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(Part- II :Metals and Alloys)

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VANADIUM

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**GOVERNMENT OF INDIA
MINISTRY OF MINES
INDIAN BUREAU OF MINES**

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18 Vanadium

Vanadium was discovered in 1801 by a Mexican Mineralogist Andres del.Rio. It is a scarce element, hard, silvery grey, ductile and malleable transition metal with good structural strength. It is a versatile metal with melting point of 1910^o c. Vanadium metal and its compounds are gaining tremendous importance in the rapidly advancing field of science & technology. It occurs naturally in about 65 different minerals among which are patronite, vanadinite, roscoelite and carnotite. It is also present in bauxite and in fossil fuel deposits. It occurs in association with titaniferous magnetite and is recovered as a by-product during iron & steel manufacture. Vanadium is also concentrated in many end-products of organic material including coal, crude oil, shale and tar sands. It is also found in small percentages in meteorites. In addition, vanadium present in bauxite can also be recovered as vanadium sludge from red mud during the production of alumina. Vanadium is widely used in green technology applications, especially in battery technology.

Vanadium has the property to increase the tensile strength of steel and its high strength to weight ratio meets fuel efficiency requirements in the Automotive and Aerospace Industries.

RESERVES/RESOURCES

In India, vanadium is associated with titaniferous magnetite which contains 0.8 to 3% V₂O₅. It also occurs in significant amounts in association with chromite, laterite, bauxite and ferromagnesian-rich rocks, such as, pyroxenite, base anorthosite and gabbro.

As per NMI database, based on UNFC system, the total estimated reserves/resources of vanadium ore as on 1.4.2015 are placed at 24.63 million tonnes with an estimated V₂O₅ content of 64,594 tonnes. The entire resources of vanadium are placed under Remaining Resources category only (Table-1). A total of 24 deposits of vanadium have been covered in NMI 1.4.2015 out of which 23 deposits are in freehold and 1 deposit is in leasehold (Public) area.

PRODUCTION

Vanadium is recovered from slag that is collected from the processing of vanadiferous magnetite ore where iron and steel are the principal products. The processing of gas and petroleum products is also an important source of vanadium, which is recovered both from the raw material and from the recycling of vanadium-bearing catalyst.

RIL has developed a low-cost & low-temperature hybrid green process to extract vanadium from gasifier slag. The green process is being scaled up from lab to pilot level. Vanadium sludge is separated as a by-product during the Bayer process for production of alumina hydrate. NALCO has completed lab-scale studies to recover vanadium sludge from various Bayer Liquors. Vedanta's Lanjigarh Alumina Refinery has developed an in-house process for extraction of V₂O₅ (vanadium pentoxide) present in the bauxite involving simple operations with very low energy consumption. Thus, it is considered as innovative, cost-effective and environment-friendly besides, ensuring optimum utilisation of natural resources. This project was taken up as a part of Vedanta's ambitious project of Zero Discharge and Zero Waste Alumina Refinery. Vanadium recovery will make the country self-sufficient in meeting demand of vanadium as most of these raw materials are imported to make ferrovanadium. Vanadium recovery projects help in additional generation of revenue. The vanadium sludge obtained at BALCO's Korba plant contains 6 to 10% V₂O₅, Hindalco's Renukoot plant 18.2% V₂O₅ and Muri & Belagavi plants 6 to 20% V₂O₅.

The reported production of vanadium as by-product was 328.10 tonnes & 114 tonnes by the Vedanta's Lanjigarh plant & Hindalco's Belagavi plant during the year 2018-19.

EXPLORATION & DEVELOPMENT

The exploration and development details, if any, are covered in the Review of "Exploration & Development" under "General Reviews".

USES

Vanadium is used primarily as an alloying element in Iron & Steel Industry for specialised

**Table – 1 : Reserves/Resources of Vanadium as on 1.4.2015
(By Grades/States)**

(In tonnes)

Grade/State	Reserves			Remaining Resources					Total Resources (A+B)		
	Proved STD111	Probable STD121 STD122	Total (A)	Feasibility STD211	Pre-feasibility STD221 STD222	Measured STD331	Indicated STD332	Inferred STD333		Reconnaissance STD334	Total (B)
All India : Total											
By Grades											
Ore	-	-	-	276530	1720000	4108100	-	232000	18297225	-	24633855
Contained V₂O₅	-	-	-	1106	2835	6032	-	487	54133	-	64594
By States											
Karnataka											
Ore	-	-	-	-	500000	4000000	-	-	14884430	-	19384430
Contained V ₂ O ₅	-	-	-	-	700	5600	-	-	43198	-	49498
Maharashtra											
Ore	-	-	-	276530	-	108100	-	-	-	-	384630
Contained V ₂ O ₅	-	-	-	1106	-	432	-	-	-	-	1539
Odisha											
Ore	-	-	-	-	1220000	-	-	232000	3412795	-	4864795
Contained V ₂ O ₅	-	-	-	-	2135	-	-	487	10936	-	13558

Figures rounded off

applications in automotive, engineering, railways, defence sectors and to some extent as a stabiliser in titanium and aluminium alloys which are used in aerospace applications. It imparts toughness and strength to steel, alloys and also acts as scavenger for oxygen. Vanadium is consumed in the Steel Industry in the manufacture of a wide-range of products, from low carbon flat rolled steels, high strength plates & structural steels to pipes, reinforcing bars, forging steels, rail steels and tool steels. Vanadium (about 80%) is mostly used in the form of ferrovanadium as a means of introducing vanadium into steel. There are two groups of vanadium steel alloys. Vanadium high carbon steel alloys that contains 0.15% to 0.25% vanadium and High Speed Steels (HSS) where vanadium content in the range of 1% to 5%. HSS steel is used in surgical instruments and other tools. The content of vanadium in ferro vanadium varies from 45 to 50% and sometimes it is up to 80%, depending upon the demand. The 45 to 50% grade is produced from slag and other vanadium containing material by silicothermic reduction of pentoxide (V_2O_5) in presence of steel scrap or by direct reduction in an electric arc furnace. The resultant vanadium steels can be divided into micro-alloy or low-alloy steels with less than 0.15% vanadium and high-alloy steels with up to 5% vanadium. Non-metallurgical applications include its use as catalyst and in ceramic, chemical, pigments, health preparations and electronic industries. It is also used to produce super conductive magnets with a field of 1,75,000 gauss. The most common oxide of vanadium, i.e., vanadium pentoxide (V_2O_5) is used as a catalyst in manufacturing sulphuric acid. In biological context, vanadium is a micro-nutrient found naturally in mushroom, shellfish, black pepper, parsley dill, grain and grain products. It exists as both vanadyl sulphate, the form most commonly used in food supplements and vanadate.

Modern applications of vanadium include its use as vanadium secondary batteries for power plants and rechargeable vanadium redox battery (VRB) for commercial applications. The main advantages of VRB are that it can offer almost unlimited capacity simply by using sequentially larger storage tanks; can be left completely discharged for long periods of time with no ill-effects; can be recharged by replacing the electrolyte if no power source is available to charge it; and suffers no permanent

damage if the electrolytes are accidentally mixed. The VRB has also been shown to have the least ecological impact of all energy storage technologies.

SUBSTITUTES

Substitution of vanadium in steel by niobium, chromium, titanium, manganese, molybdenum and tungsten is possible although at higher cost or with lower performance. Heat-treated carbon steels can replace vanadium steels in some applications. Platinum and nickel can be used in some catalytic processes but at higher cost. Presently, there is no acceptable substitute for vanadium in titanium alloys used in aerospace application.

WORLD REVIEW

The world reserves of vanadium were about 22 million tonnes of metal located mainly in China, Brazil, Russia, Australia, South Africa, and the USA (Table-2). Titaniferous magnetite is the most important source accounting about 85% of current world V_2O_5 production from which vanadium could be extracted as a by-product of iron. The resources are also available in crude oil (in Caribbean basin, parts of Middle East and Russia), tar sands (in Western Canada), phosphate rock, uraniferous sandstone and siltstone. In all these cases, extraction depends on economic recovery of the product.

Table – 2 : World Reserves of Vanadium (By Principal Countries)

(In '000 tonnes of vanadium content)

Country	Reserves
World: Total (rounded off)	22,000
USA	45
Australia	4,000#
Brazil	120
China	9,500
Russia	5,000
South Africa	3,500

Source: Mineral Commodity Summaries, 2020

For Australia, JORC-Compliant reserves were 1.1 million tonnes

The world production of vanadium in 2018 was 84,000 tonnes of metal content which marginally decreased from 90,000 tonnes of metal content in the previous year. This excludes vanadium recovered as by-product; includes vanadium in slag product but from refining and burning of heavy oils. Major producing countries were China (48%), South Africa (21%) and Russia (20%) (Table-3).

Nearly most of the world's vanadium supply originates from primary sources or co-production.

Table – 3 : World Mine Production of Vanadium (By Principal Countries)

Country	(In tonnes of metal content)		
	2016	2017	2018
World: Total (rounded off)	84000	90000	84000
China ^e	41000 ^e	40000 ^e	40000 ^e
South Africa	18000 ^e	22400 ^e	18000 ^e
Russia	16886	18636	17052
Brazil	4461	5206	5505
Poland	2930	2720	2640
Kazakhstan ^e	1000 ^e	1000 ^e	1000 ^e

Source: World Mineral production, 2014-18 e. estimated

A generalised view of the development in various countries with countrywise description sourced from latest available publication of Minerals Yearbook 'USGS' 2017 is furnished as below:

Australia

Multicom submitted an environmental impact statement to the Queensland Government outlining its details for developing the Saint Elmo vanadium project, 25 kilometers (km) east of Julia Creek, Queensland. The project estimates a production of 50,000 t/yr of V₂O₅ with a 30-year mine life.

Brazil

Largo Resources Ltd's (Toronto, Ontario, Canada) Maracas Menchen Mine, located 813 km northeast of Brasilia, produced 9,300 tonnes of V₂O₅ in 2017, a 16% increase as compared to the 8,000 tonnes of V₂O₅ produced in 2016. Annual production capacity was expected to be 9,634 t/yr of V₂O₅. According to the Company, vanadium is contained

within a massive titaniferous magnetite deposit that has much higher grades of V₂O₅ and iron than any other vanadium deposit in the world. The very low level of contaminants in the deposit, particularly silica, was expected to make the extraction and processing of vanadium much easier. Largo has an offtake agreement with Glencore International plc for 100% of its material for the first 6 years of operation.

Canada

In December, Vanadium Corp Resource Inc. (Vancouver) announced the successful completion of Phase II of its production trials at the Electrochem Technologies & Materials Inc. facilities in Boucherville, Quebec. According to Electrochem, Phase II resulted in the efficient processing of a variety of feedstocks using chemical technology that other related industries are unable to use. Electrochem also announced the successful production of a battery-ready electrolyte.

Russia

EVRAZ Nizhny Tagil Metallurgical plant (NTMK), an integrated metallurgical complex located in Nizhny Tagil in the Sverdlovsk region, continued to be one of the world's leading processors of VTm. The Vanady Tula facility, located 200 km south of Moscow, used low-cost, highly efficient technology to process the vanadium slag produced by NTMK. Vanady Tula has a capacity of 5,000 t/yr of FeV and 7,500 t/yr of V₂O₅ in its electrometallurgical and hydrometallurgical plants.

China

Many vanadium producers in the Panzhihua Vanadium and Titanium High-Tech Industrial Development Zone continued to suspend or decrease vanadium production due to environmental pollution of water in River Jinsha in Panzhihua. In February, the Standardisation Administration of China (SAC) released a new high strength rebar standard that would increase the overall consumption of vanadium in China by approximately 10,000 t/yr.

In August, it was announced that 24 types of materials, including vanadium slag, would be prohibited in China. The ban on vanadium slag

imports was expected to reduce the amount of raw material available for Chinese V_2O_5 production. In September, the China National Development and Reform Commission published a document that called for more investment in energy storage, specifically flow batteries. One such battery flow system was the 800-megawatt-hour vanadium flow battery project being built on the Dalian Peninsula in northern China. The project was expected to come online in 2020 with anticipation that it will store any unused wind energy for later use rather than wasting the power.

Czechia

Nikom (part of EVRAZ plc) had an FeV production capacity of 4,600 t/yr. Nikom had one processing facility, which was used to process V_2O_5 from Russia and China and also vanadium trioxide from Vametco into FeV.

South Africa

In June, Arcelor Mittal South Africa and Highveld Structural Mill Pty Ltd (a subsidiary of EVRAZ Highveld Steel and Vanadium Ltd) officially restarted the heavy structural mill. The terms of their agreement were that Arcelor Mittal would provide the raw steel and Highveld would toll process the final product. The remainder of the plant was transformed into the Highveld Industrial Park which consisted of 17 businesses. The park also had a fully equipped vanadium slag crushing plant, which was designed to process vanadium from titaniferous ore deposits.

In September, the Mapochs Mine was auctioned off and purchased by International Resources Ltd (Hong Kong, China). The Mapochs Mine is an open pit mine near Roosemekal in the Mpumalanga Province.

In November, Bushveld Minerals Ltd announced the completion of its acquisition of Bushveld Vametco Ltd. Through this acquisition, Bushveld Minerals was expected to own a 78.8% interest in Strategic Minerals Corp. Strategic Minerals, in turn held a 75% interest in Vametco Holdings, which had a 100% interest in the Vametco vanadium mine and plant in Brits, North West Province. Vametco produced 1,440 tonnes of contained vanadium in the form of vanadium nitride and vanadium oxide in the first 6 months of 2017. Vametco had the capacity of approximately 3,000 t/yr of contained vanadium. Vametco commenced a multiphased expansion project to increase annual production to more than 5,000 t/yr over the next 3 to 5 years. Vametco used the standard salt roast and leach process to

produce a trademark vanadium carbon nitride product called Nitrovan.

Glencore plc (Baar, Switzerland) announced that its Rhovan vanadium facility, 30 km northwest of Brits, produced 9,480 t of V_2O_5 in 2017.

FOREIGN TRADE

The export of ferrovanadium increased sharply to 474 tonnes in 2018-19 as compared to 214 tonnes during the previous year. Exports were mainly to Belgium (49%), Oman & USA (17% each) and UAE (8%) (Table-4). On the other hand, the imports of ferrovanadium were 713 tonnes during the year 2018-19 as compared to 718 tonnes during the previous year. The imports were mainly from Germany (51%), China (17%) and Netherlands (13%) (Table-6). The exports of vanadium ore and concentrates were reported at 10 tonnes in 2018-19 (Table-5). The imports of vanadium ores and concentrates during 2018-19 increased exorbitantly to 2658 tonnes as compared to 491 tonnes in the previous year. The imports was mainly from Kuwait (80%) (Table-7).

Table – 4: Export of Ferrovanadium (By Countries)

Country	2017-18(R)		2018-19(P)	
	Qty (t)	Value ('000)	Qty (t)	Value ('000)
All Countries	214	410525	474	1832964
Belgium	50	88803	230	975012
Oman	42	64473	80	352978
USA	20	41069	80	279103
Netherlands	80	189130	30	130078
UAE	15	18264	39	50510
Thailand	++	1	6	29845
Turkey	2	3253	1	3345
Philippines	-	-	1	2365
Pakistan	1	1296	++	2184
Bangladesh	1	1094	1	1839

Figures rounded off

Table – 5 : Exports of Vanadium Ores & Conc. (By Countries)

Country	2017-18(R)		2018-19(P)	
	Qty (t)	Value (€ '000)	Qty (t)	Value (€ '000)
All Countries	-	-	10	2320
Latvia	-	-	10	2320

Figures rounded off

Table – 7 : Imports of Vanadium Ores & Conc. (By Countries)

Country	2017-18(R)		2018-19(P)	
	Qty (t)	Value (€ '000)	Qty (t)	Value (€ '000)
All Countries	491	89745	2658	451825
Kuwait	-	-	2127	303070
Taiwan	133	22841	106	46569
Mexico	18	7614	121	43855
Vietnam	130	10273	219	26290
Netherlands	208	48934	36	16661
USA	-	-	20	9148
UAE	-	-	10	4093
Iran	-	-	19	2135
Germany	-	-	++	4
Korea, Rep. of	2	83	-	-

Figures rounded off

FUTURE OUTLOOK

The worldwide demand for vanadium is directly linked to the demand for steel specially with demand of high-strength steel. In vanadium batteries, the consumption may increase in future.

On the other hand, with growth of Automobile and Casting Sectors, demand for ferrovanadium is expected to increase and this will have to be met by imports. The accelerated growth in the Forging Industry and increased demand for die

Table – 6 : Imports of Ferrovanadium (By Countries)

Country	2017-18(R)		2018-19(P)	
	Qty (t)	Value (€ '000)	Qty (t)	Value (€ '000)
All Countries	718	1489369	713	2881355
Germany	-	-	361	1332287
China	113	251126	120	719556
Netherlands	20	56525	95	331054
Korea, Rep. of	194	484485	60	278688
USA	36	22757	50	123484
Latvia	58	99121	27	96191
UK	-	-	++	95
Japan	132	239479	-	-
Russia	88	127134	-	-
South Africa	32	87014	-	-
Other countries	45	121728	-	-

Figures rounded off

steels and tool steel too, have paved way for increased vanadium consumption. Imperatives for utilisation of the huge vanadium-bearing titaniferous ores available in the States viz, Karnataka, Maharashtra and Odisha, through R&D efforts will have to be initiated to meet the domestic demand of vanadium pentoxide and ferrovanadium.

As more than 90% of vanadium is used in steel production, its demand is correlated to gross crude steel production. Use of vanadium in manufacturing of rebar in China and other emerging markets have picked up, as these countries are increasingly adopting western standards in the fabrication of high-strength rebar used in construction activities.