NML'S ACTIVITIES ON NON-FERROUS METALS EXTRACTION

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INTRODUCTION

India is not well endowed with high grade deposits of ores and minerals of nonferrous metals except bauxite ore of aluminium and beach sand containing titanium, zirconium, and rare earth metals. Hence, the National Metallurgical Laboratory, Jamshedpur, which was first laboratory in the country established to cater the need for developing metal extraction processes, had to concentrate on the beneficiation of available lean grade ores of non-ferrous metals and the extraction of valuable metals from the concentrates, industrial wastes and secondary resources. This paper briefly mentions the technologies developed, infrastructure and facilities established and the current activities in the field of non-ferrous metal extraction in the laboratory.

TECHNOLOGIES DEVELOPED

The laboratory developed several processes and conducted pilot plant trials and transferred the know-how of metal extraction processes to several industries. Some of these are mentioned below:

- Electrolytic manganese metal (EMM) was produced in laboratory on a 50Kg/day basis and the know-how was provided for the establishment of a 700 T/year plant for M/s Indian Manganese Metal Co., Rourkela. The pilot plant data were also provided to clients in Yangoon (Myanmar).
- A process for production of chemical manganese dioxide is ready for commercialization.
- The 'ALNAMA Process' of the laboratory enables the extraction of lead from galena concentrates by a pyrometallurgical process and has been well received.
- A process for production of lead from battery scrap is ready for commercialization
- The process for vanadium extraction, as ferro-vanadium from alumina sludge was developed and transferred to four entrepreneurs in the country.
- A process for recovery of vanadium pentoxide from vanadium bearing sludge of aluminium industry has been developed.
- Studies were conducted on extraction of tin from cassiterite ore of Bastar and trials were conducted on a large scale. Extraction of tin from dross and tin sludge has also been conducted on tonnage scale and transferred to the industry.

- A process designed to reduce the loss of copper in the dump slag of Indian Copper Complex, Ghatsila, has been successfully implemented.
- A process technology for production of synthetic cryolite from metallurgical grade fluorspar has been developed in the laboratory.
- A process for production of zinc oxide from zinc ash has been developed and the process technology has been transferred to various industries.
- Technology has also been developed and transferred for the production of electrolytic grade copper powder for powder metallurgical applications.
- A major achievement of the laboratory has been the design, erection, and operation of a 250 T/year plant for the production of magnesium metal. The unit based on the well-known Pidgeon process has been transferred to the private sector and re-established with increased capacity of 600 T/year.
- A process for recovery of nickel from spent catalyst has been developed and ready for commercialization.
- The laboratory worked for many years on the extraction of nickel from the lean ores of the country and the overburden of chromite mining and developed the suitable flow sheets after conducting studies on a pilot scale. Some of the information generated has been used in the construction and operation of the technology demonstration plant for nickel, which has been established at the Regional Research Laboratory, Bhubaneshwar.

INFRASTRUCTURE AND FACILITIES

During the bench scale and pilot scale studies of non-ferrous metal extraction by pyro, hydro and electrometallurgical routes, a number of state-of-art facilities have been created in the laboratory. Some of the facilities are listed below:

- **Characterisation :** Optical microscope, electron microscope, image analyzer, X-ray diffraction, thermal analysis, thermo-gravimetric and a variety of techniques for instrumental chemical analysis such as AAS, UV-Vis spectroscopy, XRF etc.
- **Pyrometallurgical facilities :** Bench scale facilities include tubular, muffle and raising hearth furnaces, fluidized bed reactor. Lintz and Tamman furnaces, induction and electric arc furnaces and a vertical retort furnace. On the larger scale, experiments can be conducted in a 50 kVA, 150 kVA and 500 kVA electric arc furnaces, rotary kiln of 15 kg/hr and 10 T/day and a vertical retort furnace of 100 kg per day capacity.
- **Hydrometallurgical facilities :** Leaching experiments can be conducted either in an acidic or alkaline medium upto 100 kg/day scale under ambient conditions. Pressure leaching on bench or large-scale at higher temperature and pressure can be done in autoclaves of 0.5, 1, 2, 20 and 50 Liter capacity. Beside, a 9-stage CCD unit for continuous leaching and decantation experiments is available.

- **Solvent extraction and recovery of metals by electrowinning :** Two 30-stage mixer-settler units of capacities of 5-8 L/hr and 30 L/hr of aqueous flow can be used for solvent extraction. Electrowinning can be carried out on a scale sufficient to yield about 50 kg of metal per day. Electrodialysis facility is also available.

- **Bio-processing :** Facilities like Laminar Air Flow Chamber, Biological Microscope with image viewing facility (1000X), Bioreactor (2L), Incubator-cum-shakers, B.O.D. Incubator, Room Type Incubator Shaker, Gel Electrophoresis, Steam Sterliser, Sonicator, Refrigerators (Culture Storage), Millipore Ultrapure System Unit, Cooling Centrifuge (20,000 rpm), Ultra-centrifuge (80,000 rpm), etc. are available.

In addition, a number of facilities have been created for mechanical milling, plasma and microwave treatments.

CURRENT ACTIVITIES

1. Processing of High Grade Ores

Electrothermal processing

At NML, considerable experience has been gained in the smelting of magnetite, calcium silicide, different types of ferroalloys, as well as vaccum extraction of magnesium from dolomite at elevated temperatures. These achievements have been resulted from studies conducted in arc furnaces ranging from 50 kVA to 500 kVA pilot plant facilities. Lean manganese raw materials such as leach residue of polymetallic sea nodules have been smelted to attain silico-manganese grade "60% Mn and 20% Si" using the electric arc process. The process was operated at 50 kVA scale has been enhanced to 150 kVA level.

With the rapid growth of the automobile sector in India, there is an increasing demand for magnesium metal. Keeping this and the past experience of the laboratory in extraction of magnesium by the Pidgeon process in view, a new attempt has been made to extract magnesium by an alternate process. Magnesium metal has been produced in a vaccum resistance melting furnace of 200 kVA, at slag temperature of 1650°C. In this process, heat is being supplied to the reactants (calcined dolomite and ferrosilicon) by resistance heating of slag (55% CaO, 24% SiO_2, 15% Al_2O_3 and 6% MgO). Magnesium recovery of 65% and 90% purity level have been achieved, and efforts are under way to optimise the process and enhance recovery.

Plasma smelting for the recovery of aluminium from dross on laboratory scale has been carried out, and this process appears to be economically viable.

Mechanical activation of bauxite

Efforts have been made over the last few years to advance mechano-chemistry/mechanical activation as one of the core research activities at our laboratory for the development of efficient extraction processes. Currently, a research project being pursued in the area is on the mechanical activation of bauxite. The main idea of the project is to improve the Bayer process performance in terms of moderation in operating conditions, minimization of alumina and soda loss and rheological characteristics of red mud to improve its settling behaviour. Since

India is richly endowed with bauxite deposits and major expansion of alumina/aluminium industry is expected in very near future based on the Eastern Ghats bauxite, this project is of national importance. Basic research connected with the project focuses on the interaction of lime with aluminium, iron, titanium and silica bearing minerals during mechanical activation.

2. Processing of Lean and Complex Ores

Polymetallic Sea Nodules Processing

This is one of the major programmes being carried out in the laboratory, funded by Ministry of Earth Sciences (MoES), Govt. of India. Polymetallic sea nodules are considered as one of the important future resources of copper, nickel, cobalt, and manganese. The laboratory has been conducting R & D studies for extraction of these metals following Reduction roasting-Ammonia leaching - Solvent extraction - Electro-winning route. The process has been scaled up to 100 kg/day scale and recoveries of valuable metals were about 90% Cu, 90% Ni and 50% Co.

Based on the results of the several trials, certain areas for further improvement in the process were identified. These are (a) Enhancement of cobalt recovery, (b) Utilisation of leached residue and (c) Processing of large volume of dilute leach liquor. All these aspects were successfully resolved during the work carried out in the 10th Five Year plan under the auspices of MoES. Brief achievements in these activities are:

– Improvement of Cobalt Extraction from Roast Reduced Polymetallic Sea Nodules in Ammoniacal Solution:

Cobalt recovery was improved from 50% to 80% with the help of an additive. This has been validated on pilot scale.

– Utilisation of leach residue :

Electrothermal smelting trials for production of standard grade Fe-Si-Mn from leached sea nodules residue were carried out. Fe-Si-Mn produced at NML was tested at Tata Steel and it was found to be at par with the standard grade Fe-Si-Mn in respect to its deoxidising and alloying properties. This process was also tested on pilot scale.

R&D work to study the adsorption behaviour of leached residue for removal of heavy metals (Cu, Pb, Ni, Cd etc.) from effluents and arsenic removal from ground water were also carried out to explore the another possible utilisation of leach residue. Removal of these elements below the permissible limits could be achieved.

– Processing of dilute leach liquor from sea nodules

Work on treatment of dilute leach liquor by bulk sulfide precipitation (Na_2S) and chloride leaching (HCl and Cl_2) of the precipitate were carried out. The concentration of leach liquor of composition about 2 g/l Cu, 2 g/l Ni and 0.16 g/l Co could be increased to about 16 g/l Cu, 18 g/l Ni and 1.5 g/l Co. Thus the volume of the leach liquor was reduced substantially leading to reduced size of equipment, low capital investment and lower energy consumption.

The process was scaled up to treat 10 kg/day bulk sulfide precipitate. Chloride leaching process with simultaneous Cu electrowinning from the bulk sulfide precipitate was also successfully established. A suitable solvent extraction scheme for metal separation from the chloride leach liquor has also been established.

Extraction of zinc from Ganesh Himal zinc ore

Our laboratory has developed a process on large scale for the extraction of zinc at ambient pressure from zinc sulfide concentrates derived from a complex zinc ore of Nepal. The concentrate is acid leached along with manganese ore in the presence of a catalyst. The salient features of the process are simultaneous winning of the zinc and manganese dioxide by electrolysis, low energy requirement, recovery of elemental sulphur and prevention of hazardous emissions.

Extraction of zinc from ores from Sikkim

Sikkim Mining Corporation has deposits of complex sulfides. The ore is beneficiated to produce concentrates of lead and zinc. However, the products were not meeting the requirements of the smelters. Our laboratory, therefore, took up the task of recovering metal from a concentrate with a typical composition of 37% Zn, 1.0% Cu, 3.0% Pb and 27% S with traces of Cd, Ag besides considerable quantities of iron and silica. Three possible routes involving a) roasting followed by leaching, b) pressure leaching in the presence of an additive and c) direct leaching in the presence of an oxidative agent have been tried. 90% recovery of zinc has been established.

Bioleaching of low grade ores and concentrates

Bioleaching has emerged as one of the most important process to extract valuable metals from low-grade ores, concentrates and wastes. It is considered as an environmental friendly and economical process. The various bacteria available in mine water, old working zone of mines, hot streams, etc. have found applications for the treatment of important ores of non-ferrous metals and wastes for extracting valuable metals such as copper, nickel, cobalt, zinc, gold and few other metals. Our laboratory is currently involved in processing of several resources to recover metals by the bioleaching approach. The specific examples are cited below to highlight the nature of research pursued:

- Bio-dissolution of copper, nickel and cobalt from a copper converter slag and copper dump slag.
- Bio-recovery of valuable metals from Indian Ocean Nodules by *Acidithiobacillus ferrooxidans* in presence of pyrite and sulphur and also by *Bacillus circulans and Aspergillus niger.*
- Selective bio-leaching of nickel and cobalt from a complex sulfide copper concentration with T_f in presence and absence of additives.
- Bio-leaching of low grade uranium ore

Recoveries of 97% copper, 85% nickel and 54% cobalt were achieved in bio-processing of sea nodules. The biorecovery of copper, nickel and cobalt obtained was 99%, 50% and 64%

respectively from copper converter slag. In the bio-processing of copper concentrate of Uranium Corporation of India limited, 80% nickel and 65% cobalt were recovered and a copper concentrate suitable for pyrometallurgical processing was produced.

Recently, the laboratory with its past experience and knowledge base in non-ferrous extractive metallurgy, has explored the field of uranium bio-leaching from low grade ore of Turamdih mines, Jharkhand. Native species of *Acidithiobacillus ferrooxidans* isolated from source mine water has found to deliver nearly 98% uranium bio-recovery on bench scale. Based on shake flask studies, further scale up studies in 80 kg and 2T column (India's first ever) were carried out to obtain 68% uranium recovery under similar conditions using 10-12 mm particles, eliminating the consumption of oxidants and reducing acid consumption substantially when compared to chemical leaching processes. These studies certainly hold the key to the exploitation of low grade uranium mineral resources in future for India's nuclear power programme. The efforts to put into practice the heap leaching for same ore on large tonnage scale and examining the amenability of other low grade Indian deposits are our targets.

Solvent extraction and ion exchange in the processing of low grade resources of non-ferrous metals

In the hydrometallurgical processing of ores, concentrates, secondaries and wastes, the desired metals are leached in suitable lixiviants leaving gangue in the residue. The leach solution is purified before metal separation and recovery. Commercially available organic extractant such as hydroxyoximes, hydroxyquinoline, substituted phosphoric acid, tertiary amines, etc. are used for the recovery of metals from acidic and alkaline solutions containing copper, nickel, cobalt, zinc, chromium, tungsten, etc. At NML, extensive R&D studies have been carried out for the extraction and separation of metals from leach solutions of different materials using different extractants. Different processes are mentioned below:

- Separation of cobalt and zinc from sulfate and chloride solutions with di-2 ethylhexyl phosphoric acid and tertiary amine respectively.
- Selective extraction of nickel leaving cobalt from the ammonium carbonate solution of lateritic nickel ore with LIX84.
- Extraction and separation of copper and zinc from the sulfate leach solution of brass ash with LIX84.
- Separation of copper, nickel and cobalt from ammoniacal leach liquor of sea nodules by LIX84.
- Recovery of tungsten from alkaline solution of wolframite concentrate with tertiary amine.
- Recovery of chromium from the sulfate solution with Cyanex 272.
- Recovery of gallium from the solution of alumina plant with Kelex 100
- Recovery of metals and metalloids (Cu, Ni, Se, Te, Ag & Au) from the leach liquor of copper electrorefining anode slime using binary extractant

The above processes have been developed initially on bench scale in the shake-out flask. Some of the processes have been developed on bench scale and then pilot plant scale in closed loop cycle operation recycling different streams in the system and metal produced by electrolysis. The design data required for further scale-up have been also collected.

3. Waste processing and effluent treatment

A number of processes have been developed for the recovery of non-ferrous metals from waste products and effluents and also to recycle the metals. Some of the interesting studies conducted in the last few years are detailed below.

Recovery of zinc from wastes

Zinc dross a product of the galvanizing industry consists of intermetallic compounds of iron and zinc and some entrapped zinc metal. Its analysis shows a concentration of 93-98% Zn and 2-5% Fe with traces of Pb and Sn. Increased demand in the country for galvanized steel sheet has resulted in the generation of significant quantities of this material. The laboratory is currently developing viable methods for the extraction of the zinc from the dross.

In textile industries, waste effluents and sludge containing zinc are generated during the manufacture of rayon yarn from the viscose in the spinning bath. The effluent containing 30-100 ppm zinc is neutralised and precipitated as sludge, which contains 5.0-18.0% Zn and other impurities. The quantity of the sludge generation is 150-400 kg/day depending upon the capacity of the plant. The laboratory has developed a process to exploit such waste material following hydrometallurgical route. A process following leaching of sludge and solvent extraction has been developed for the recovery of zinc on bench scale. The zinc from the leach liquor is directly recovered using the solvent extraction process. The process produces the zinc containing solution suitable for the recycle in the spinning bath of the rayon plant.

Utilization of red mud

Utilization of red mud, bauxite tailings produced during the Bayer process of alumina production, has been investigated for different metallurgical and non-metallurgical applications. The research being persued includes: (a) Building tile from red mud and flue dust/fly ash, (b) Smelting of red mud with scrap for the recovery of iron as cast iron and titanium as synthetic rutile, and (c) Chemical beneficiation of red mud using a process based on the roasting of red mud-soda-carbon mixture without fusion.

Production of nickel and copper powders from the copper bleed solution

Copper bleed solution is generated during the electrorefining of the impure copper metal obtained in the smelting. In the electrorefining plant, the nickel present in the copper anode dissolves and remains in the solution. The copper electrolyte solution is recycled which causes built up of nickel in the solution. The recycling is carried out till the level of nickel concentration increases to 20 g/L. Similar bleed electrolyte is generated during the close-loop solvent extraction-electrowinning process of the polymetallic sea nodule leach solution. A part of the electrolyte is discarded as bleed electrolyte and processed to recover metal values. A process has been developed at NML to produce value added products such as nickel and copper powders. In this process, the bleed is partially de-copperised and then crystallized to form mixed nickel-copper salt. The salt is then dissolved and copper and nickel powders produced under controlled operating condition with hydrogen pressure.

Value added products from the leach liquor generated during refining of low grade molybdenite concentrate

The molybdenite concentrate produced at Uranium Corporation of India Limited, Jaduguda was only of about 69% purity containing impurities especially SiO_2 (9.6%), Al_2O_3 (1.6%), Fe (2.9%), MgO (1.0%), Ni (0.36%), Cu (0.27%) and graphite (1.2%). As high grade molybdenite (MoS_2) is the starting material for all molybdenum bearing products, the low-grade concentrate is enriched to over 97% purity by hydrometallurgical techniques using hydrofluoric acid and hydrochloric acid. During processing, the said impurities are reporting to the leach liquor in the form of valuables such as 0.32 M hydrofluosilisic acid, 0.06 M hydroflouauminic acid, 0.01 M hydroflouferric acid, copper and nickel. It was considered necessary to recover fluoride chemicals (sodium silicofluoride and cryolite), copper, and nickel from the leach liquor to make the total process economical and ecofriendly.

Experiments were carried out to achieve precipitation of both the fluoride compounds. At a pH value of 1.35 a complete precipitation of sodium silicofluoride takes place, whereas above this pH i.e. at 2.2, cryolite is precipitated along with sodium silicofluoride. For the recovery of two fluorides, conditions were optimised. The recovered materials find critical applications in aluminium and beryllium industries. Further, from the synthetic mix solutions, copper and nickel were also recovered by solvent extraction under suitable conditions.

Recovery of nickel and alumina from nickel spent catalyst

As an industrial waste, nickel spent catalysts are not considered hazardous and hence are not listed under red list of Basel convention. Consequently, it can be imported to meet the requirement for reprocessing along with the indigenously generated catalyst. The main interest has been to develop a cost-effective process for the recovery of nickel from an indigenous/imported spent catalyst of fertilizer industries, which can operate in medium and small scale sector. Our laboratory has developed a very simple and novel process for recovery of nickel catalyst from a fertilizer plant. By this method, almost 99.9% of nickel recovery from spent catalyst has been achieved under moderate conditions (70°C & 3% acid) in presence of a very little quantity of additive without which it is found to be very poor recovery (6%). The process also recovers high grade alumina as a by-product.

Metal is recovered as pure nickel sulfate and nickel oxide. The process has been optimised and material balance for the spent catalyst to produce various products of nickel has also been made. Role of additive in the process of faster and higher metal recovery is identified. The process was tested on 1 kg scale with overall nickel recovery of 96.2%. Advantages of the process are: (i) high nickel recovery; (ii) high pulp density leaching resulting in high productivity; (iii) generation of leach residue as alumina - a high value by-product, and (iv) less energy requirement.

By aluminothermic as well as electrothermic smelting processes, nickel is also recovered as ferronickel of grade 30-80% Ni. The process has selectivity and flexibility to prepare desired grades and purity of ferronickel, which is required for alloying of steel.

Recovery of valuable metals from the tungsten-containing alloy scrap using hybrid hydrometallurgical process

Tungsten is one of the strategic metals used with different alloying elements viz. copper, nickel, iron, cobalt, tungsten carbide etc. for the various applications such as heavy-duty electrical contactors, circuit breakers, relays, switches, armour plates, cutting tools etc. Among the various tungsten scraps generated world over, approximately 24% generated from the products at the end of service life whereas 10% is generated during processing. The heavy electrical components are manufactured by the powder metallurgical route from the tungsten and copper powders. The hard and soft tungsten-copper alloy scraps are generated during the manufacture of the components. Electroleaching process is one of the promising processes for the dissolution of the tungsten-copper wastes. Thereafter, the recovery of copper values (as copper powder/copper salt) and the tungsten (as tungstic acid) from the electro-leach liquor can be done by the solvent extraction and precipitation process, respectively. NML has developed a process for the recovery of tungsten and copper from the alloy scrap following electro-leaching and solvent extraction route.

Bioremediation for treatment of waste streams containing metals including chromium.

The application of biosorption in the purification of waste water offers a high potential for large-scale exploitation. The naturally abundant microbial biomass can be successfully used in selective removal of metal ions from aqueous solutions. A pure culture of saprophytic fungus, *Aspergillus niger* adapted with various concentration of trivalent chromium has been used to study the biosorption of chromium (III) from model tanning solution. A removal of 85% Cr (III) was observed from model tanning solution (100 ppm Cr (III)) by using alkali pre-treated fungal biomass within 50 h at 2.5 pH and 35°C. When alkali pre-treated biomass is used, 52% biosorption of Cr (III) was observed from 2000ppm feed as against 65% biosorption from a dilute feed of 1000 ppm within 24h.

Photocatalytic detoxification of industrial effluents

Photocatalytic removal of cations and anions seems to be a viable green alternative for the treatment of wastewater that may eliminate most of the problems associated with the existing treatment processes. At NML, Photocatalytic removal of cations and anions were studied using commercial as well as synthesized catalyst under both UV and visible light. Degussa P25 and Hombikat 100UV were used as the commercial catalyst. Uniform sized silica and zirconia mixed titania samples were prepared in presence of a surfactants (CETAB) using controlled hydrolysis of corresponding alcooxides. Among the studied materials 10wt% silica mixed titania and 10wt% zirconia mixed titania gave the best results in UV and visible light respectively. Photocatalytic activity towards reduction of lead, cadmium and mercury metals in aqueous solution was evaluated in 100-500 ml capacity reactors. Similarly reductive removal of selenium and nitrates were also studied using different catalysts. In the photoreduction process, organic additives and pH play important role. Sodium formate was found to be the best hole scavenger among all the studied organic chemicals. The complete removal of toxic metal ions like lead, mercury, and cadmium within 60 minutes of reaction were achieved by photocatalytic method with titania based binary oxides in presence of UV/visible light.

4. International collaborative projects

Collaboration with Russia under the Integrated Long Term Plan (ILTP)

Two important projects have been taken up under the ILTP programme of Indo-Russian collaboration. These projects address some of the urgent and relevant issues for India and briefly recounted below.

— *Recovering metal and metalloids from the copper electro-refining anode slime*

Anode slime is the insoluble product deposited at the bottom of the electrowinning tank during electro refining copper. Anode slime from Indian sources contains about 12% Cu, 37% Ni, 11% Se, 3% Te, 1.5% Ag and 0.6% Au. A dilute sulfuric acid leaching process in presence of chloride ion additive for the recovery of the valuable metals has been developed at NML. A maximum of 91% Cu, 80% Ni, 80% Se, 79% Te and 77% Au recovery are achieved. The leach liquor arising from such a process contains about 7.0 g/l Cu, 0.2 g/l Au, 1.0 g/l Ni, 5.0 g/l Se, 2.0 g/l Te and 11.0 g/l Mn. Separation of the metals from the leach liquor involves solvent extraction using binary extractant. Kurnakov Institute of General and Inorganic Chemistry of the Russian Academy of Sciences, Moscow, and the National Metallurgical Laboratory are collaborating to develop the process.

— *Recovery of acid and metal values from spent pickle liquor*

Surface finishing of steel sheets and strips for the removal of iron oxide scale generates huge amount of waste sulfate / chloride pickle liquor. So far in India, very limited attempts have been made to recover both acid and metal values from spent pickle liquor. Therefore an attempt has been made to develop a suitable solvent extraction process to recover both acid and iron values as value added product. Since this is a collaborative work between National Metallurgical Laboratory, Jamshedpur and Kurnakov Institute of General Inorganic Chemistry, Russia, treatment of metal sulfate waste solution has been carried out at NML whereas chloride solution treatment has been taken care by Russians.

Acid extraction from sulfate waste pickle liquor (WPL) was carried out by solvent extraction method using various amine based and solvating solvents such as alamine 336, trialkylphosphine oxide and 2-ethyl-N,N-bis(2-ethylhexyl)-1-hexanamine. The extraction studies were carried out with WPL from steel industry containing 92 g/L sulfuric acid. Various parameters were optimized to establish an optimum condition for extraction as well as regeneration of acid. Extraction of iron from waste pickle liquor was also investigated using binary extractants and is recovered as high grade iron oxide.

Russia has studied the equilibrium distributions of iron and rare earth metals in binary extractant systems. Binary extractants based on monocarboxylic acids (for example, caprylic acid) appear to be effective reagents for recovery of iron from waste and rare earth metal solutions.

Experiments were carried out to explore the possibility to use pseudo liquid membrane (PLM) devices with natural circulation of continuous liquid membrane phase to recover iron from waste and rare earth metal containing solutions. The efficiency of the process in the PLM-device is determined by the interface contact area in the chambers and the flow ratio of the phases.

Collaboration with Korea Institute of Geosciences & Mineral Resources (KIGAM), South Korea

Two important projects have been taken up with Korea Institute of Geosciences and Mineral Resources. These projects address some of the urgent and relevant issues for India which are briefly recounted below.

— *Studies on recovery of manganese as Fe-Si-Mn from low manganese containing materials*

India possesses substantial reserve of manganese ore (approximately 270 million tones), out of which manganese alloy grade ore constitute only11%. The rest of the ore reserves are of blast furnace grade, not suitable for the production of manganese alloy due to low manganese and high iron content (i.e. undesirable Mn/Fe ratio). The demand for manganese alloy has increased sharply in recent years due to boost in steel production. The present position with respect to availability of high grade manganese ore cannot fulfill the expanding steel industry requirements in future. Hence a suitable technology for processing high iron containing low grade manganese ores and other low manganese containing materials for the production of manganese alloy is necessary.

In view of the above, a collaborative project with Korea Institute of Geosciences and Mineral Resources (KIGAM) has been under taken to recover manganese as Fe-Si-Mn from low grade manganese containing materials. In this, leach sea nodule residue of NML and sea nodules smelting slag of KIGAM have been utilized for the production of Fe-Si-Mn by electrothermal smelting route. So far 76% recovery of manganese has been achieved.

— *Solvent extraction studies for removal of hazardous metals from the sulfate leach solution of electronic wastes.*

The leach liquor generated in the processing of e-wastes contains copper, nickel, zinc, precious metals along with toxic elements such as chromium, cadmium, lead, mercury, tin etc. Their composition and concentration of the metallic constituents are different depending on the source. The hydrometallurgical route offers the most attractive method for the recovery of metals from the solutions. Initially, the studies have been carried out for extraction and separation containing 1000 mg/L copper, 100 mg/L cadmium, 100 mg/L zinc, and 100 mg/L nickel from sulfate solution. The studies showed that copper can be selectively extracted with LIX84 diluted in kerosene leaving other metals in aqueous raffinate at O/A ratio 1 and pH ~2.0-2.5. Subsequently, the scheme has been developed for the separation of zinc, cadmium and nickel from the same raffinate using 5% DEHPA plus 1% isodecanol in kerosene.

CONCLUSIONS

- National Metallurgical Laboratory has contributed significantly to the development of the non-ferrous sector of India and will strive to maintain its pre-eminent position in the years to come

- The laboratory with its vast experience and well developed infrastructure in the field of non-ferrous metallurgy, will look forward to the future with confidence and pride.