1.1 Global metal production scenario

There are nearly 80 metals in the periodic table, and all these are produced in different quantity as required by the mankind. Table 1.1 shows the world production of some metals in 2015 to give an impression of their relative magnitude. It could be noted that iron and steel production is in much larger quantum (~1600 million tons/annum) than nonferrous metals which all put together do not exceed ~95 million tons/annum. The order of metal production magnitude in India has a similar pattern (USGS, 2015; WSO, 2015).

Table 1. 1 Production of some primary metals in the world and India during 2015

Metals	Production in 2015 (million ton)			
	World	**India**	**World**	**India**
	Ferrous		Non ferrous	
Steel	1600	90	-	-
Aluminium	-	-	58.3	2.35
Copper	-	-	18.7	0.45
Zinc	-	-	13.4	0.83
Lead	-	-	4.7	0.13
Tin	-	-	0.3	-
Total	1600	90	95.4	3.76

India is the 3rd largest global steel producer (90 million ton in 2015). These steel plants are the primary source for generation of solid waste materials like slags from blast furnace and LD plant, fly ash/ bottom ash from the power plant, iron ore slime from ore washing plant, coal/coke from coke ovens, etc.

Table 1.2 shows the quantum of solid waste generation in India by taking the different inputs from the literature (CEA, 2015; IMY, 2015; TATA, 2015; VEDANTA, 2015).

Table 1. 2 Generation of major industrial solid waste in India

Solid waste	Generation (Million tons/annum)	Generation (%)	Source
Iron ore tailings and slime	125	43	Integrated Steel plant
Coal combustion residues (FA/BA)*	120	41	Integrated Steel plant, Nonferrous plant, Power plant
Blast furnace slag	11	4	Integrated Steel plant
Waste gypsum	6	2	Cement plant
Red mud	5.5	2	Nonferrous plant
Copper tailing	4	1.5	Nonferrous plant
Lime sludge	4	1.5	Pulp and paper mill
Zinc tailing	4	1.5	Nonferrous plant
Rest	10	3.5	Different plants
*FA- Fly ash; BA-Bottom ash			

From the Table 1.2, it is evidenced that significant amount (>80%) of total solid waste generation in India comes in the form of iron ore tailing and slime and coal combustion residues. The major portion of these waste is being generated from Integrated Steel Plants (ISP).

1.2 Metal production techniques and routes

There are three technologies widely used for the primary metal production worldwide: pyrometallurgy, hydrometallurgy, and electrometallurgy. Among these three routes, pyrometallurgy route produces bulk of the total metal production (~95%) as shown in Table 1.3 (HINDALCO, 2015; TATA, 2015; VEDANTA, 2015). Pyrometallurgical route is preferred over all other routes due to its economics. However, this route of metal production generates appreciable amounts of solid waste causing disposal problems.

Table 1. 3 Different routes of metal production and their quantity share

Routes	Total Production (million tons)	% Share
Pyrometallurgy	1650	~95
Hydrometallurgy	58	~4
Electrometallurgy	14	~1

1.3 Pyro-metallurgical method for metal production

Pyrometallurgy is a thermal technique of metal extraction. It consists of the thermal treatment of minerals, ores and concentrates to bring about physical and chemical transformations in the materials to enable recovery of valuable metals. It involves the following processes:

a) Ore preparation: It includes sizing of ore, roasting and agglomeration processes. The run of mines (ROM) ore is not suitable as direct feed for extraction of metals in reduction/ smelting units. Therefore, suitable size reduction of ore is done by crushing and grinding. In some cases, the ore is crushed to finer size for removal of undesired minerals. In such cases the beneficiated ore particles may be agglomerated to make the feeds suitable for furnace charging.

b) Reduction/ Smelting: In this process chemical reduction or smelting occurs to produce metal from their respective raw materials.

c) Refining: The metal produced from the reduction/smelting units is not pure and therefore, it is treated by suitable refining methods to render it useful.

d) Casting and finishing: The liquid product after metal refining process is cast as ingot, billet or thin plate for further shaping and treating.

1.4 Major solid waste generation in Integrated Steel Plants and its utilization

Figure 1.1 shows the different solid waste generation, their partial utilization and rest as unutilized waste generated in an integrated steel plant (ISP) (Gupta, 2013). The two major unused solid waste produced in the ISP are identified as iron ore slime from ore processing units and bottom ash from power generation units. The thermal power plant is an integral unit for a steel plant to meet uninterrupted power supply in case of grid failure. These two solid waste are dumped in separate ponds, which cause adverse impacts on economy and environment. The loss of valuable metals in iron ore slime affects metal production economy while dumping expense adds to the product cost. These solid waste dump yards are known for their pollution and health hazard which cannot be ignored nowadays due to the strict legal framework enforced by the government.

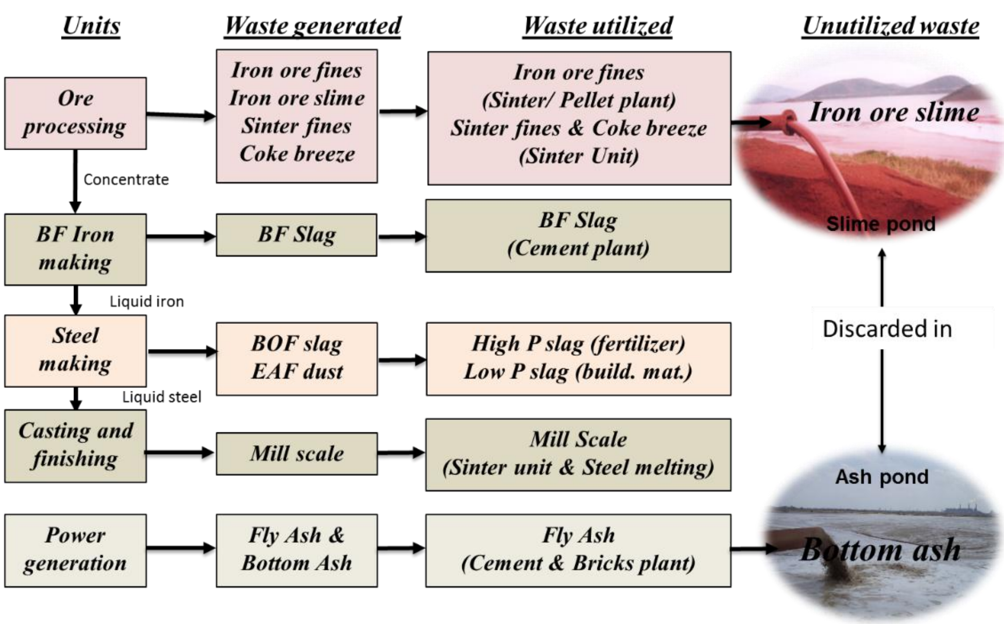

Figure 1. 1 Different solid waste generation and utilization in ISP

For the production of one million tons of crude steel, solid waste generation statistics is listed in the Table 1.4 (KALYANI, 2015). It indicates that the two major solid waste generated are iron ore fines and slime followed by ash as coal combustion residues. These two solid waste quantity is many times more than the production of slags (BF + SMS).

Table 1. 4 Different solid waste generation for the production of one million ton of crude steel

Name of the solid waste	**Generation** (Tons per day)
Iron ore fines and slime	20,000-25,000
Coal combustion residues	6,000-7,000
BF slag	850-950
Steel making slag	350-450
DE system and flue dust	50-65
Mill scale	35-40
Scrap	125-135
Lime and Dolo fines	85-90

1.5 Literature Survey

Extensive literature survey on the subject was carried out for the past 25 years (i.e. ~1990-2015) and has been noted briefly in the following sections.

1.5.1 Iron ore slime

The major un-utilized solid waste from ore processing units is identified as iron ore slime as shown in Figure 1.1.

Iron is the second most common metal in the earth's crust. The principal minerals in iron ores are hematite, magnetite, limonite, and siderite. The major iron ore producing countries in the world are USSR, Brazil, India, United States, and Australia. Run of mines ores are usually not suitable for commercial smelting and hence requires beneficiation. The beneficiation processes are classified as (a) mineralogical beneficiation (for the enrichment of iron content and the decrease of impurities like alumina, silica, phosphate) and (b) sizing of the ore and agglomeration of the ore fines. India is one of the leading producers of iron ores in the world. The total iron ore reserves of India is amounting to 19.3 billion tons (13.1 billion tons hematite and the rest magnetite). Although these ores are rich in iron content but they also contain significant amounts of alumina.

The composition of the Indian iron ores is identified by high iron content with the relatively higher amount of alumina as high as 7% (Sengupta and Prasad, 1990). An adverse alumina/ silica ratio (ideally it should be less than 1, with an alumina/iron ratio below 0.05) is detrimental to blast furnace chemistry as well as to sinter plant operations. A significant amount of alumina in iron ore and sinter leads to a highly viscous slag in the blast furnace, resulting in a high coke rate, so washing is a mandatory step for preparing ore for a blast furnace. Washing of iron ore leads to three products. Coarse ore lumps (+10 mm size) which are being directly charged to the blast furnace; classifier fines (- 10 mm + 150 mesh) which are fed to a sintering plant with or without beneficiation (mainly gravity separation); and iron ore slimes (- 150 mesh) which are being presently discarded as waste (Figure 1.2).

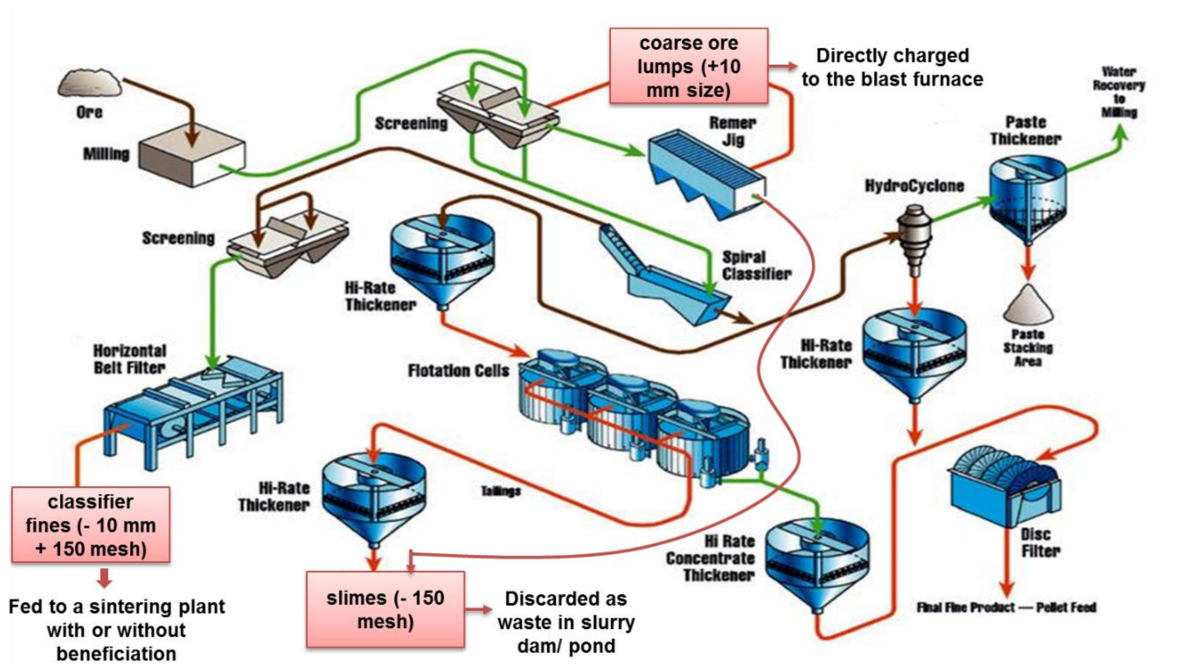

Figure 1. 2 Typical iron ore beneficiation circuit

The losses of iron in slimes (assaying 50-60% Fe) are estimated to be the order of 10-25% by weight of the iron ore mined, which is around 18 million tons (MT) per year in India (Pradip, 1994). This operation, coupled with the increased mechanization of mines, has resulted in the substantial production of inferior quality fines and slimes. Besides the loss of iron, enormous environmental hazards result. Therefore an urgent need to find ways of utilizing these iron ore slimes (Singh and Singh, 1997).

In India, the generation of all non-hazardous inorganic industrial waste is estimated to be ~200 million tons, out of which approximately 80 million tons tailings are from iron, copper and zinc ores processing (Pappu et al., 2007). Indian iron ore is known to be softer in nature with high clay content, that's why typically generates more fines (-10 mm) size during preparation of the ore. These fines being relatively of lower grade cannot be used directly in a blast furnace, hence, rejected into the tailing dam. Accumulation of tailing in ponds, increases day by day and in India roughly 10 million tons (MT) of this material is produced yearly having 48-60% iron, causing environmental and ecological problems (Das et al., 2008).

1.5.2 Bottom ash

The major un-utilized solid waste from thermal power generation units is identified as the bottom ash as shown in Figure 1.1. It is because of coal has the largest share available as fossil fuel reserves in the world and thus they are expected to play a major role in the energy production at present as well as will remain in the future (Kincay and Ozturk, 2010), (Gray et al., 2002). It has one of the most abundant natural resources in some countries like India and it is being used significantly for the energy production. However, its efficient utilization, except fuel for power generation, has not yet being developed. For that reasons, coal is used dominantly for burning in Thermal Power Stations (TPS) worldwide (Murakami et al., 2001).

Indian coal used in power plants has high ash content and of low calorific value (Mathur et al., 2003; Senapati et al., 2013). The average ash content in Indian coal is around 35-38 % while imported coal contains only 10-15 % ash. Presently the rate of annual increase in India, the power generation is ~5%, and at this rate, the annual electricity generation is expected to be 180,000MW by the year 2020, which would be generating 200MT of ash per annum. In view of this terrible future problem expected due to huge ash generation, it is very essential time for ash utilization and increase its acceptability for ash based products among the end users (Sharma et al., 2012).

1.5.2.1 Type of boilers and ash characteristics

The ash properties depend not only on its constituents but it is affected by combustion method which differs with boiler design.

(a) Fluidized Bed Combustion (FBC) Boiler

In this type of boiler, the coal particles are injected in a fluidized state which are heated to the ignition temperature continuously and burn rapidly giving an uniform flame temperature. The fluidized bed combustion (FBC) takes place at about 840°C to 950°C which is much below the ash fusion temperature and therefore melting of ash and other associated problems are avoided.

(b) Pulverized Coal Combustion Boiler

In this type of boiler, the coal (bituminous type) is ground (pulverized) to a very fine size such that less than 2 % coal remains coarse (+300 micro meter) and 70-75% coal is reduced below 75 microns size. It may be noted that too much finer size powder is undesirable due to increase power need for grinding. On the other hand, having larger proportion of coarser coal would not burn completely in the combustion chamber resulting higher unburnt carbon losses. The pulverized coal is blown with part of the combustion air into the combustion chamber through a series of burner nozzles. The secondary and tertiary air may also be added for complete combustion depend on coal type and burner design. The combustion takes place at temperatures 1300-1700°C, depending mostly on coal type. The coal particle residence time in the flame is typically 2 to 5 seconds, and these particles must be small enough for complete combustion.

1.5.2.2 Production of bottom ash quantity and use

The mechanism of coal ash formation under pulverized fuel firing conditions have been described extensively in the literature (Gray et al., 2002; Kincay and Ozturk, 2010). In the burning process of coal, the various mineral matter constituents undergo thermal decomposition, fusion, dissolution, and agglomeration. Some volatile constituents may vaporize, and non-combustible minerals present in it results in the production of coal ash. The finer and lighter particles of coal ash escape with the flue gasses and are extracted in the ESP (electro static precipitators) before reaching the atmosphere. The coal ash collected from the ESP is termed, Fly Ash (FA). The fused/ melted ash accumulates on the boiler walls and steam tubes which solidifies to form clinkers. The clinkers build up and fall to the bottom of boiler/furnace and are cooled in the water sump. The coal ash collected at the bottom of the furnace is called Bottom Ash (BA) (Ghosh, 2010). When pulverized coal is burned in a dry bottom boiler, a major amount of the unburned material or ash is entrained in the flue gas and is captured and recovered as fly ash. The remaining ash in bottom termed as bottom ash, a dark gray, granular, porous, mostly sand-size material that is collected in water-filled hoppers at the bottom of the furnace. In general, coal ash in a power plant consists of 25% bottom ash and 75% fly ash (Chandel et al., 2009) or 20% bottom ash and 80% fly ash (Senapati et al., 2013).

In wet bottom boilers, bottom ash is kept in molten state and collected when it flows into the ash hopper below. The water in the hopper immediately fractures the molten material into crystallized pellets. In this case, the bottom ash is referred to as Boiler Slag (also known as Black Beauty) which is a hard, black, glassy material. The typical Power Generation System picture diagram is showing in Figure 1.3 (Earth and Industry, 2015).

The data for bottom ash generation is not available for Indian plants. But considering 20-25% of 190 MT coal combustion residues, the bottom ash generation by 2020 may increase up to 40-50 MT per annum (CEA, 2011).

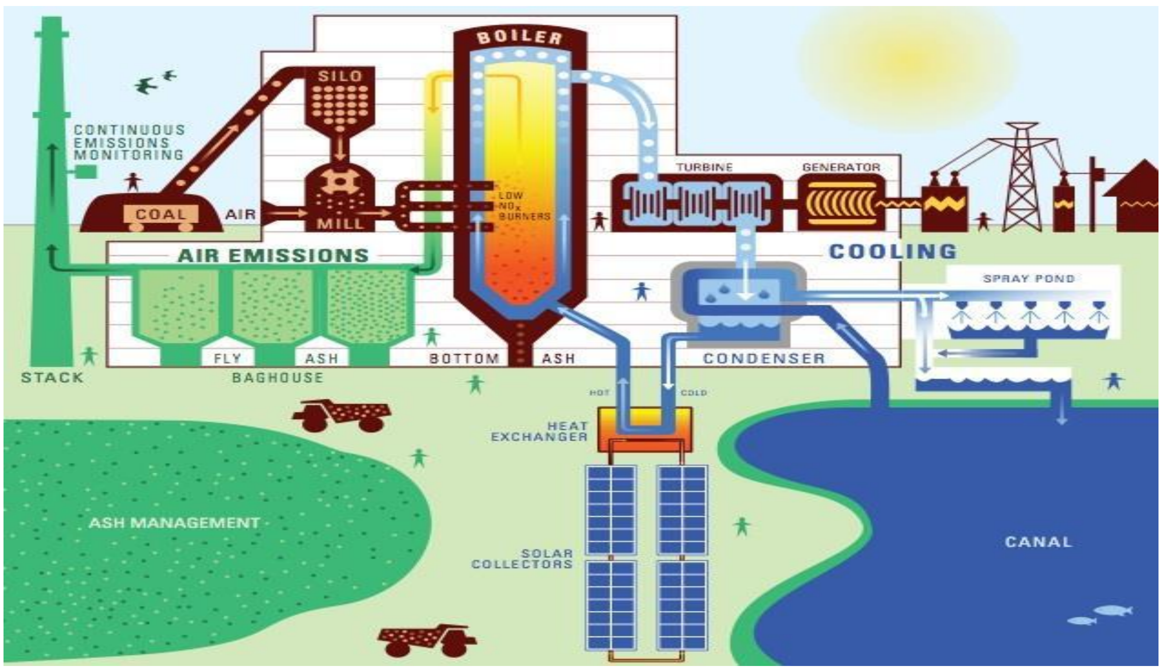

Figure 1. 3 Fly and bottom ash generation process (Earth and Industry, 2015)

1.5.2.3 Disposal and environmental problems

The generated coal ash (fly ash + bottom ash) is deposited either in a dry landfill over a vast area of land or mine backfilling as in slurry form. In India the wet disposal of bottom ash is commonly used in which bottom ash is made as slurry by mixing water, and pumped into storage pond called 'Ash Ponds.' The disposal of bottom ash in ponds poses a risk to human health and the environment. The hazardous constituents present in bottom ash migrate and can contaminate the ground water or surface water, and hence affect living organisms. The high concentrations of sulfates and other ionic species were observed in drinking water of the many water wells which are situated nearby the ash ponds. It is originated from the interaction between circulating ground water and the coal ash slurry (Spadoni et al., 2014).

1.5.3 Properties of Iron ore slime and Bottom ash

1.5.3.1 Microstructure

From the literature it is noted that scanning electron microscopy (SEM) image of iron ore slime shows the presence of metallic as well as gangue phase whereas, in case of bottom ash, it shows irregular rough surface texture along with spherical ball-like particles (Figure 1.4).

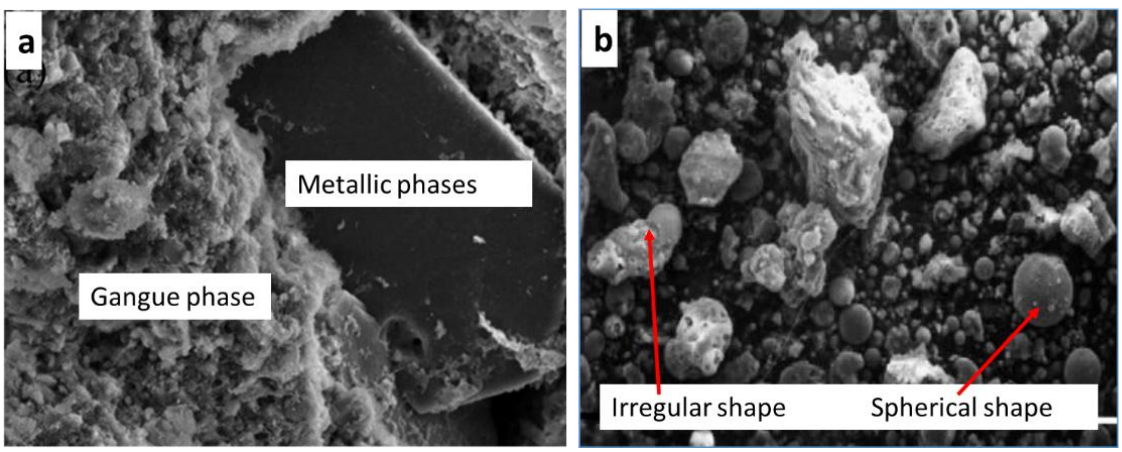

Figure 1. 4 SEM micrograph of (a) iron ore slime and (b) bottom ash

1.5.3.2 Composition and physical properties

Typical composition of iron ore slime and bottom ash from different sources are given in Table 1.5. The composition of iron ore slime will be different at the different collection points.

Table 1. 5 Typical composition of iron ore slime and bottom ash from different plants

Constituents	Iron ore slime			Bottom ash	
	Wt. %			Wt. %	
Fe_2O_3	55.78	75.7	52.5	6.1	5.28
SiO_2	16.58	6.1	7.82	48.81	18.90
Al_2O_3	15.46	9.95	7.4	10.12	4.59
CaO	1.44	-	-	11.81	26.63
MgO	0.13	-	-	5.61	7.77
LOI	9.11	8.7	-	9.75	2.7
Source	(Giri et al., 2011)	(Pradhan et al., 2006)	(Singh and Singh, 1997)	(Uçurum et al., 2011)	(Arro et al., 2004)

If the collection was done from thickeners overflow, then particle size will be finer and heavy metals content such as iron oxides will be less than gangue materials such as silica-alumina. It also depends upon the quality of the raw material being washed whether it was soft or hard in nature otherwise lean grade or reach grade ore (Giri et al., 2011; Pradhan et al., 2006; Singh and Singh, 1997). Table 1.6 shows the different physico-chemical properties of iron ore slime and bottom ash reported in the literature. Form the table it is found that, specific gravity and bulk density of the iron ore slime are more than the bottom ash which is due to the presence of heavy metallic phases. Surface area of the iron ore slime is higher due to the finer structure. Iron ore slime is more acidic in comparison to the bottom ash.

Table 1. 6 Different physicochemical properties of raw materials

Parameters	Iron ore slime			Bottom ash		
Specific gravity	4.6	-	3.9	1.6	2.1	-
Surface area (m^2/kg)	3900	4200	4050	212	-	87
Bulk density (kg/m^3)	2850	3000	2910	691	776	630
pH	5.0-6.0	6.6	5.4-5.9	-	-	8.5
Source	(Giri et al., 2011)	(Pradhan et al., 2006)	(Singh and Singh, 1997)	(Geetha and Ramamurthy, 2010)	(Prakash and Sridharan, 2009)	(Mittal et al., 2006)

1.5.3.3 Particle size analysis

Particle size analysis of iron ore slime and bottom ash reported in the literature is shown in Figure 1.5. The major particle size lies in the range of silt in case of iron ore slime, where as it lies in the range of sand for bottom ash respectively (Aggarwal et al., 2007; Arumugam et al., 2011; Roy et al., 2007; Srivastava et al., 2001). From the figure, it is observed that, iron ore slime has finer in structure comparison to bottom ash.

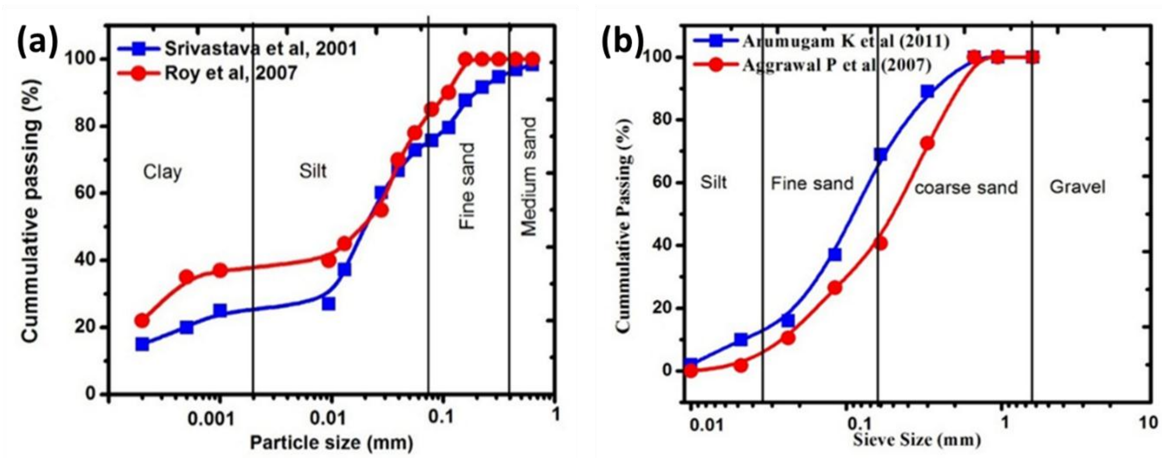

Figure 1. 5 Particle size analysis graph of (a) iron ore slime and (b) bottom ash

1.5.3.4 Geotechnical properties of bottom ash compared to sand

Sand is commonly used as a filter materials in dyke/dams. The bottom ash has the potentiality to substitute sand as filter material. In view of this, a comparision is needed between the two materials which is given below.

The specific gravity of bottom ash is ~2, whereas sands are found to be 2.5-2.6. Bottom ash is well graded whose coefficient of curvature values lies within 1 to 2 and coefficient of uniformity values lies within 3 to 5 whereas sand whose coefficient of curvature lies within 1 to 2 and coefficient of uniformity lies within 1 to 4. Strength parameters of coal ashes and sand subjected for higher compaction energy, and static stress is found to be higher when tested at their minimum and maximum densities. Both these samples possess little cohesion, but the angle of internal friction is substantially high due to interlocking between particles. After crushing due to both static and dynamic compaction, the coefficient of permeability of coal ash decreases due to porous structure than sand samples. At low load intensity crushing coefficient of coal ash is higher than sand but at very high load intensity crushing coefficient of sand is higher than coal ash. The coefficient of permeability of all the virgin samples and layered samples decrease with increase in time due to the settlement of fly ash slurry. After some time, values of coefficient of permeability of all samples are found to be same and do not change with time. So as per permeability criteria, bottom ash can replace sand in filters. Bottom ash meets the filter criteria as per Indian standard of practice partially due to excessive porous structure although crushed in both static and dynamic compaction. The comparison of geotechnical properties for sand and bottom ash are summarized in Table 1.7.

Table 1. 7 Comparison of different geotechnical properties of Bottom ash and Sand

Property	**Bottom ash**	**Sand** (reference material)
Particle size (mm)	0.01-1.00	0.075-4.2
Specific gravity	2	2.5-2.6
Grading Coefficient of curvature (C_c) Coefficient of uniformity (C_u)	C_c-(1-2) C_u-(3-5)	C_c-(1-2) C_u-(1-4)
Compaction property	High Compaction energy at static stress	
Internal friction	More for bottom ash than sand due to interlocking	
Coefficient of permeability	Decreases more after loading due to degradation	
Crushing coefficient	More at lower load due to porous structure	More at higher pressure due to less strength of silica compared to aluminum silicate of bottom ash
Bed Filter material criteria	Fulfills partially	Widely used as a filter material

1.5.4 Studies on the applications of iron ore slime

Efforts have been made in the past decades for possible utilization of iron ore tailings as such in different domains. The comprehensive utilization of tailings has been receiving considerable attention, especially the recovery of iron and other metals from tailings which is a well-recognized process because of substantial economic benefits. Major work was done towards beneficiation of slime for making pellet grade concentrate (~80% of total research done in this area). However, it generates problem of disposal and creates secondary pollution again. However, using tailings to produce building materials may not only realize zero-emission of tailings waste but would also offer a new raw material for building industry, which is a more effective resource of alternative recovery. The little work has been done in the area of producing ceramic tiles, refractory bricks, etc. by firing as well as autoclave route. The work done in the past is given in Table 1.8.

1.5.5 Studies on the applications of bottom ash

The research on utilization of bottom ash was initiated in various sectors like use as an adsorbent for removal of hazardous dyes, toxic gases, etc. The separation of carbon as well as alumina was also tried, but due to secondary waste generation, the process was discouraged. The major work was undertaken for making different products for building construction. Due to the coarseness of the bottom ash, grinding was required which rendered it uneconomical. The preparation of fired aggregate was also tried to assess its feasibility. The different areas of work on bottom ash are highlighted in Table 1.9.

Table 1. 8 Research on utilization of iron ore slime

Area of work	Routes	Authors name	Methods	Major conclusion
Beneficiation of slime	Hydrometallurgical methods	(Pradhan et al., 2006)	Bio beneficiation In-situ leaching	They achieved 51% Fe(T), 5.8% Al_2O_3, from 53% Fe(T), 9.56% Al_2O_3,
		(Mishra et al., 2011)	Solvent extraction	Fe(T) increases from 51.82 to 97.52% and 8.94 to 97.19% with increase in HCl and extractant concentrations from 1.67 to 9.7 M and 0.025 to 0.4 M, respectively.
		(Singh and Singh, 1997)	Flocculation	They achieved 65% Fe(T), 1.6% Al_2O_3, 1.2% SiO_2 from 50.5% Fe(T), 7.2% Al_2O_3, 7.84% SiO_2
	Pyro/ Pyro+ hydrometallurgical methods	(Roy and Das, 2008)	Roasting followed by magnetic separation	They achieved 66.97% Fe(T), 1.7% Al_2O_3, 1.52% Al_2O_3 from 37.86% Fe(T), 14.4% Al_2O_3, and 19.08% SiO_2
		(Prakash et al., 2000)	Roasting followed by magnetic separation Magnetic coating enhances magnetization	They achieved 65.9% Fe(T), 1.56% Al_2O_3, 1.0% Al_2O_3 from 59% Fe(T), 6.5% Al_2O_3, and 3.98% SiO_2
		(Li et al., 2010)	Roasting followed by magnetic separation	They achieved 61.3% Fe(T), from 24.82% Fe(T)
		(Giri et al., 2011)	Roasting followed by magnetic separation Acid leaching for kaolinite separation	They achieved (98.30% as Fe_3O_4) having good yield (~58%)
	Firing route	(Das et al., 2000)	Ceramic tiles with the help of clay and fluxing material	They produced tiles of high strength and hardness compared to conventional tiles, well conformed to EN standard
		(Liu et al., 2010)	Production of lightweight campsite with the help of clay and fly ash and municipal sewage sludge	They produced ceramisite, suitable to serve as the bio medium in the municipal wastewater treatment.
		(Chen et al., 2011)	Construction bricks with the help of clay and fly ash	They produced bricks, well conformed to Chinese Fired Common Bricks Standard (GB/T5101-2003)
	Autoclave	(Zhao et al., 2012)	Autoclave bricks with the help of lime, sand and gypsum, cured at steam for different time	The produced bricks, well conformed by Autoclaved lime-sand bricks standard (GB-11945)

Table 1. 9 Research on utilization of bottom ash

Area of work	Routes	Authors name	Methods/Materials	Major conclusion
Separation of unburnt carbon	Floatation	(Demir et al., 2008)	Column flotation	53% combustible recovery
		(Uçurum et al., 2011)	Forth flotation	40% carbon recovery
Adsorbent/ removal of toxic dye and organic pollutant	Leaching	(Gupta et al., 2004)	Toxic textile dye 'Malachite green' removal ~100%	
		(Mittal et al., 2005)	Hazardous Azo dye 'Amaranth' removal ~100%	
		(Mittal et al., 2006)	Hazardous dye 'Tartrazine' removal 84%	
		(V. Gupta et al., 2006)	Hazardous Azo dye 'Acis orange 7' removal 78%	
		(V. K. Gupta et al., 2006)	Hazardous dye 'Brilliant blue FCF' removal ~100%	
		(Sun et al., 2008)	Organic pollutants removal from waste water of paper mill	
	Firing	(Park et al., 2012)	Bottom ash was fused with alkali at 600°C	CO_2 capture was done by meso-pores silica produced by bottom ash and flux.
Valuable products	Pozzolanic material	(Furlong and Hearne, 1994)	Patent on geopolymer	Possible to make geopolymer by fly ash lime gypsum etc
		(Cheriaf et al., 1999)	Pozzolanic property check of PCC bottom ash using Ca(OH)2	Very slow pozzolanic activity at early stage Adequate grinding improves pozzolanic property
	Cement replacement	(Targan et al., 2002)	Bentonite + Bottom Ash + Portland cement morter made	3-5% Portland cement could be successfully replaced by bottom ash which increases strength in morter with bentonite Beyond 15% replacement compressive strength decreases below required limit
		(Jaturapitakkul and Cheerarot, 2003)	Bottom ash having blain fineness 3787 cm^2/g was taken to replace Portland cement	20% cement could be replace by bottom ash without decreasing concrete properties Beyond 40% replacement, strength decreased below required limit
	Replacement of fine aggregate in concrete	(Cheng, 2012) (Kim et al., 2012) (Kim and Lee, 2013) (Siddique et al., 2012) (Singh and Siddique, 2013)	Bottom ash replaces 0-30% fine aggregates (sand) in concrete. 28 days curing	Bottom ash decreases setting time, compressive strength, bulk density, abrasion resistance, and increases workability, water absorption, in fresh concrete
		(Aggarwal and Siddique, 2014)	Bottom ash replaces fines aggregate upto 60%	Strength of the concrete remains within the limit upto 50% replacement
		(Singh and Siddique, 2014)	Bottom ash replaces fine aggregates upto 100% cured upto 180days	Compressive strength does not affects upto 28days curing. Over 90 days, strength suppressed to the normal concrete
	Firing	(Geetha and Ramamurthy, 2011)	Bottom ash and clay binder (800-1100°C)	Feasibility for making fired aggregates with clay binder was performed
		(Tayler and Diadone, 2011)	Clay bricks with 15% bottom ash	Upto 15% bottom ash increases strength with increasing porosity

1.5.6 Utilization scenario of bottom ash

The ash is generated globally in thermal power plants including India, China, Russia, United States (US), European Union (EU), South Africa and other nations. Recently, governments in many countries have encouraged the use of ash. The US, EU nations and Japan are leading nations with regard to efficient use of ash. The present status in utilization of bottom ash (including boiler slag) in US, EU and India are shown in Figure 1.6. About 50% and 35% of bottom ash was used in civil engineering fields in EU and US, respectively, (Feuerborn and Eck, 2010) while no such application is reported in India. Compared to US, in EU a higher proportion of bottom ash was utilized in cementitious composites, such as mortar, concrete, concrete blocks, and grouting, a similar amount was meanwhile used in geotechnical applications.

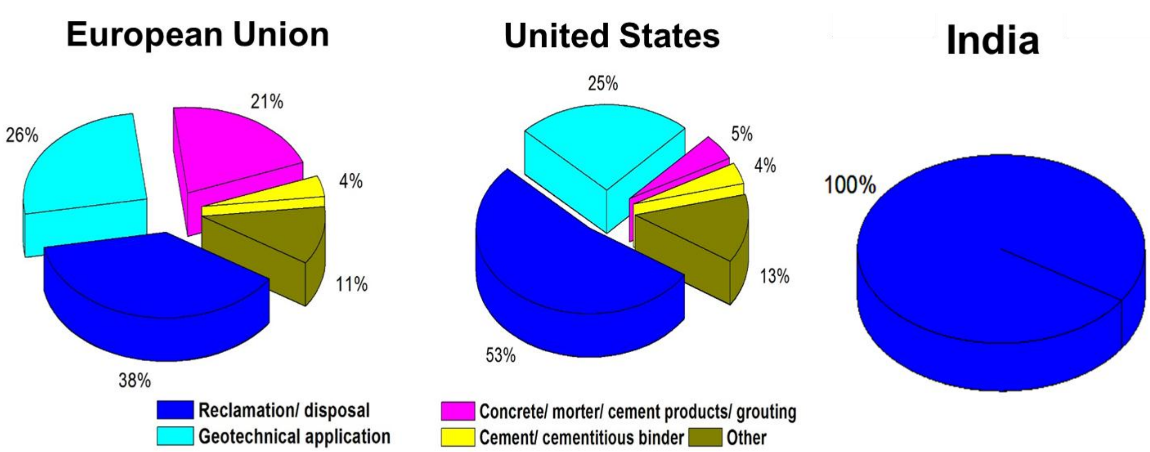

Figure 1. 6 Bottom ash utilization status in the world

1.6 Conclusions from literature survey

Based on the literature survey, following conclusions may be drawn:

(a) Iron ore slime

1. Iron ore slime has very fine structure and high specific gravity due to iron content, and major grain size of slime lies in the range of clay.

2. Work on beneficiation of iron ore slime for making pellet grade concentrate has been effectively done by using different physical and chemical methods of separation.
3. Ceramic tiles, fired lightweight and construction bricks as well as autoclave bricks could be made from iron ore slime.

(b) Bottom ash

4. Bottom ash is coarser in nature but due to porous structure its specific gravity is less.
5. Alumina is present as a combined phase of aluminium silicate.
6. Carbon content in bottom ash could be effectively separated.
7. Bottom ash has been fruitfully employed for the removal of hazardous dye.
8. Bottom ash can replace portland cement upto 20% without hampering mortar property after adequate grinding.
9. Geopolymer sample with bottom ash has been made.
10. Without grinding bottom ash could be utilized as a replacement of fine aggregates in concrete.
11. Feasibility for making lightweight aggregate of bottom ash without grinding was successful with clay binder.
12. Al_2O_3 extraction from fly ash has been attempted by hydro- as well as pyro-metallurgical routes.
13. Lightweight aluminium-fly ash composite has been successfully made.

1.6.1 Detection of unexplored areas for studies

Following are the unexplored area identified from the above literature survey:

1. Numerous studies done on physiochemical and geotechnical properties showed that bottom ash has properties like sand which fulfill partially the filter material criteria due

to the porous structure of pulverized coal combustion (PCC) bottom ash. Feasibility of fluidized bed combustion (FBC) bottom ash as filter material has not yet been attempted.

2. Pulverized coal combustion bottom ash having inert aluminium silicate react with highly alkaline solution for making geopolymer sample. Feasibility for making geopolymer from FBC bottom ash having silica and alumina should be separately examined.
3. Earlier research studies utilized bottom ash as an additive in the clay bricks for strengthening purpose due to its coarser nature. Utilization of bottom ash as major constituents in bricks with suitable binders or/ and additives may ensure bulk utilization of bottom ash, especially for making insulation bricks.
4. Number of processes claim good recovery of carbon, but Al_2O_3 recovery was poor due to the presence of inert aluminium silicate phases and was not so cost effective. Aluminium silicate phase dissociation requires very high temperature source such as plasma arc furnace.
5. At high temperature, respective oxides presents in the bottom ash could be reduced in presence of reductant to their metallic (aluminium) phases, which could further dissolve into iron melt and will form Al-Si-Fe alloy (alsifer alloy).

1.6.2 Objective of this study

In view of arriving at the unexplored area, the following objectives have been targeted for this study.

1. Characterization of the solid waste of integrated steel plant (ISP).

2. Preparation of value added products from ISP solid waste materials for the use of furnace insulation bricks, building bricks, bed filter material and ferro-alloys.
3. Protection of ISP environment by avoiding solid waste dumping, promoting sustainable development.
4. Improved economy of the ISP by waste utilization.

1.7 Plan of work for the present study

Based on the literature survey and considering the above objectives, the present work was undertaken. The solid waste available from Indian steel plant was selected for the study to be relevant nationally. The study was planned as below:

(a) Characterization of the solid waste (i.e. iron ore slime and bottom ash) for its possible utilization.

(b) Bed filter material suitability test with bottom ash.

(c) Development of bricks (building as well as insulation) making process utilizing iron ore slime and bottom ash with using two different methods, i.e. geopolymerization & firing respectively.

(d) Extraction of multi-metallic constituents from iron ore slime and bottom ash using electric arc furnace (EAF) under the environment of nitrogen and hydrogen plasma, respectively.

The detailed study undertaken according to the work plan is given in the following chapters.