Fundamental Research and Utilization of LD Slag - An Overview

Priyank Lohiya
Phd scholar, Mechanical engineering department, UIT-RGPV, Bhopal

Abstract:Reduce, reuse, and recycle are important techniques for waste management. These become significant forimproving environmental and economic condition of industries.Slag generated from basic oxygen converter(LD-slag) is one of the recyclable wastes in integrated steel plants. It is suitable to beused in road making due to its high hardness and cementing property, Due to its highmetallic value (Fe0-18%) and lime content (Ca0-45%), it is possible to use in BF iron makingand steelmaking to replace lime and recover iron. High phosphorous content(1-3%) restricts its use in iron making and steelmaking. The paper gives an overview of different approaches taken worldwide by several investigators for dephosphorisation of LD slag which makes it possible to be reused iniron and steel making.

I. INTRODUCTION

Recently, the industrial sector has grown rapidly, producing alarge amount of by-products, which have harmed the environmentalbalance and have become a major problem for disposal .Slags are undesirable byproductsfloat above the steel which consist of ionic solutions ofmolten metal oxides and fluorides. The slags have positive ornegative effects on the metal production industry. Componentssuch as SiO_2, Al_2O_3 and sulfur are considered slag components thatreduce the quality of the steel. The slag has a special role in steelproduction. The slag minimizes heat loss by staying on the liquidsteel and protects the metal from oxidation, nitrogen and hydrogen absorption. Waste disposal can best be supported by recycling,reuse of wastes produced in other production processes, and theuse of optimization tools and sustainable production theories.

In the recent years, the reuse of waste material has becomevery important because of the reinforcement of newlyenvironmental regulations, in which waste disposal need tobe minimised. Steelmaking operations are specificallyconcerned by this problem because of the origination of ahuge quantity of by-products. These by-products including,LD converter slag, fly ash, sludge and alloyed scarp containsome amount of heavy metals that may cause many environmentalproblems [1]. Therefore, recycling and reuse ofwaste has become a necessary act in these days due toshortage of dumping space for economic and environmentaladvantage. In the era of increasing environmentalawareness, disposal, recycling and reuse of steel slagwastes with less harming the environment has been a primeconcern for the steel industries [2]. LD converter steel slagsare industrial by-products resulting from a steelmakingprocess in oxygen converters (Linz–Donawitz process).Their interesting mechanical properties made it possible touse in civil engineering as natural aggregates replacementin road construction [3–5]. Use of the LD slag will bebeneficial because it helps save natural resources [6] andreduces the accumulation of slag grains in every year.Their negative impact on the environment needs to have efficient management system for the wastes coming fromthe large-scale industrial plants which can be further usedfor landfill or reuse [7].

The average rate of generation of LD slag is approximately 150–180 kg per ton of crude steel in India [8]. Researchersalso found that this rate of production of LD slag sometimes reaches a high of 200 kg per ton of crude steel [9]. In India, over12.15–14.58 metric tons of steelmelting slag has been generated in the financial year 2013, and this rate is still increasing withthe escalation of steel production. However, it depends on the quality of raw materials and yield efficiency of the steelplants. In India, the utilization of LD slag is a meager 25% compared to a high of 70–100% in other countries [10]. Therefore,disposal of this huge mass of waste slag has become a problem due to environmental and space constraints in the steel plants.The utilization of integrated steel plant waste by an economical and environmental friendly technique will decrease a majorportion of the production cost. If these steel plant wastes are reused as a raw material substitute, then it is possible to conservevaluable natural resources like dolomite that are used as fluxing material to reduce the iron in steelmaking and thereby reducethe environmental hazards of mining the ore and reduce slag dumping space [11]. Special processing of slag can produce similaraggregate products originating from the rock and mineral industries. Therefore, much effort has been exerted on utilization of slags as raw materials for infrastructure sector. The LD slag is utilized as a raw material for concrete production, roadconstruction, railway ballast, plastering, and other civil engineering works [12]. Such utilization of the slags will bring in the3R (reduce, reuse, and recycle) concept to provide an effective and sustainable disposal system for this industrial waste.

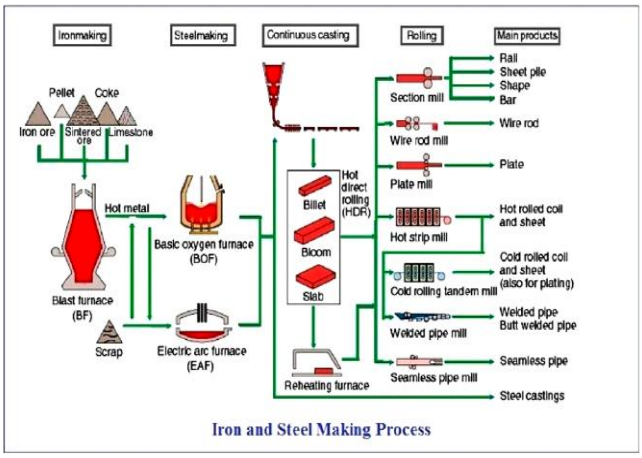

Fig. 1. Flowchart of iron and steel making processes and slag generation in modern steel plant.

Published By:
International Journal of Engineering Research in Current Trends

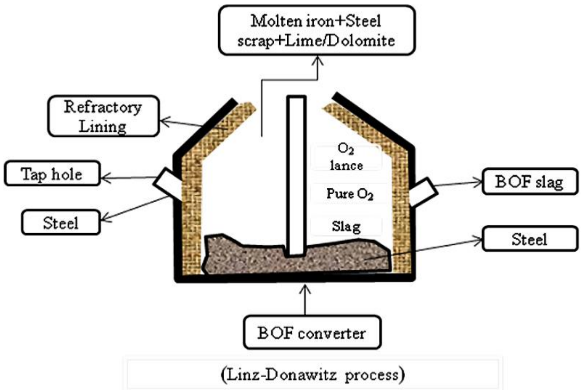

Fig. 2. Schematic representation of the basic oxygen furnace process.

II. PRESENT USES OF LD-SLAG

LD slag bolder is used in road making and floor preparation for its high hardness and cementingproperty. In Durgapur Steel Plant a major portion of the LD-slag is sold in the formof bolders for roadmaking. Similarly all the steel plants in India are selling more than 50%LD slag for road making and ground filling. Tata Steel's LD- slag has been proved to be anexcellent railway ballast material and, as such, is being used by Indian Railways. The limeand magnesia present in LD-slag absorb moisture and CO, from atmosphere to form hydroxidesand carbonates respectively which lead to the volume expansion or swelling resulting incrack formation in roadand building materials.

LD-slag is used as cement making for replacement of clinker. Although LD-slag usage incement making is commercialised in China, Indian cement manufacturers are still unwillingto take advantage of the low cost raw material for cement manufacture'". LD-slag has higherCaO content in comparison to BF-slag, which acts as an activator and gives better strength.However, presence of P,05 results in corrosion of reinforced materials in concrete structure.If only 10% LD-slag is used in cement, the P,O, content will be around 0.3% which is not soharmful in portland slag cement (PSC), because low P,05 in PSC react; with alkali in slagcontributing little strength of cement'". Therefore, more than 10% LD-slag use in PSC is notpossible. Iron oxide present in LD-slag forms a phase, tetra calcium aluminoferrite (C4AF)which has an adverse effect on the quality of cement'". The total iron oxide content shouldnot be 5%.The ferrugeneous portion of LD-slag can be separated by magnetic separation technique. However, for magnetic separation, crushing and grinding are required which are very costly. LD-slag is harder to crush compared to lime stone and therefore, it may be difficult to attainthe desired fines. At Tata Steel the two staged crushing facility at the raw materials beddingyard has been found to be adequate to crush it to the desired size (90% to —3mm) for sinter making.

LD-slag does not demand heat for calcination when used in sintering. It contains a substantialamount of calcium silicates. Pure di-calcium silicates are high melting compounds (2403K)and so are the solid solutions rich in calcium silicates. This temperature is not attained withina sintered bed. However the presence of iron oxide environment around calcium silicatesprevailing in a sinter bed changes the situation. A mixture of 23% di-calcium silicate(2CaOSiO,) and 77% FeO would melt at around 1553K only. Similarly, the lime rich phaseshaving melting ranges over 2273K, when adequately mixed with iron oxides can have liquidustemperatures of the order of 1473K. Micro-structural observation of laboratory sinter andplant sinter were taken up and found that characteristic micro-structural feature of LD-slagcould not be detected in any of these samples. Therefore, it can be said that for all practicalpurposes, LD-slag got completely assimilated during the sintering. Incorporation of LD-slaghas not been found to affect the quality and properties of sinter in terms of size, strength andRBI even up to 40kg per ton of sinter. small-scale industries like foundries andelectric arc furnaces.

III. RECYCLING OF LD-SLAG

LD-slag may be used in refining of steel or in ironmaking due to its high metal value andlime content. It may also be used as a fertilizer due to its high phosphorous content. Presentlyit is neither used in steel melting and iron making nor in fertilizer making. To use thisslag in melting or in iron making, dephosphorisation is required, whereas, to use it in fertilizermaking, high phosphorus contents are required. In this age of competitiveness to minimize production cost, a good step can be taken to reuse LD-slag in steelmaking and ironmakingprocess. The phosphorus content of the blast furnace usually ranges from 0.1 to 0.3 % dependingupon the type of burden used, whereas the bulk of quality steels must have phosphoruslevel below 0.02%. Thus almost 90% phosphorus present in the hot metal is removed as and magnesia which can easily substitute almost equal amount of limestone in the Blastfurnace burden provided phosphorus is removed from the slag. However, the phosphoruscontent of hot metal will increase. if phosphorusis present in the recycled slag. This will require additional consumption of flux at later stage.Therefore, steelmaking slag for recycling must have low (<.0.01%) phosphorus. An alternateapproach for producing low-P(<.0.01%) steelmaking (BOF) slag could be pretreatmentof hot metal before it is sent to converter. The removal of phosphorus from hot metal ismuch easier due to its relatively lower temperatures (1573-1623K) compared to the removalin BOF where high temperatures (1873-1993K) prevail. However, intensive desiliconizationof the hot metal is a prerequisite for an effective dephosphorization. Therefore, removal ofphosphorus from Steelmaking slag is a better option to make it recyclable to Iron makingprocesses. Several attempts for the dephosphorisation have been made to addressthis problem which are Physical Process, Chemical Process, Physico-Chemical Process.

IV. UTILIZATIONS OF LD SLAG

Use for soil stabilization and as a soil conditioner. LD slag is used as a soil additive to improve its physicochemicalproperties and in situ stabilization of Cu and other trace metals in a sandy Cu contaminated soil. It was found that soil pHincreases with a higher incorporation rate of LD slag and allows bean growth, foliar Ca concentration, and further reducedfoliar Cu concentration below its upper critical value, thus avoiding excessive soil EC and Zn deficiency [16]. Experimentshave found that the soil pH increases from 5.3 to 6.4 with the use of 7500 kg of slag per hectare, the second year responsebeing higher, i.e., 41% increase in the soil pH with 3000 kg slag per hectare

[17]. This is in the natural range and shows a positiveeffect on mustard and wheat seedling growth. Thus, this can be used in rural agriculture for better plant growth [18]. TheGovernment of India, Ministry of Finance, has issued a circular (Circular No 553/49/2000-CX New Delhi, October 18, 2000)notifying that LD slag may be used as a soil conditioner after certain processing such as crushing, washing, and addition ofrock phosphates. LD slag contains 29% calcium in the form of CaO. LD slag also contains phosphorous in the form of P_2O_5.Thus, use of LD slag has a limiting to ground limestone and is used regularly to reduce the need of liming on acidic soil [19].Steel slag has also been used as amendment for metal-contaminated soils after proper environmental assessment.

Use as a fertilizer. Attempts have been made in Tata Steel, India, to use LD slag after grinding to 300 mesh as a soilconditioner in paddy fields, tea gardens, etc. [20]. Nippon Kokan Corporation (NKK) Japan has developed a process to produceeco-friendly slow-release potassium silicate fertilizer from the slag that shows less release effect rather than conventionalfertilizers [21]. Many experimental works have been conducted for the production of fertilizers from LD slag, semi-calcineddolomite, and ammonium sulfate, and their agricultural applications for agro-forestry and pasture farming. The potentialeconomic benefits of applying this new fertilizer to the soil were also evaluated [22]. According to soil type and agriculturaluse, by adding a concentration of LD slags between 1.5 and 5.0 tons/ha it is possible to achieve an increase in soil pHand hence to improve the soil quality and productivity. Experimental works were also carried out using pulverized LD slagfor growing vegetables and crops like tomato, potato, onion, spinach, and wheat in acidic soil [23].

Use for road making and floor preparation. With increasing environmental awareness, the waste utilization ofsteel plants has become an attractive alternative to disposal. For the sustainable development of the steel industry, innovativeenvironmental solutions should be applied. Nippon Slag Association in Japan is using LD slag in port and harbor construction[24]. LD slag bolders are used for floor preparation and in road making for its high hardness and cementing properties.Many steel plants are selling more than 50% of LD slag for construction and ground filling. The LD slag has proved to be anexcellent railway ballast material and is being used by Indian Railways. In the Durgapur Steel Plant (Steel Authority of India),the LD slag is sold in the form of boulders for road making. Due to the presence of lime and magnesia, LD slag absorbs moistureand CO_2 from the atmosphere to form hydroxides and carbonates, which leads to volume expansion or swelling in road
or building materials. This problem can be overcome by weathering the slag for aduration of 6 to 9 months for the hydrationof free lime before its use [25].

Use in cement making for replacement of clinker. In India, cement manufacturers are unwilling to take advantageof the LD slag as a low cost raw material for cement manufacture, whereas its use in cement making is commercialized inChina. At Tata Steel, India, a project was initiated in collaboration with Lafarge India for use of LD slag for cement making[20]. In a comparison of LD slag and BF slag, LD slag has higher CaO content and acts as an activator and gives betterstrength, though the presence of P_2O_5 creates corrosion in reinforced concrete structure. If only 10% LD slag is used in cement,then the P_2O_5 content will be around 0.3%, which is not so harmful in Portland slag cement (PSC), because low P_2O_5in PSC reacts with alkali contributing additional strength of cement [26]. Thus, it is not possible to use more than 10% LDslag in PSC. Due to the presence of iron oxide in LD slag, it forms a phase, tetracalcium, aluminoferrite which has an adverseeffect on cement quality. This ferruginous part of LD slag can be separated by magnetic separation [27].

Use in sinter plant after removal of phosphorus. Removal of phosphorus from LD slag is a better option for recyclable iron making processes. Many authors prefer physical processes like magnetic separation, flotation, dual phase separation, etc. for the same. In magnetic separation study, particles with high magnetic susceptibility are separated by a lightmagnetic field, and weaker magnetic particles will be separated by a strong magnetic field. Therefore, heterogeneous magnetic fields of different intensities can separate different particles. However, this is not a very effective way of dephosphorization[28-29]. A numbers of workers have performed chemical treatment (pyrometallurgical) of LD slag [30]. Phosphorus is alsoremoved through evaporation by adding silicon to the Fe–P–C alloy obtained slag with carbon. During reduction of converterslag in an electric furnace, it is possible to form two different phases: one metallic and other nonmetallic [31]. The reductionof phosphorus in molten slag containing 8.3% Al_2O_3 and 3.5% P_2O_5 with basicity of CaO/SiO_2 of 1.1 at 1735 K, 1823 K, and1893 K has been studied. It shows that temperature has an effect on the reduction of phosphate by graphite. The possibility ofreduction of phosphorus by CO gas at 1823 K and the increase in reduction rate with increasing CO gas flow rate has alsobeen investigated. It was concluded that the reaction rate of P_2O_5 was not controlled by diffusion of the P_2 gas phase productbut by the chemical reaction [32].

Use in recovery of different metal values. The metal values recovery from LD slag was carried out by differenttechniques. Out of these techniques, the smelting reduction technique was carried out for valuable metals recovery, i.e., vanadiumand chromium using a Tamman furnace. The recoveries of metal from LD slag are as high as 98% at 16000C in 30 min[38]. This process was carried out by addition of a small quantity of mineral additive to the molten slag followed by crystallizationof the slag. The additive acts as nuclei for crystallization of dicalcium silicate in the slag, and the breaking of slagproduces 65–80% slag and 10–15% chips [39]. It was also reported that the most harmful components in LD slag are phosphorusand sulfur, which are to be removed before use either in the sintering plant or the blast furnace. In the Bhilai SteelPlant, India, LD slag was used in the blast furnace but later discontinued due to the high sulfur and phosphorus content [40].However, the slag is not suitable in cement making due to the presence of a high percentage of iron oxide. The study has beencarried out by magnetic separation techniques, and it was found that the combination of low and high intensity magneticseparation of ground LD slag at 63μm in the wet process is effective.

Use for wastewater treatment. The use of steel slag in industrial wastewater treatment has received intensive attentionin recent years. Due to the porous structure and large surface area of steel slag, it is easy to separate from water due toits high density. A high adsorptioncapacity of steel slag was observed in the treatment of mercury-containing seawater [41].The steel slag has been used as a low cost adsorbent for arsenic in aqueous systems, showing 95–100% removal efficiency atpH 2. The removal mechanism included the co-precipitation of the analyte from the solvent and its adsorption in $CaCO_3$ [42].The removal of copper from wastewater using steel slag was conducted by adsorption and precipitation [43]. Additionally,steel slag can be used as a separate adsorbent to remove aqueous ammonium nitrogen [44], phosphorous [45], and phenol [46].

Use in CO_2 capture and flue gas desulfurization. CO_2 is one of the primary greenhouse gases and a large contributorto climate change. Thus, carbon capture and storage (CCS) research has been the focus of CO_2 reduction technology.With the current CO_2 sequestration routes, mineral CO_2 sequestration is regarded as a potentially important technology due toits benefi ts such as environmental freindliness and permanent trapping of CO_2 in the form of carbonate and without the needfor post-storage surveillance for CO_2 leakage [47]. CO_2 gas is stored by allowing magnesium or calcium oxides in silicate minerals to react with carbon dioxide and form carbonates in mineral carbonation [48]. It is possible to store CO_2 in carbonateform using steel slag slurry under mild conditions of temperature and CO_2 pressure though steel slag contains a largeamount of CaO [49]. The method of flue gas desulfurisation includes wet, dry, and semidry processes, among which the wetlimestone/lime method is most widely used. It was also concluded that aglomeration gas desulfurization with steel slag wasfeasible [50]. The experiment was carried out on wet flue gas desulfurization with scrap slag powder residue. It was inferredthat a more than 60% wet desulfurization rate could be achieved with a reasonable design and suitable operation by usingsteel slag. However, this technology is still limited to the laboratory research stage [51]. From this study, it can be confirmedthat LD slag may be used in different fields due to its various properties.

Important Properties, Uses, Advantages, and Disadvantages of LD Slag

Properties	Uses	Advantages	Disadvantages
Resistance to heavy load, durability	Concrete, asphalt, ballast, road base	Greater hardness, better adhesion, greater stability and reduced wear	Greater weight compared to natural rock
Free drainage, resistance to skidding, inertia, hydraulic property	Ballast, road base, terrain preparation, base course materials	Greater hardness, better Adhesion	Impact on logistics and transport costs
Basicity/CaO content	Cement, agricultural use	Replacing the use of clinker, reducing energy consumption and CO2 emissions	Emissions of airborne pollution in the form of dust, gases, noise, and vibration when operating machinery
Soluble P2O5	Fertilisers/soil conditioner, agricultural use	Amending acid soil and improving plant growth	Possible leaching of heavy metals, potential risk to biosphere

V. CONCLUSIONS.

LD slag is one of the important waste materials generated in steel plants. Besides its use as road making and cement producing, it can very well replace lime addition to the steelmaking route due to its high lime content. However, the presence of phosphorous in it is quite high which restricts its utilization in iron and steelmaking. The amount of phosphorous can, however, be reduced by physical and chemical means.

New technologiesand/or the improvement of existing technologies have been investigated and developed in order to achieve the ambitioustarget of “zero-waste” in the incoming years. The effective utilization of LD slags turns into a high-value added product andallows improving the steel plant competitiveness. Due to its high lime content, LD slag can replace lime addition in steelmaking. It can also be used for road makingand floor preparation, cement making for replacement of clinker, and recovery of metal values. The phosphorus-enriched slagcan also be used as a fertilizer for agricultural purposes and as a soil conditioner for acidity correction of soil. The presenceof endemic phosphorus in LD slag is sometimes high, which restricts its reutilization in iron production and steelmaking. Theamount of phosphorus can be reduced by physical, chemical, and biological means. As phosphorus is intimately associatedwith other elements in slag, bioleaching may be an ideal approach for its removal from the LD slag. Also it is possible to useLD slag for recovery of metal values, CO2 capture and flue gas desulfurization and wastewater treatment through LD slag byapplying alternative techniques. However, dephosphorization consumes fluxes and produces a high phosphorus slag, whichagain needs to be disposed of. Therefore, reuse and recycling of LD slag after removal of phosphorus seems to be a betterapproach. This will not only solve the present-day problem of LD slag but will also lead to the achievement of zero wastestatus and sustainable utilization of byproducts of the steel industry.

A detailed study on steel manufacturing with waste management of LD slag reveals that it can be cost effective if handled properly. For reuse of LD slag, after tapping of heat, the slag can be treated under a slow cooling process. The three phases (dicalcium silicate, dicalcium ferrite, and wustite) can be separated. After separation, the iron-rich portion (wustite) can be recycled for iron manufacture or steelmaking, and the lime-rich portion (dicalcium ferrite) can be converted to Mg–

Mn-wustite by adding a mixture of metallic powder and coke breeze. If the P content is within tolerable limits in dicalcium ferrite, it can be used directly in iron manufacture or steelmaking. The P-rich portion (dicalcium silicate) can be used for fertilizer making. On the other hand, LD slag can be used for land filling after checking its long-term leaching properties.

REFERENCES

1. Aarabi-Karasgania M, Rashchi F, Mostoufi N, Vahidi E (2010)Leaching of vanadium from LD converter slag using sulfuricacid. Hydrometallurgy 102:14–21
2. Singh R, Gorai AK, Segaran RG (2013) Characterisation of LD slag of Bokaro Steel Plant and its feasibility study of manufacturing commercial fly ash-LD slag bricks. Environ TechnolManag 16(1):129–145

3. Xue Y, Wu S, Hou H, Zha J (2006) Experimental investigation of basic oxygen furnace slag used as aggregate in asphalt mixture. J Hazard Mater 138:261–268
4. Wu S, Xue Y, Ye Q, Chen Y (2007) Utilisation of steel slag as aggregates for stone mastic asphalt (SMA) mixtures. Build Environ 42:2580–2585
5. Shen DH, Wu CM, Du JC (2009) Laboratory investigation of basic oxygen furnace slag for substitution of aggregate in porous asphalt mixture. Construct Build Mater 23:453–461
6. Motz H, Geiseler J (2001) Products of steel slags an opportunity to save natural resources. Waste Manag 21:285–293
7. van der Sloot HA (1996) Developments in evaluating environmental impact from utilization of bulk inert wastes using laboratory leaching tests and field verification. Waste Manag 16:65–81
8. U. S. Yadav, B. K. Das, A. Kumar, and H. S. Sandhu, "Solid waste recycling through sinter status at Tata Steel," Proc Int. Environment and Waste Management., NML, Jamshedpur, India (2002), pp. 81–94.
9. T. Umadevi, S. P. Rao, Pankaj. Roy, et al., "Infl uence of LD slag on iron ore sinter properties and productivity," 6th Int. Seminar on Mineral Processing Technology, NML Jamshedpur, 747–757 (2010).
10. J. Pal, P. N. Chaudhary, and M. C. Goswami, "Utilisation of LD slag – An overview," J. Met. Mater. Sci., 45, No. 2, 61–72 (2003).
11. H. Kolb and W. Leipold, "Slag for the building industry," Redex Rundschau, No. 1–2, 261-9 (1993).
12. H, Schoenberger, "Final draft: best available techniques reference document on the production of iron and steel,"Publications of EC: European Commission, Joint Research Centre, IPTS, European IPPC Bureau (2001).
16. O. Negim, M. Mench, C. Bes, et al.,"In situ stabilisation of trace metals in a copper-contaminated soil using P-spikedLinz–Donawitz slag," Environ. Sci. Pollut. R., 19, 847–857 (2012).
17. M. Pinto, M. Rodrigvez, and G. Besga, "Effects of Linz–Donawitz (LD) slag as soil properties and pasture productionin the Basque country (Northern Spain)," New Zealand J. Agri. Res., 38, 143–155 (1995).
17. N. Pradhan, R. N. Kar, L. B. Sukla, et al., "Use of steel plant waste (LD Slag) as soil conditioner," Proc. Int. Seminaron Downsizing Technology for Rural Development (2003), pp. 224–229.
18. M. Mench, V. Didier, M. Löffl er, et al., "A mimicked in-situ remediation study of metal-contaminated soils withemphasis on cadmium and lead," J. Environ. Qual., 23, 58–63 (1994a).
19. D. M. Proctor, E. C. Shay, K. A. Fehling, and B. L. Finley, "Assessment of human health and ecological risks posedby the uses of steel industry slags in the environment," Hum. Ecol. Risk. Assess., 8, 681–711 (2002).
20. G. S. Basu, R. P. Sharma, and A. S. Dhilon, "Solid waste management in steel plants challenges and opportunities,"Tata Search., 39–42 (2002).
21. "Promoting effective utilisation of steel making slag," NKK Monthly, Dec. 25, 2000.
22. F. A. Lopez Gomez, R. Aldecoa, M. A. Fernandez Prieto, et al., "Preparation of NPK fertilisers from ferrous-metallurgy,"Simoes. C. Eur. Commun. [Rep.], 18616, 1–57 (1999).
23. M. Maslehuddin, A. M. Alfarabi, M. Sharif, et al., "Comparison of properties of steel slag and crushed limestoneaggregate concretes," Construct. Build. Mater., 17, No. 2, 105–12 (2003).
24. S. Ozeki, "Properties and usage of steel plant slag. Encosteel: steel for sustainable development," International Ironand Steel, Stockholm, Sweden (1997), pp. 16–17.
25. A. K. Mukherjee and T. K. Chakraborty, "Towards zero waste concept and possibilities in Indian iron and steel industry,"Proc. Int. Environment and Waste Management, NML, Jamshedpur, India (2000), pp. 37–49.
26. R. P. Sharma, G. S. Basu, M. D. Maheshawari, et al., "Utilisation of LD-slag in cementmaking-experience at TataSeel," Proc. ASIA Steel Int. Conf., Jamshedpur, India (2003), pp. 1.i.7.1–1.i.7.7.
27. H. N. Banerjee (ed.), The Technology of Portland Cement and Blended Cement, A.H. Wheeler and Co., Bengalore(1980), pp. 8–15.a.
28. H. Suito, Y. Hayashida, and Y. Takahashi "Minaralogical study of LD converter slags," Tetsu-to-Hagane., 63, No. 8,1252–1259 (1977).
29. B. Das, S. Prakash, P. S. R. Reddy, et al., "Effective utilisation of blast furnace fl ue dust of integrated steel plants,"Eur. J. Miner. Process. Environ. Prot., 2, No. 2, 61–7 (2002b).
30. S. Shiomi, N. Sano, and Y. Matsushita, "Removal of phosphorus in BOF slag," Tetsu-to-Hagane., 63, No. 9, 1520–1528 (1977).
31. M. Dziarmagowski, M. Karboniczek, M. Pyzalsky, and J. Okon, "Reduction of converter slag in electric arc furnace,"Ironmaking and Steelmaking, 19, No. 1, 45–49 (1992).
32. Z. Guo, D. Wang, and Z. Xu, "Fundamental research on phosphorus removal in the smelting reduction process,"Steel Res., 65, No. 2, 47–52 (1994).
33. T. K. Roy, B. B. Sinha, B. Singh, and A. K. Das, "The metallurgy of solid waste recycling in integrated steel plant,"Tata Search., 123–126 (1998).
34. E. Fregeau-Wu, S. Pignolet-Brandom, and I. Iwasaki, "Liberation analysis of slow cooled steel making slags: implicationsfor phosphorus removal," Proc. 1st Int. Conf. on Processing Materials for Properties, sponsored by TMS,MMIJ Punl by Minerals, Metals & Materials Society (TMS) (1993), pp. 153–6.
35. G. H. Thomas, "Investigations on LD slag with particular reference to its use for road construction (pamphlet),"Commission of the European Communities, Boite Postale, Luxembourg, 1003, 75 (1983).
36. N. Pradhan, B. Das, S. Acharya, et al., "Removal of phosphorus from LD slag using a heterotrophic bacterium,"Miner. Metall. Process., 3, No. 21, 149–52 (2005).
37. R. Panda, R. N. Kar, and C. R. Panda, "Dephosphorisation of LD slag by penicillium citrinum," The Ecoscan: Int.Quart. J. Envir. Sci., 3, 247–250 (2013).
38. H. S. Park, B. C Ban, and K. S. Cho, "Smelting reduction for vanadium-recovery from LD-slag (I)," J Korean Inst.Met. Mater., 32, No. 8, 982–8 (1994).
39. F. J. Weiss, M. A. Goksel, J. L. Coburn, G. E. Metius, "The recycling of steel plant waste oxides using the PTC(Pellet Technology Corporation) cold bond carbon bearing pellet technology," Disposal, Recycling and Recovery ofElectric Furnace Exhaust Dust, Iron and Steel Society, AIME, 410, Commonwealth Drive, Warrendale, Pennsylvania15086, USA (1987), pp. 115–20.
40. K. K. Sharma, S. Swaroop, and D. S Thakur, "Recycling of LD slag through sinter route on direct charging in blastfurnace at Bhilai Steel Plant," Proc. National Seminar on Pollution Control in Steel Industries (1993), pp. 72–9.
41. Y. D. Shi, J. Wang, and P. G. Tan, "Study on the Treatment of Mercury in Sea Water with Steel Slag," J. Qingdao.Univ. Technol. (in Chinese), 32, No. 3, 80-3 (2011).
42. C. Oh, S. Rhee, M. Oh, J. Park, "Removal characteristics of As(III) and As(V) from acidic aqueous solution by steelmaking slag," J. Hazard. Mater., 213–214, 147–155 (2012).
43. D. H. Kim, M. C. Shin, H. D. Choi, et al., "Removal mechanisms of copper using steel-making slag: adsorption andprecipitation," Desalination, 223, 283–289 (2008).
44. J. M. Duan, J. M. Lin, H. D. Fang, et al., "Adsorption characteristic of modifi ed steel-making slag for simultaneousremoval of phosphorus and ammonium nitrogen from aqueous solution," Chin. J. Environ. Eng. (in Chinese), 6,No. 1, 201-4 (2012).
45. A. N. Shilton, I. Elmetri, A. Driz, et al., "Phosphorus removal by an 'active' slag fi lter-a decade of full scale experience," Water Res., 40, 113-8 (2006).
46. J. Gao, S. Y. Liu, Y. J. Yang, et al., "Study on adsorptive removal of phenol by steel slag," Chin. J. Environ. Eng.(in Chinese), No. 2(4), 323-6 (2010).
47. Y, Sun, M. S. Yao, J. P. Zhang, and G. Yang, "Indirect CO2 mineral sequestration by steelmaking slag with NH4Clas leaching solution," Chem. Eng. J., 173, 437–445 (2011).
48. S. Eloneva, S. Tei, J. Salminen, et al., "Fixation of CO2 by carbonating calcium derived from blast furnace slag,"Energy, 33, 1461-7 (2008).
49. C. Kunzler, N. Alves, E. Pereira, et al., "CO2 storage with indirect carbonation using industrial waste," EnergyProcedia, 4,1010-7 (2011).
50. J. H. Feng, J. S. Wang, and S. H. Ke, "The basic study on desulfurisation of agglomeration gas by using convertersteel sediment," Hebei Polytech. Univ. (Nat. Sci. Ed.) (in Chinese), No. 1(32), 6–9 (2010).
51. X. L. Ding, Y. C. Guo, S. W. Tang, et al., "Experimental study on wet fl ue gas desulfurisation with scrap slag powder residue," Environ Eng. (in Chinese), No. 3(27), 99–102 (2009).

This Paper is presented in conference
Conference Title : Advances in Mechanical, Industrial and Material Engineering (AMIM-2020)
Organised By : Mechanical Department, Sagar Institute of Research and Technology-Excellence, Bhopal, MP
Date : 28-May-2020