Course Type	Course Code	Name of the Course	L	T	P	Credits
DE	NFMD514	Rare Earth Elements: Resource, Processing, Separation and Applications	3	0	0	3

Course Objective

- This course aims to develop an integrated understanding of rare earth elements, from their chemistry, classification and occurrence in global and Indian resources to their processing, separation and conversion into metals and alloys, including solvent extraction, ion exchange and alternative techniques, and their role in magnets, catalysts, phosphors, batteries and other technologies.

Learning Outcomes

- Classify rare earth elements and relate their properties to electronic structure and the lanthanide contraction; identify their minerals, deposit types, and primary, secondary, and lean resources, including Indian resources.
- Select and justify beneficiation and decomposition routes for different rare earth sources, with reference to Indian practice.
- Develop fractionation and separation schemes for producing individual rare earth elements from mixed concentrates using solvent extraction, ion exchange, or alternative techniques.
- Describe routes for converting rare earth oxides and halides into metals and alloys, including molten salt electrolysis and metallothermic reduction.
- Explain rare earth applications in magnets, catalysts, phosphors, batteries, and other technologies, and discuss related supply-chain issues.

Unit No.	Topics to be Covered	Lecture Hours	Learning Outcome
1.	**Introduction to rare earth elements.** Discovery and history; the 17 elements and their classification (light, medium, heavy; Y and Sc); electronic configuration, oxidation states, lanthanide contraction; chemical and physical properties; basic chemistry of REE ions in solution and the 4f basis of their behaviour.	3	Classify rare earth elements and explain how their electronic structure, oxidation states, and lanthanide contraction influence their properties.
2.	**Rare earth resources.** Geochemistry and abundance; REE minerals and the forms in which REE occur (bastnasite, monazite, xenotime, loparite, eudialyte, allanite, apatite, ion-adsorption clays); deposit types (carbonatite, alkaline igneous, placer, laterite, hydrothermal); world reserves, production and trade; classification as primary, secondary and lean sources; Indian resources (monazite in beach sands of Kerala, Tamil Nadu, Odisha and Andhra Pradesh; Ambadongar and other carbonatites; xenotime; fly ash and other lean sources) and the role of IREL and AMD.	6	Identify major rare earth minerals and deposit types, and distinguish global and Indian primary, secondary, and lean resources.
3.	**Processing of primary sources.** Exploration and beneficiation (gravity, magnetic, electrostatic separation, flotation); decomposition of monazite (caustic and acid routes), bastnasite, xenotime and carbonatite concentrates; leaching of ion-adsorption clays; thorium and uranium management and radiological aspects; mixed REE chloride and oxide production; Indian flowsheets (monazite processing at IREL, Aluva and Chavara).	7	Select beneficiation and decomposition routes for primary rare earth sources, including suitable leaching and radiological management practices.
4.	**Processing of secondary and lean sources.** Coal fly ash, red mud, phosphogypsum, mine tailings and apatite; end-of-life NdFeB and SmCo magnets, NiMH batteries, phosphors, FCC catalysts and e-waste; pretreatment, leaching and recovery routes; process economics and environmental considerations.	4	Evaluate recovery routes for secondary and lean sources, considering process economics and environmental impacts.
5.	**Fractionation and group separation.** Development of a separation scheme for a mixed REE feed; classical methods (fractional crystallization and precipitation, double salts); oxidation of Ce, reduction of Eu, Sm and Yb; Y separation; light, middle and heavy REE grouping; choice of sequence for monazite, xenotime and carbonatite feeds.	3	Develop a group fractionation scheme for a mixed rare earth feed using appropriate classical separation and redox methods.
6.	**Solvent extraction.** Principles: distribution, separation factor, extractants (acidic, neutral, solvating, basic; D2EHPA, PC88A, Cyanex 272, TBP, Versatic acid, amines); diluents and modifiers; mechanism and stoichiometry; Thermodynamic consideration in separation, scrubbing and stripping; McCabe-Thiele diagram and counter-current	6	Design and assess solvent extraction circuits for rare earth separation using extractant selection, process design, and material balances.

	design; mixer-settlers and columns; saponification; tetrad effect; separation of Nd-Pr, Sm-Eu-Gd, and Dy-Tb-Y; industrial circuits. Concept on development of process flowsheet for recovery of rare earths from various types of resources. Materials balance etc.		
7.	**Ion exchange and alternative techniques.** Ion exchange and displacement chromatography with complexing eluents (EDTA, DTPA); extraction chromatography; supported liquid membranes; ionic liquids and deep eutectic solvents; supercritical fluid extraction; novel adsorbents and biosorption; electrochemical and precipitation-based methods; comparison with solvent extraction on scale, purity and cost.	4	Compare ion exchange and alternative separation techniques with solvent extraction in terms of scale, product purity, and cost.
8.	**Conversion to rare earth metals.** Preparation of high-purity oxides, fluorides and chlorides; metallothermic reduction (calcium, lanthanum, lithium); molten salt electrolysis of oxide-fluoride and chloride melts; refining by vacuum distillation, zone melting and electrotransport; metal purity and handling; Indian experience.	3	Describe methods for converting rare earth compounds into high-purity metals and refining the products.
9.	**Rare earth alloys.** Master alloys and mischmetal; fused-salt and metallothermic alloy preparation; NdFeB, SmCo and other magnet alloys; hydrogen storage alloys (LaNi5 type); rare-earth additions to steel, magnesium and aluminium; powder metallurgy and sintering of magnets; recycling loop.	3	Describe rare earth alloy preparation routes and relate alloy applications to processing and recycling methods.
10.	**Applications and importance of REE.** Why REE are key materials: 4f electrons, magnetic, optical and catalytic behaviour; permanent magnets for motors, wind turbines and electric vehicles; phosphors and lasers; catalysts and polishing; batteries, glass, ceramics and nuclear applications; criticality, balance problem, supply risk, policy and the Indian outlook.	3	Explain the importance of rare earth elements in key technologies and assess their criticality, supply risks, and policy context.
	Total	**42**	

Text Books:

1. Extractive Metallurgy of Rare Earths by C.K. Gupta and N. Krishnamurthy, CRC Press
2. Separation Hydrometallurgy of Rare Earth Elements by Jack Zhang, Baodong Zhao, and Bryan Schreiner, Springer

Reference Books:

3. Hydrometallurgy: Fundamentals and Applications by Michael L. Free, 2nd Edition, Springer
4. Handbook on the Physics and Chemistry of Rare Earths, Elsevier Science