350 ° C
4.	PLC	0.8% at1350°C	1% max. At1350°C
5.	Porosity	23.7%, 24.2%	25 % max.
6.	Sp. Gravity	2.74, 2.74	2.82,2.81

Five tonnes of such bricks were produced and used in steel emergency containers and was found to be very encouraging. Apart from the physical properties, a sample of the brick was analyzed for its micro structural analysis and is as shown in Fig 7.2 below. The homogeneity in the microstructure indicated its stability in its future use.

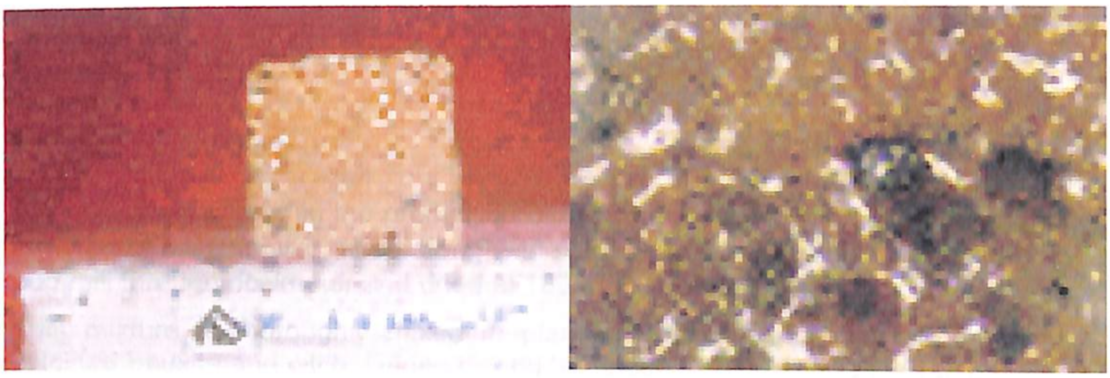


Figure 7.2: Regenerated Fire Clay Brick and its Microstructure*

(Magnifacation: 200 times,Optical Microscope - Jenapol, Camera –Contax 167MT)

7.2.3 Fire Clay Mortar: -

Fire Clay mortar is another product, which has been developed under research programme.

A) Methods & Material: -

The fireclay brick grog is ground to -0.1mm and mixed with suitable binder to produce fire clay mortar. Every year about 1600T of firebrick grog is utilised for this purpose.

B) Results & Discussion: -

1. FIRECLAY BRICKS: -

The cost of production was 35% of the cost of new bricks. Properties were found to be very near to new bricks. These could be used at areas of little less importance & severity.

2. FIRECLAY MORTAR: -

The cost of fireclay mortar prepared were only 30% of cost of new mortar purchased. These have been used successfully for cementing material for ladle & mixer lining. The PCE and PLC were found as good as new mortar. The following advantages were registered: -

- ✓ Cost reduction.
- ✓ Reduction on Environmental load.

7.2.4 Tap Hole Mass: -

Tap hole mass is used to plug tap hole of blast furnaces till it is ready for next opening. During next tapping time the portion of tap hole is to be drilled. This should have good plugging properly. Application should be smooth. Slag metal erosion should be negligible.

A) Methods & Material: -

Fire clay grog is used in the production of tap hole mass for blast furnace. The grog, crushed to suitable size. Grog along with coke breeze and plastic clay is charged to pug mill through dosimeter and dried at 100^0 C in a drier.

This mixture is thoroughly mixed in planetary mixer along with silicon carbide, calcined bauxite and pitch. During mixing tar is added. This mix is then dried and cut into pieces of 3 to 5 kilogram in weight. This is used in tap hole of blast furnaces for plugging purpose. During closing this mix provides mushroom umbrella. Fluidity is good which helps in easy application.

B) Results & Discussion: -

Tap Hole Mass: -

The cost of tap hole mass so prepared is only 40% cost of new mass purchased. This has shown good result in respect of

- Drillability.
- Less slag metal erosion properties.
- Less spitting.
- Good plugging properties.
- Easy applicability.
- Negligible slag metal infiltration.

7.2.5 Magnesia Carbon Brick Grog: -

The magnesia carbon bricks are the most preferred refractory lining the world over because of its superiority over the other types of bricks in many aspects. These bricks are having properties: -

- Non-wettability to molten steel and slag.
- Superior slag resistance.
- Superior oxidation resistance.
- High thermal conductivity.

The basic raw material required to produce these bricks is high purity magnesia, which is highly expensive. Hence, in spite of its much superior quality than the others, it contributes significantly to the cost of production of steel. The residual bricks of this type i.e. magnesia carbon brick grog consists of the high cost seawater magnesia. Previously, this grog was being used for producing low value products or it was being dumped. It was thought of utilizing this material as a value added product so as to improve upon the techno economics that would have the added advantage of reduction in dumping.

The various ways in which this material can be used is as detailed below: -

7.2.6 Recycling: -

The magnesia carbon grog thus obtained is sorted for bigger size grog i.e.+200mm which is then used for patching the converter lining. During the running of converter, localized erosion of the lining takes place and if this is not taken care of, it may result in reduced lining life of converter.

The salvaged+200mm magnesia carbon bricks are used for making up of the localized erosion of the lining, which is known, as patching. This helps in keeping the erosion pattern of the converter lining uniform and thus helps in achieving optimum life of the lining. The quantity of grog that has been utilized in converter for patching has been as shown in the Table7.3 below: -

Table 7.3: Magnesia Carbon Brick Grog Utilization

Period	New Bricks inTonnes		Grog Utilization in Tonnes in Converter
	VAD Ladle	Converter	
2001-2002	2217	4441	1244
2002-2003	2004	4180	1040

7.2.7 Rejuvenation: -

The recycling of magnesia carbon bricks is not enough to consume the total quantity of mag-carbon grog that is generated. The rest of the quantity can be utilized gainfully through reintegration and regeneration. Here, the grog is crushed and graded to the required size fraction for making mag-carbon bricks. The flowchart for making these bricks is shown in Fig. 7.3.

The Mag-Car is selected and clean pieces are collected for crushing. After crushing, it is screened to 1-4mm and 0-1mm fraction. Some portion of 0-1mm fraction is further crushed in tube mill to generate micro fines. These three fractions are taken in required proportion and mixed along with graphite aluminum powder and resin thoroughly in a mixer.

The so prepared mix is kept for aging to allow resin to form bonding. After aging, mix is pressed in a hydraulic press into required size of bricks. These bricks are cured in a controlled temperature, in a tempering furnace. These bricks are inspected and dispatched for end use.

A) Results & Discussion: -

The properties of the regenerated bricks as obtained were comparable with that of the new bricks as can be seen in the Table-7.4 below. -

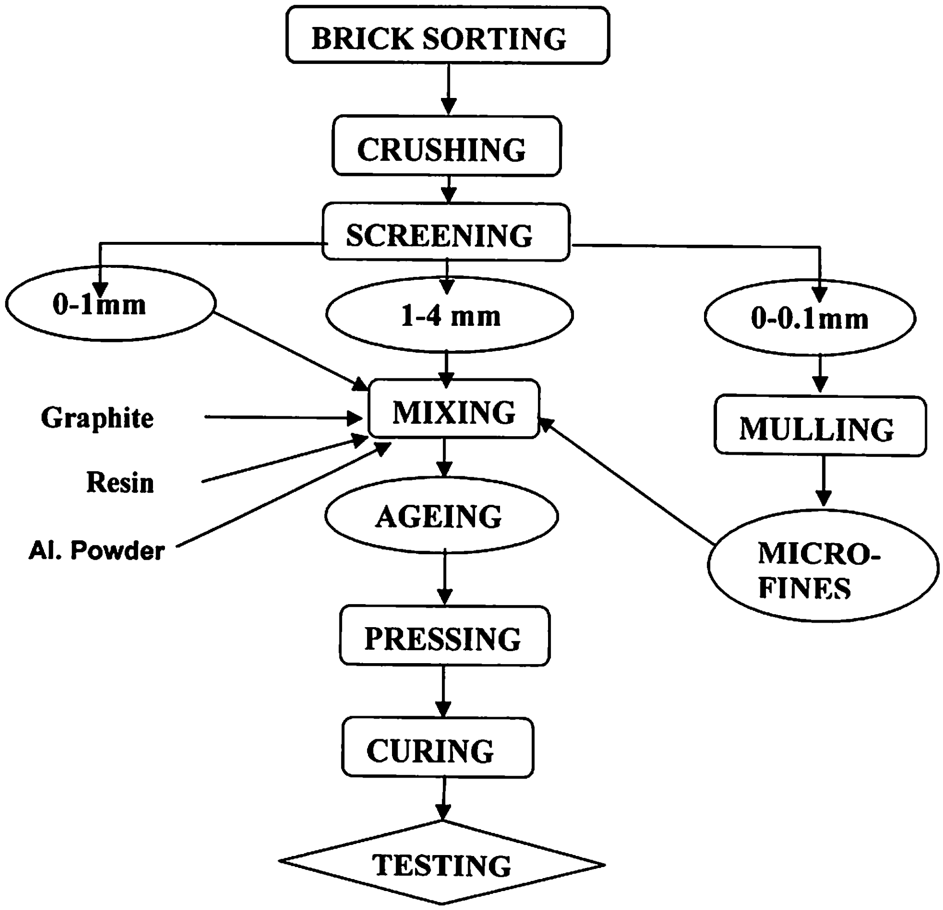


Figure 7.3: Magnesia-Carbon Grog, Process for Regeneration of New Bricks

Table 7.4: Properties of Regenerated Mag-Carbon Bricks vs. New Brick

Properties	Sample1	Sample2	New Bricks
Physical			
1. A.P.%	7.00%	6.20%	6.80%
2. B.D. (g/cm^3)	2.90	2.91	2.95
3. CCS (kg/cm^2)	370	407	423
Chemical			
1. MgO	92.61%	92.10%	93.84%
2.CaO	1.00%	1.02%	0.77%
3. SiO_2	1.99%	2.22%	1.28%
4. Al_2O_3	2.97%	1.90%	2.48%
5. Fe_2O_3	1.52%	2.03%	0.86%
6. F.C.	8.40%	8.60%	12.74%

These bricks have been utilized in the following areas with excellent results: -

7.2.8 Converter Bottom Bricks: -

The bottom zone of converter is less critical area compared to the other areas. The mag-carbon bricks made out of regenerated grog can be utilized gainfully by replacing the backup lining of the converter bottom made of fresh mag-carbon brick with these bricks. This results in a net saving of $10,000 per campaign of converter lining at the rate of $180 per tonne of these bricks used.

7.2.9 Steel Ladle & VAD Ladle Slag Line Bricks: -

The slag belt of the steel ladle lining is being lined with magnesia carbon bricks, which are being purchased at high cost. The design of these bricks was entirely different from that of the bricks, which were being produced in-house. The bricks were redesigned so, that could be produced with the present moulds. These types of bricks were produced with the regenerated magnesia carbon grog and were applied in these steel ladles successfully. The lining life obtained from these bricks was 25% more compared to heats obtained with that of the purchased alumina magnesia-carbon bricks.

7.2.10 Skimmer Plate: -

The BF skimmer plate is made of refractory bricks. This brick was not giving good life. It was thought of using mag-carbon bricks, made out of regenerated grog instead. The skimmer plate life with these bricks was almost doubled and its cost was 30 % of new bricks.

7.2.11 Rocking Runner Bricks: -

The hot metal falls on the rocking runner from a height of about one meter. The force of the hot metal used to cause localized erosion of the refractory mass at the point of fall. This caused immature failure of the ramming mass. Since the compaction or bulk density of a brick will definitely be much better than a monolithic mass, it was decided to line the runner with magnesia carbon bricks made of regenerated magnesia carbon grog. Results were encouraging.

7.2.12 Coating and Ramming Mass: -

The regenerated magnesia carbon grog is ground to - 0.1mm. It can be used as coating and ramming mass by mixing it with suitable binder.

The cost economics of these bricks have been very encouraging and hence is a great booster in it to go for recycling. The cost of the regenerated bricks vis-à-vis new bricks used in different areas is as shown in Table 7.5.

Magnesia carbon brick grog - This has cost advantage also it proved to be better way to solve dumping problem. Properties of bricks from grog compared to new bricks were no way inferior with respect to apparent porosity bulk density and cold crushing strength and Chemistry. Cost wise these bricks are very cheap. The use is continuous in the plant.

Table 7.5: Costs of Regenerated Mag-Carbon Bricks for Different Applications

S.NO.	Application	Cost
1.	Ladle bricks for steel ladles	25% of new bricks
2.	Converter bottom bricks	25% of new bricks
3.	Skimmer plate for Blast Furnace cast house	30% of new refractory
4.	Rocking Runner	30% of new refractory
5.	Converter coating material	25% of dead burnMagnesite
6.	Slag line bricks for VAD ladle	25% of new bricks
7.	Patching bricks	40% of new bricks
8.	Ladle ramming mass	40% of new refractory

7.2.13 High Alumina Brick Grog: -

High alumina grog is used where the application temperature ranges between 800-1600°C. These bricks are extensively used throughout the plant and hence the grog of these bricks forms a major chunk of the total generation of the grog. The alumina content of these bricks is 45% min. The quantity of grog of these bricks that has been utilized is as shown in Table 7.6.

Table 7.6: Utilization of Grog of Non-Basic Bricks

Period	New bricks Tonnes	Salvaged, Grog Utilized, Sold Tonnes	Percentage
1999-2000	32489	10717	33%
2000-2001	28579	8962	31%
2001-2002	31597	8781	27.79%
2002-2003	29593	11174	37.76%

7.2.14 Converter Ladle Mortar: -

A) Methods & Material: -

Residual high alumina bricks are sorted, ground to - 0.1mm and can be used as mortar after mixing with the binder. This mortar is used as a cementing material for steel and hot metal ladle refractory lining.

B) Results & Discussion: -

Pyrometric cone equivalent and permanent linear change was checked and found to be as required for this application. Cost of this mortar is only 25% of cost of new mortar.

7.2.15 Blast Furnace Trough Mass: -

Blast Furnace runner is for flow of hot metal from furnace to ladle, which is finally transported to Steel Melting Shop. The runner is rammed with mass so that hot metal does not penetrate the base. This has good refractory property.

A) Methods & Material: -

The BF trough mass is an alumina based material for which the raw material used is calcined bauxite. The regenerated high alumina grog could replace this virgin material by sorting and crushing it into the required size fractions. This regenerated material has few additional advantages over the virgin material. Its loss on ignition is almost zero and secondly there will not be any further expansion during its application thus preventing the formation of undesirable cracks if any.

B) Discussions and Recommendation: -

HIGH ALUMINA BRICK GROG: –

a) The used bricks were salvaged & utilization from 27 to 37% has been a good attempt on recycling.

b) Mortar prepared by high alumina brick grog was costing 30% of new mortar. The use for jointing during lining of steel & hot metal has proved to be cost saving at the same time less burden on dump sites.

c) BF trough Mass -High percentage of alumina attracted lower cost of trough mass. The through put cost worked out to be 6 paise per ton of hot metal as compared to 40 paise per tonne of purchased mass.

7.2.16 Basic Refractory Grog (Chrome or Magnesite based): -

Basic bricks grog is generated when converter vessel lining, twin hearth roof lining, rotary kiln lining and steel ladle lining is dismantled.

A) Methods & Material: -

Basic bricks are used at various places throughout the plant. They require a cementing material, which essentially should be basic in nature. This mortar was being procured from refractory manufacturers. The basic brick grog is utilized for this purpose by making Magnesite and Chrome Magnesite mortars. The grog is first sorted and then ground to micro fines. It is then mixed with binders to produce mortars. The quantity of grog thus utilized has been as shown in Table7.7.These grog have been used for converter coating between blows to enhance lining life.

B) Results & Discussion: -

This grog after converting to mortar was used as cementing material in lining of basic bricks. The so prepared mortar was costing 20% of new mortar. This has better PLC & PCE as these were subjected to high temperature during earlier application. This has reduced dumping. When this mortar was used for converter coating, it has improved lining life of vessel by 10%

Table 7.7: Percentage Utilization of Grog

Period	New Bricks in Tonnes	Grog Utilized Sold/Salvaged in Tonnes	Percentage
1999-2000	21728	5619	25.86%
2000-2001	29661	7448	25%
2001-2002	25386	6826	26.39%
2002-2003	30982	8316	26.84%

7.3 Hazardous Materials Used in Transformers: -

The iron and steel industry is one of the seven energy intensive industries viz iron and steel fertilizer, aluminum, textiles, cement, chemical, pulp and paper which account for nearly 80% of energy consumption. The iron and steel industry is the largest consumer of energy in industrial sector. The source of electrical energy is either captive power plant or electricity boards. For transmission and distribution to reduce losses, transmission is done at high voltage and used at required voltage by stepping down high voltage. Thus large number of transformers is employed for this purpose.

Poly Chlorinated Biphenyl (PCB) has been extensively used in many countries, in electrical equipments such as closed transformers and capacitors. It is used mainly as dielectric fluid (Lenicek *et al* 1997). PCB is a stable compound, resistant to decomposition, soluble in most common organic solvent, fire resistant and possesses superior dielectric properties. Hence PCB has influenced the electric industries to use them in transformers and capacitors as coolant and for insulation purpose. Use of PCB was permitted in equipments, which are fully closed and were kept under rigid control from the time of commissioning. It is considered a hazardous toxic chemical, because PCB and its pyrolysis products are capable of producing extreme toxicological risk .By any means, if PCB gets exposed to the temperature range of 300°C to 800°C it becomes extremely dangerous as it can produce polychlorinated dibenzodioxins and dibenzofurans. Their toxicity is 10,000 times greater than potassium cyanide and 500 times greater than arrow poison, curare. (IARC1983, IARC1984, IFCS1996). Hence, it is of utmost importance that PCB filled equipment should not be subjected to fire. It is imperative that used electrical equipment and used PCB stored in barrels should not in any case be exposed to these temperature limits. PCB are considered highly dangerous toxic chemical for reasons stated above (UNEP1997). That is why; its use has been banned in 1982 under US Toxic Substance Control Act of 1976 (TSCA). No adequate hazard free disposal system could be envisaged; when the PCB & PCB filled equipment life is over and goes out of circulation from service(Johnson and stringer1994). Hence, an attempt has been made, described in this work, a process adapted to dispose off the PCB by incineration in the rotary kiln.

7.3.1 Present Status: -

After the mandatory ban imposed on use of P C B as coolant and insulating media, a few suitable substitutes such as mineral oil, silicon or synthetic Ester liquid etc. are being used now in transformers & capacitors. Dry type transformer is also available in service. Hence, use of such coolant in equipments instead of PCB has eliminated the risk of handling and disposing of these equipments after the end of effective service life. Retrofitting of transformers with PCB by any other substitute such as mineral oil is not recommended. The reason is that even a slight residual quantity of PCB in the system can cause high degree of risk of toxicity fall out to nearby area due to oxidative pyrolysis of PCB in the event of any induced fire occurred near the installed equipments. (Asolekar1999).

7.3.2 Destruction Technology: -

Destruction technology depends upon PCB concentration in used up transformer coolant (UNEP 1992). No restriction has been imposed for disposal of 50 ppm PCB. Between 50 to 500 ppm disposal options are (a) Incineration (b) Storing at chemical waste dump (c) Burning at high efficiency incinerators or utility boilers (Bracewell *et al* 1993). For contaminated liquid above 500ppm of PCB concentration approved methods are combustion in high efficiency incinerator in cement kiln or rotary kiln. These industrial processes have the potential for recovering the heat value of the waste, removing chlorides and providing destruction and removal efficiency, equivalent to hazardous waste incinerators (Oppelt1986, Hunt *et al* 1984, Macdonald *et al* 1977). By incinerating PCB in rotary kiln have been many advantages viz:

i) Large number of plants exists at different parts of country and controlled incineration can be made possible.

ii) It is a high temperature combustion process 1350°C – 1700°C with a gas residence time in seconds.

iii) Less investment for the process.

iv) Alkaline environment in the kiln absorbs Hydrochloric acid.

v) Kilns are operated under negative draft therefore there would be little or no outward leakage of fumes, if any it would be inside the kiln.

vi) Some portion of solid, liquid or gaseous fuel may be substituted by PCB which can help in energy saving.

Following points were taken for consideration during trial burning of PCB: -

(a) HCl emission measurement at stack.

(b) Distribution of chlorine at the discharge end.

(c) Emission of SO_2 during incineration.

7.3.3 Experimental Details: -

Before the start of experiment with a trial run, at first it was decided to mix PCB in a day tank of rotary kiln with PCM tar as a fuel mix in a ratio of 5:95 with an idea that less concentration in PCB may not result in the problem of Cl_2 and HCl emission. With further elaborations, it was decided to find the means to nullify the chance of ingress of PCB in the working equipment.

Hence, to improve the process of experiment during trial run it was decided to install a filtering machine with a built in pump for injection process. Elaborate arrangement is shown in Fig.7.4 attached where 200 liters drum of PCB is connected via 80 mm diameter pipe with outlet of pump, which is further, reduced at delivery side 32 mm diameter pipe and connected to a lance in rotary kiln hood. Fool- proof safety care is to be adhered to prevent any ingress of unburnt PCB in existing line of kiln, its burner, and pump and storage tank during the run of experiment. For working personnel nose pads, leather gloves, safety goggles and uniforms were provided and Kerodex cream was applied in their bodies.

A fire tender was a must and also to be requisitioned during operation in case of any fire etc. A detailed meeting was held with all the concerned personnel connected with the experiment to thoroughly understand each one's specific role and responsibility during trial run. Finally, a protocol was made for trial burning of PCB at rotary kiln of RMP-2 (Fig.7.4). Prior to the day of experiment, two PCB drums and filtering machine were shifted to kiln platform. Lance was connected with a flow regulator to supply predetermined quantity of PCB in stages. Below the pumping set some dolomite dust was kept to soak in case of any leakage form pump.

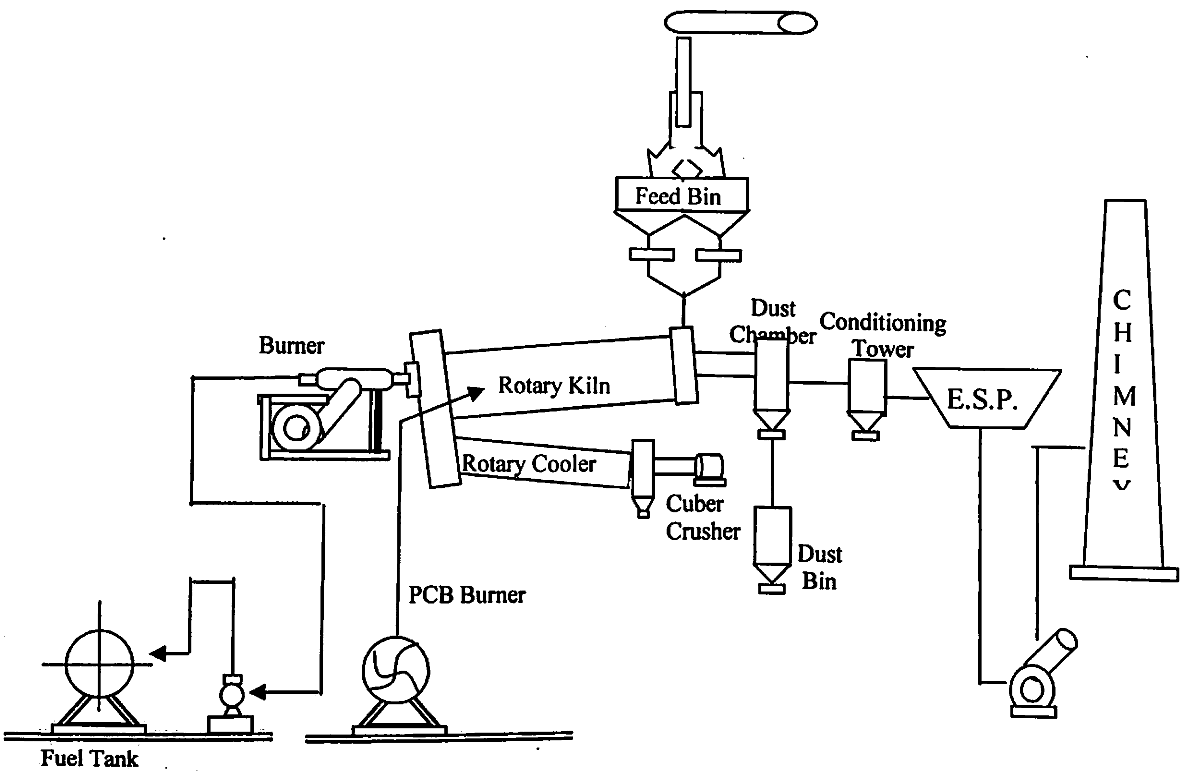


Figure 7.4: P.C.B Burning Scheme in Rotary Kiln

A trial experiment was started on 2.11.2001 in rotary kiln. Initially 50 kg/hr. PCB was burnt and gradually in stages it was increased to 100 kg/hr and then finally 200kg/hr. Time to time at different stages of supply, Cl_2 & SO_2 gas concentration at work zone and HCl emission & HCl load were measured at inside chimney, by occupational health center staff and EMD personnel. Electrical staff were operating filtering machine during trial. The trial lasted for 45 minutes.

7.3.4 Observation: -

In the beginning flame was bright and later on it turned yellowish. Flame zone also got shifted towards discharge end. Some leakage in pumping system was observed which was immediately rectified. Leaked PCB was soaked with dolomite dust and charged back in the kiln for complete destruction. Data recorded are shown in Table 7.8.

Table 7.8: Norms and Observation

S. No.	Parameters	Norms	Obserbations
1	HCl emission concentration	34 mg/Nm^3	At 50 kg/hr incineration rate= 7.2 mg/Nm^3 At 100 kg/hr incineration rate= 14.3 mg/Nm^3 At 200 kg/hr incineration rate= 28.5 mg/Nm^3
2	HCl emission load	4 kg/hr	At 50 kg/hr incineration rate = 252 g/hr At 100 kg/hr incineration rate = 500.5 g/hr. At 200 kg/hr incineration rate = 1001 g/hr. (Fuel gas flow rate = 35000 Nm^3 /hr)
3	Chlorine emission concentration	15 mg/Nm^3	4 mg/Nm^3
4	Work zone concentration of Cl_2	1ppm	At kiln platform - Below detectable limit At the kiln side - Below detectable limit
5	Work zone concentration of SO_2	2ppm	At kiln platform - Below detectable limit. At work zone side - Below detectable limit.

7.3.5 Discussions and Recommendation: -

The experiment of high temperature incineration was conducted for the first time in India. The Cl_2 & SO_2 concentration was observed to be zero ppm in the kiln platform and nearby area. This high temperature combustion in rotary kiln appears to be effective and could be adopted at large scale also. The reason of no contamination at the work area may be state of negative pressure at kiln outlet. For this the following further guidelines have been developed:

a) Values have been extrapolated on the actual reading obtained from 900- liters /hr flows.

b) Leakage at pumping station is to be totally eliminated.

c) The flow rate of PCB should not exceed 200 kg/hr, otherwise there can be a chance of overshooting the norms.

Through this experiment an efficient process of PCB destruction has been evolved. To improve the further applicability of the process a favorable management view in the further course of action is solicited. Other sister ISP's, Electricity Board and Pollution Control Board may be interested in these finding.

7.4 SUMMARY: -

Special quality refractory material's use in steel plant for furnace operation is most essential single element, without which steel production can, not be imagined. Generation of spent refractory in a steel plant is about 3 to 10kg/Tof crude steel produced. An enormous quantity of spent refractory normally generates, after its taking life is over and dismantled from furnaces. In this chapter, it has been thoroughly described how this varied kind of refractory material, instead of dumping which was and still is in practice can be reclaimed by adopting various suitable methods of recycling process. Special mention is given of reuse partly of the residual (spent) refractory such as Fireclay grog, Magnesia carbon grog, and High Alumina grog in different plant equipment application as regenerated product.

This study, also describes, this experiment has also been able to develop an effective method for destruction of PCB. The high temperature prevailing in Rotary Kiln has ensured a complete destruction with maximum efficiency and minimum cost. Simultaneously the heat energy generated during destruction was used for sinter production.

Chapter 8

CONCLUSION AND RECOMMENDATIONS

8.0 Introduction: -

The nature of operation in Iron & Steel industry calls for large-scale inputs of both raw materials and energy and is inevitably associated with huge quantities of byproducts/wastes. Though our main effort is directed towards attacking the problem at source, generation of substantial amount of pollutant/waste cannot be avoided due to vary nature of the operation. While pollution control is being attempted using various equipment, and the recycling/reuse of waste the problem is still insurmountable. We still find a substantial gap between generation and utilization of solid wastes. Hence in Indian steel industry wherein the material and resource (including energy) productivity is relatively low compared to developed countries, more concerted efforts is required.

8.1 Conclusion: -

This research work was carried out with active support and encouragement from Bhilai Steel Plant Management and the various jobs undertaken were location specific in different plant units. Experimental works on new recycled products, made in-house, were conducted along with technologist of concerned units of the plant. Several trial runs were conducted with a change in composition of the recycled product (if necessary) till required methods were established. The results achieved were critically examined with in-house technologist of plant before giving final recommendations for regular use of the new product. Raw material plant of the Bhilai Steel Plant was finally chosen to be the nodal agency for preparation of solid waste recycled products.

This research work has been particularly successful in the preparation of following recycled products. Many of them are either in the regular use or are under active consideration for use by the Bhilai Steel Plant: -

1) COKE BREEZE: - i) 0-10mm size agglomerated coke breeze were found suitable for small smelting furnace. Scope exists for the experiments on its use in Blast Furnaces.

   ii) 10-25mm size nut coke was directly used in blast furnace in place of coke.

2) PROCESS WASTE: - Blast furnace dust, ventilation dust, converter sludge and sinter plant sludge – Recommended to be used in BOF furnace of steel making operation as coolant.

3) IRON ORE FINES: - Being used as iron ore agglomerates in sinter making and coolant in Basic Oxygen furnace.

4) BF SLUDGE: - Used after hydro-cyclone treatment in iron making via sinter plant.

5) ESP MICRO FINES: - Recycled for sinter making.

6) BOF SLUDGE: -

   i. Recommended and reused as to arrest slopping (i.e. restricting foaming) during converter blowing operations.

ii. Used for sinter production after being dried by dolomite fine spreading.

7) CONVERTER SLAG: - Recommended to use this dry product (reconditioned) as insulating agent to cover steel ladle so as to arrest temperature drop of the steel.

8) PLATE MILL SLUDGE: - In sinter making after adjusting/ removing the oil content.

9) HAZARDOUS WASTE: - Destruction of polychlorinated biphenyl and utilizing the heat for sintering in rotary kilns.

10) REFRACTORY:-

i. FIRE CLAY GROG: -

a) Recommended for use in hot steel holding containers after conversion to fire clay bricks.

b) As mortars in refractory relined steel ladles.

c) Tap Hole Mass

ii. MAGNESIA CARBON GROG: -

a) BOF vessel bricks

b) Steel and VAD ladle bricks

c) Skimmer plate

d) Rocking runner bricks

e) Coating and Ramming mass

iii. HIGH ALUMINA BRICK GROG: -

a) Steel ladle mortar

b) BF trough mass

iv. CHROME MAGNESITE BRICK GROG: -

a) Converter coating mass

v. SLIDE GATE REFRACTORY PLATES: -

a) Refractory portion is used for blast furnace which replaces calcined bauxite for preparation of runner mass.

b) Steel encasing parts of used slide gates are reused as scrap in steel melting charge material.

vi. LIME DUST: -

a) Used in sinter plant to enhance CaO component of sinter

b) Briquettes made out of it used during converter blowing operation as lime requirement.

c) Ladle covering compound

11) FLY ASH (POWER PLANT): -

a) Experiments were conducted to make bricks and results show cheaper and better quality bricks. It is also found suitable for civil construction material.

b) Pond ash clay bricks suitable for building construction.

This work on waste management has established the way for regular use of the solid waste generated from iron and steel making process. The process adapted to recycle this waste at plant unit level is definitely cost effective and economic way of recycling, reconditioning and reuse.

The environment compatibility of a product produced in integrated steel plant should be determined during the process of development instead of tackling the problem when it becomes obligatory by the law of the country. Hence, to maintain pollution free environment in and around the plant, it will be a wise decision today to take steps for incorporating the recycling units in the main process so as to avoid probable regulatory problems.

In Indian perspective, a proper thought is needed to be given so that at a later stage of plant operation the plant personnel are not forced to hurriedly consider the methods for tackling solid or hazardous waste. Rather it is prudent to convert these wastes into a profit earning products resulting in none or minimum dumping in a landfill.

8.2 Costs Involved in Implementation of the Technologies: -

While communications were made to many foreign technology developers, there was no response from them. It has been found from the previous experiences and the present experience that foreign technology developers respond only to queries on specific projects.

But indirectly, one may rest assured that all the technologies covered in this study are, prima-facie, economically viable since only commercially established processes or processes due for commercialization have been covered in this study and the technologies specified permit, prima-facie, `sustainable development`.

One key factor, which swings economics either way, is the cost of handling and transportation of the wastes for dumping. Some of the costs reported in literature are furnished below.

Transportation of non-hazardous wastes to a landfill may cost $20/T (Hoffman 2000). Handling of hazardous wastes like EAF dust and its transportation to a landfill may cost $150/T (Hoffman 2000).

With opening up of economy in the country, corresponding costs will not be less than the above costs.

8.3 Specific Contribution: -

The economics of beneficiation have been and will continue to be an important determinant as to whether recycling/reuse occurs. The final beneficiation costs will be determined based upon the complexity and costs associated with beneficiation, the amount of material being processed, the consistency and purity of the desired processed material, and the shipping distances involved.

Typically, beneficiation involves sorting, primary crushing, again sorting, and separation, screening, secondary crushing, screening, storage or water treatment, flotation, leaching, drying and storage. Different stages of the beneficiation cycle may be eliminated, depending upon the desired purity and particle size of the finished material and the condition of the starting material. Recoverable material, such as iron, must be separated to hold improve beneficiation economics. If hazardous waste is present, beneficiation may be used to concentrate this material, reducing the amount of material requiring treatment or costly disposal. Keeping the spent refractory clean during removal and storage before beneficiation is important in helping lower beneficiation costs.

In this research work the experiments were carried out to utilise the solid waste generated during pollution control activities in different zones of the plant with an idea to establish a new process or manufacturing a new product using the waste material. Due approvals were taken from the BSP Management for conducting the experiment after discussing with management representatives regarding the experiment, material to be used and necessary units help in conducting the experiment.

After elaborate discussions with the concerned authorities and the experts from RDCIS, Ranchi the trial experiments were conducted, where the representative of the sections also participated for collecting data, its updating, and wherever needed the retrials were conducted.

Experimental work on new recycled products, (made in-house) was conducted along with technologists of concerned units of the plant. Several trials were conducted with change in composition of the recycled products (if necessary) till required methods were established. The results achieved were critically examined with in-house technologists of the plant before giving final recommendations for regular use of new products. Refractory Material Plant was finally chosen to be the nodal agency for preparation of solid waste recycled products.

The aim of these elaborate exercises was to evolve the process methodology, which could be out into actual practice in steel plants. Obviously, this objective encompassed all factors pertaining to the engineering, economics and the ease in adoption. Only the trials, which could satisfy the three 'E' criteria that is engineering, economy and ease, were put forward for the approval of the management for actual adoption. It is a matter of satisfaction that most of the trials being reported here have already been accepted for implementation and the rest are being adopted.

Table 8.1: Cost Involved for Conversion, Cost of Useful Product and Potential Savings.

S No.	Waste	Product Developed	Cost of Conversion in @Rs./T	Cost of New Product in @Rs./T*	Savings in @Rs./T
1.	Under size Coke	a) Coke Breeze b) Nut Coke	500.00 100.00	2600.00 3,400.00	2100.00 3,300.00
2.	Process Waste	Coolant in Converter.	200.00	500.00	300.00
3.	Iron Ore Fines	a) Agglomerate in Sinter making b) Coolant in Converter.	a) 500.00 b) 240.00	500.00 500.00	- 260.00
4.	Blast Furnace Sludge	Sinter Making	200.00	500.00	300.00
5.	ESP Micro Fines	Pellets for Sinter Production	150.00	500,00	350.00
6.	B O F Sludge	Sinter Production	100.00	500.00	400.00
7.	Converter Slag	Ladle cover Compound	5400.00	27,000.00	21,600.00
8.	Plate Mill Sludge	Sinter Making after Adjusting Oil	-	-	600.00
9.	P.C.B.	Heat Energy	500.00	10,000.00	95,000.00
10.	Fire Clay Grog	a) Fire Clay Bricks b) Mortar c) Tap Hole Mass	a) 3850.00 b) 2040.00 c) 7200.00	a) 11,000.00 b) 68,00.00 c) 18,000.00	a) 7,150.00 b) 4,760.00 c) 10,800.00

S No.	Waste	Product Developed	Cost of Conversion in @Rs./T	Cost of New Product in @Rs./T*	Savings in @Rs./T
11.	Magnesia Carbon Grog	a) BOF Vessel Bricks b) Steel Ladle Bricks c) VAD Ladle Bricks d) Skimmer Plate e) Rocking Runner Bricks f) Coating and Ramming Mass	a) 6900.00 b) 5500.00 c) 7500.00 d) 7500.00 e) 7200.00 f) 6000.00	a) 27,900.00 b) 22,000.00 c) 28,000.00 d) 26,000.00 e) 24,000.00 f) 15,000.00	a) 21,000.00 b) 16,500.00 c) 20,500.00 d) 18,500.00 e) 16,800.00 f) 9,000.00
12	High Alumina Brick Grog	a) Steel Ladle Mortar b) B F Trough Mass	a) 2040.00 b) 3000.00	6800.00 15,000.00	a) 4760.00 b) 12,000.00
13.	Chrome Magnesite Brick Grog	Converter Coating Mass	3,000.00	15,000.00	12,000.00
14.	Used Slide Gate Plate	a) Runner Mass b) Steel casing as Scrap	a) 3000.00 b) 200.00	a) 12,500.00 b) 9,000.00	a) 9,500.00 b) 8,800.00
15.	Lime Dust	a) Sinter)Briquettes c) Ladle Cover compound	a) 100.00 b) 400.00 c) 5400.00	a) 2500.00 b) 4800.00 c) 27,000.00	a) 2400.00 b) 4400.00 c) 21,600.00
16.	Fly Ash	a) Fly Ash Lime Bricks b) Pond Ash Clay Bricks	@Rs.1.50 per brick @Rs.1.25 per brick	@Rs.2.50 per brick(red brick)	@Rs.1.00 per brick @Rs.1.25 per brick

(SOURCE: Cost Control Booklet of Bhilai Steel Plant)

Since the raw materials, manpower and the equipments used were from indigenous sources, no additional cost is involved. Further the benefits are substantial and it is proved that these wastes could be utilized gainfully avoiding the dumping of the material, which was a routine earlier.

However calculations were done to arrive cost involved for conversion, cost of useful product and potential savings for the above-recycled product were shown in Table 8.1.

Enormous saving is expected if entire waste is converted to useful product. With regard to capital cost involved, an on-site waste processing facility may be allowed to be build, owned and operated by a third party, allowing steel makers to conserve capital funds for more priority facilities in production chain and avoiding responsibility of another hot end operation.

Moreover, economics is very much specific to region, location, local conditions, capacity involved, etc. Therefore, tailor-made economic study only will be the effective tool for decision-making.

8.4 Recommendations: -

The study has achieved many aspects at integrated steel plants in management of steel plant solid wastes. Recommendations based on this study are presented as under: -

i. For minimizing the waste generation and maximization of their utilization (or minimization of quantity to be dumped) the suggested measures are furnished in Table- 8.2 for ISPs.

Table - 8.2: Management of Solid By-Products in ISPs

Shop	Name of Solid By-Product	Recommended Maximum Generation of By-Products kg/T of Product	Recommended Management Procedure
CO & BPP	Neutralized acid sludge		• Acid regeneration unit may be provided in all the plants generating acid sludge
BF plant	BF flue dust	13	• Use of prepared burden to the extent of 80-85% • Use of high top pressure • Screening of all raw materials just before charging into the furnaces • BF dust should be fully reused through sinter plant • BF sludge may be reused after discarding finer fractions through hydro cyclone separation
	BF sludge	7	
	BF slag	350	• Coal should be selectively imported, based on the composition of iron ore • Use of prepared burden to the extent of 80-85% • Slag generated to be fully granulated • Efforts should be made to promote cast house slag granulation • BF slag should be used for production of Portland slag cement • Dry slag granulation technology to be incorporated to the extent practicable • BF slag may be mixed with BOF slag for quality road making
BOF shop	BOF dust + sludge		• To plan for lower silica level in hot metal • To arrange screening of flux just before charging into BOF • To be fully reused, because there is no contamination of zinc in the scrap • Point of reuse should be shifted from sinter plant to BOF, in which case BOF dust/sludge to be dewatered and briquetted
	BOF slag	150	• Can be used for manufacture of Portland cement and Portland slag cement • Preparation of mixture along with BF slag for quality road making and as rail ballast
Hot rolling mill	Mill scale	15	• Computerization of reheating furnaces • To be fully reused in sinter plant

Shop	Name of Solid By-Product	Recommended Maximum Generation of By-Products kg/T of Product	Recommended Management Procedure
Hot rolling mill	Mill sludge		• To be reused in sinter plant after drying and removal of oil
Captive power plant	Fly ash	250	• Maximum use of low ash non-coking coal • Increased in-house consumption • Separate handling of fly ash and bottom ash • Provision of dry fly ash collection system • 100% reuse in manufacturing a variety of products viz. ash-bricks etc.

ii. Thrust may be given for value-added utilization of steelmaking slag in Portland cement manufacturing, its use as railway ballast, in soil conditioning and in preparation of quality road using suitable mixture with BF slag.

iii. More cost-effective management by adopting the technology of cold briquetting and recycling the briquettes directly into BOF.

iv. For utilization of fly ash at steel plants, attention may be paid particularly to the following uses: -

a) As a raw material for the manufacture of Portland cement

b) As a partial replacement of the cement in cement mix

c) In manufacture of bricks

d) In road construction

e) In developing new products like ceramic floor and wall tiles, synthetic granite tiles, wear-resistant ceramic products and wood substitute.

v. Greater attention is necessary to segregate spent refractory at the source of generation. It is advisable to use them for less critical applications after necessary conditioning and/or use them as raw material for the manufacture of new bricks/mortars.

vi. Further researches should be carried out for the indigenous technology development and its commercialization.

vii. Proper engineering and technological care be taken at the conceptualization and installation stages of a new plant so as to cause minimum waste generation at source.

8.5 Future Scope of Work: -

It is worthwhile to identify other areas of plant where more research work can be undertaken. The involvement of Management is essential as such work may entail involvement of large number of plant personnel and the inputs of financial & material help from various sections.

Areas where research work may be done in future are as follows: -

a) BOF Area: - For cold briquetting of BOF sludge to be re-used as oxide briquette during furnace operation. M/s National Heavy Recovery System Inc.

and their consortium of steel makers have developed this. It will be worthwhile to develop the process indigenously in consultation with them and shop management.

b) Oily Mill Scale Injection in Blast Furnace: - Normally less than 15% oily mill scale is used in sinter making, but it is often found that oil content goes up and these oil rich mill scale may be experimented to be used in Blast Furnace where oil is a reductant and iron from mill scale is an input to kiln oil. British Steel, UK, has developed the method for this process but the Indian companies have not been able to do so.

c) Fly Ash: - It is envisaged to do work in this area as about 90 MT/year fly ash gets generated and mostly dumped. Few experimental jobs in fly ash are anticipated, though some pioneering work on fly ash, re-use and management has been done by National Labs and other Research Centers. The idea is to do more research on product making and encouraging entrepreneurs to buy fly ash from plant for producing the value added products. Certain jobs which are earmarked for future studies are:-

   i) Ceramic floor and wall tiles manufacturing using fly ash

   ii) Roof sheets using fly ash instead of asbestos, which is carcinogenic in nature

   iii) Partial replacement of certain amount of cement.

Conversion of waste to wealth is one of the major thrust areas in achieving sustainable development. Implementation of clean technology in reduction or generation of wastes, effective recycling and gainful utilization of one's waste as input to the other industry will strengthen the supportive and assimilative capacity of the region. Continual innovation towards full utilization of resources and residues will progressively improve the bottom line and protect the environment.

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APPENDIX I

A. List of Papers Published/Under Process of Publication

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APPENDIX II

Brief Biography of Candidate

Raj kumar Agrawal

Raj kumar Agrawal passed H.S.S.C. Examination securing 12th position in M.P.Board and earned B.E. (Electrical) with Honours from Pandit Ravishankar University Raipur M.P. in 1971. Thereafter he joined Bhilai Steel Plant SAIL in the year 1972 and was posted in Rail and Structural Mill as Electrical Maintenance Engineer. Soon after on promotion he was transferred to BSP Branch Office Mumbai as Resident Engineer (Inspection). In the year 1985 he was called back to join as Manager Electrical Maintenance in senior position to Converter and Continuous casting Shop of steel making division.

As a maintenance Engineer, working of slab casters, bloom caster and overhead cranes were established and availability of equipments was improved by him. Standard maintenance practice was developed and maintenance guide was published for in-house staff. Electrical energy conservation projects were given special thrust by him for reducing production cost.

As an Assistant General Manager he was transferred to Refractory Material Plant and was promoted as a Deputy General Manager in the year 1999. During his tenure to Refractory Material Plant he developed Magnesia Carbon Bricks production for the first time in Steel Authority of India Limited which gave record life of converter vessel lining at reduced cost. Subsequently several new products from virgin material and steel plant waste were developed which earned several crores of rupees in profit to company. On further promotion he took over as General Manager Town Administration in the year 2002. Presently he is looking after key area of audit in the company as General Manager Internal Audit.

During his service, at BSP, he was trained in USSR steel plants and British Steel in operation management. Extensive foreign visits were undertaken by him to Spain, Canada, W.Germany, Switzerland and attended many technical conferences and published tutorial papers in Magnesia Carbon Bricks and steel plant waste management. About 20 papers in National and International Conference and journals were published to his credit.

Recipient of prestigious Nehru Award candidate takes keen interest in Research work on reusable products of steel plant wastes. He is a Chairman of Indian Ceramic Society, Bhilai Chapter in addition to fellow member of Indian Institute of Metals, Indian Institute of Engineers, Indian Institute of Refractory Engineers and Bhilai Management Association.

Presently he is pursuing PhD. from Birla Institute of Tech and Science Pilani.

APPENDIX III

Brief Biography of Supervisor

Professor Piyush Kant Pandey

Professor Piyush Kant Pandey has done his BSc. from College of Science, Pt. Ravishanker University and MSc in Chemistry. Subsequently he has done P.G. Diploma in Management from same University. The Ministry of Human Resources Department Govt. of India selected him as a Scientific Exchange Fellow. Under which he underwent PG Research fellowship in Environment Science from Jan Evenglista Universita from Usti Czeh. He was awarded Doctorate in Chemistry from Pt. Ravishankar Shukla University, Raipur. His research work relates to "Analytical studies on Environmental Depositions." This work spans the status of environment in two continents i.e. Europe and Asia wherein the levels of the polycyclic aromatic hydrocarbons and their atmospheric chemistry was studied in detail.

He has worked in various positions in India and abroad in the field of teaching and research. He was a Lecturer from September-1987 to October-1998 in Bhilai Institute of Technology, Durg. Then he took up a job as Scientist-C at Regional Hygiene Station, Usti. N.L.Czech Republic from March-1994 to October-1994. Subsequently he was became Reader in 1998 and a Professor in April-2003. Presently he is working as Professor and Co-coordinator, Centre for Environmental Science and Engineering in Bhilai Institute of Technology, Durg (Chhattisgarh).

He has published 10 papers in International Journals and 18 papers in Indian Journals to his credit and a large number of papers are under the process of publication. He has guided many Doctoral and Post Graduate candidates. Four scholars have been awarded Ph.D. Degree in Engineering and Applied Chemistry under his guidance from Pt. Ravishankar Shukla University Raipur. One candidate has submitted his draft thesis to the Birla Institute of Technology and Sciences Pilani. Presently about 6 candidates are working for Ph.D. in Engineering faculty under his guidance. He has also guided 8 PG Diploma Theses in Industrial Safety Engineering and two M. V. Sc. Projects in the topics of Environmental Health Effects of Toxins on Cattle's awarded by the Agricultural University, Raipur.

He has visited USA, Germany, and the Czech Republic for presenting papers and higher studies. He is a Fellow of International Congress on Chemistry and Environment, Indian Institution of Environmental Engineers, Member American Society for Advancement of Science.

He is an Expert Advisory Member to the Department of Science and Technology, Govt. of India, on Development of Technology Systems for Water Purification and Biodegradable Polymers.