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(Part- II : Metals & Alloys)

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VANADIUM

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GOVERNMENT OF INDIA
MINISTRY OF MINES
INDIAN BUREAU OF MINES

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19 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 1,910 ^{0}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. 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% V_2O_5. 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 V_2O_5 content of 64,594 tonnes. The entire resources of vanadium are placed under Remaining Resources category (Table-1). A total of 24 deposits of vanadium have been covered in NMI 1.4.2015 out of which 23 deposits are in free- hold 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 V_2O_5 (vanadium pentoxide) present in 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 its demand as most of these hitherto was 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% V_2O_5, while that at Hindalco's Renukoot plant contains 8.2% V_2O_5 and Muri & Belagavi plants 6 to 20% V_2O_5.

The reported production of vanadium as by-product was 34.20 tonnes & 42 tonnes by the Vedanta's Lanjigarh plant & Hindalco's Belagavi plant during the year 2019-20.

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

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		Total (A)	Feasibility STD211	Pre-feasibility		Measured STD331	Indicated STD332	Inferred STD333	Reconnaissance STD334	Total (B)	
		STD121	STD122			STD221	STD222						
All India : Total													
By Grades													
Ore	**-**	**-**	**-**	**-**	**276530**	**1720000**	**4108100**	**-**	**232000**	**18297225**	**-**	**24633855**	**24633855**
Contained V_2O_5	**-**	**-**	**-**	**-**	**1106**	**2835**	**6032**	**-**	**487**	**54133**	**-**	**64594**	**64594**
By States													
Karnataka													
Ore	-	-	-	-	-	500000	4000000	-	-	14884430	-	19384430	19384430
Contained V_2O_5	-	-	-	-	-	700	5600	-	-	43198	-	49498	49498
Maharashtra													
Ore	-	-	-	-	276530	-	108100	-	-	-	-	384630	384630
Contained V_2O_5	-	-	-	-	1106	-	432	-	-	-	-	1539	1539
Odisha													
Ore	-	-	-	-	-	1220000	-	-	232000	3412795	-	4864795	4864795
Contained V_2O_5	-	-	-	-	-	2135	-	-	487	10936	-	13558	13558

Figures rounded off

element in Iron & Steel Industry 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 is 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 in some cases 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 vanadale.

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 (43%), Russia (23%), Australia (18%), South Africa (16%) and the remaining share was accounted for by USA & Brazil (Table-2). Titaniferous magnetite is the most important source of 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: *USGS, Mineral Commodity Summaries,2021*

 # For Australia, Joint Ore Reserves Committee-Compliant reserves were 1.1 million tonnes

The world production of vanadium in 2019 was 81,000 tonnes of metal content which increased from 79,000 tonnes of metal content in the previous year. This includes vanadium in slag product and from refining and burning of heavy oils. Major producing countries were China (49%), Russia (23%) and South Africa (18%) (Table-3).

Remaining countries together contributed 10% of the total world mine production. Most of the world's vanadium supply originates from primary sources or co-production.

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

(In tonnes of metal content)

Country	2017	2018	2019
World: Total (rounded off)	**85000**	**79000**	**81000**
China	45400	40000	40000
Russia	18636	17052	18380
South Africa	14222	14904	14858
Brazil	5206	5505	5923
Kazakhstan	1000	1000	1000
USA	-	-	470
India	400	442	400

Source: *BGS, World Mineral production, 2015-19*

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 V_2O_5 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 t of V_2O_5 in 2017, a 16% increase as compared to the 8,000 tonnes of V_2O_5 produced in 2016. Annual production capacity was expected to be 9,634 t/yr of V_2O_5. According to the Company, vanadium is contained within a massive titaniferous magnetite deposit that has much higher grades of V_2O_5 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 V_2O_5 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 ferro-vanadium increased marginally to 532 tonnes in 2019-20 as compared to 474 tonnes during the previous year. Exports were mainly to Belgium (42%), UAE (19%), Netherlands (15%), China (10%), Bahrain & Iran (4% each) and Thailand (3%) (Table-4). The exports of vanadium ore and concentrates were reported at 10 tonnes in 2019-20 which was same as during last year (Table-5). On the other hand, the imports of ferro-vanadium were 596 tonnes during the year 2019-20 as compared to 714 tonnes during the previous year. The imports were mainly from Germany (36%), Japan (21%) and Russia (15%) (Table-6). The imports of vanadium ores and concentrates during 2019-20 increased exorbitantly to 7,005 tonnes as compared to 2,658 tonnes in the previous year. The imports were mainly from Kuwait (59%) and Canada (39%) (Table-7).

Table – 4: Export of Ferrovanadium
(By Countries)

Country	2018-19 (R)		2019-20 (P)	
	Qty (t)	Value (₹'000)	Qty (t)	Value (₹'000)
All Countries	**474**	**1832963**	**532**	**883571**
Belgium	230	975012	225	398727
UAE	39	50510	103	140008
Netherlands	30	130078	82	121635
China	-	-	52	84841
Bahrain	-	-	20	31877
Iran	-	1572	20	48270
Thailand	6	29845	16	29814
Oman	80	352978	8	12390
Brazil	-	-	2	5191
Other countries	89	292968	4	10818

Figures rounded off

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

Country	2018-19 (R) Qty (t)	2018-19 (R) Value (₹'000)	2019-20 (P) Qty (t)	2019-20 (P) Value (₹'000)
All Countries	**10**	**2320**	**10**	**10801**
Latvia	10	2320	10	10801

Figures rounded off

Table – 6 : Imports of Ferrovanadium (By Countries)

Country	2018-19 (R) Qty (t)	2018-19 (R) Value (₹'000)	2019-20 (P) Qty (t)	2019-20 (P) Value (₹'000)
All Countries	**714**	**2881355**	**596**	**1143397**
Germany	361	1332287	216	342960
Japan	-	-	124	224188
Russia	-	-	92	174162
Korea, Rep. of	60	278688	56	151770
USA	50	123484	39	35971
Netherlands	95	331054	33	107490
China	120	719556	14	78472
Czech Republic	-	-	10	12928
Switzerland	-	-	10	13218
Malaysia	-	-	2	2223
UK	-	95	-	15
Latvia	27	96191	-	-
Other countries	45	121728	-	-

Figures rounded off

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

Country	2018-19 (R) Qty (t)	2018-19 (R) Value (₹'000)	2019-20 (P) Qty (t)	2019-20 (P) Value (₹'000)
All Countries	**2658**	**451826**	**7005**	**349104**
Kuwait	2127	303070	4113	212171
Canada	-	-	2762	100607
Netherlands	36	16661	66	17462
Taiwan	106	46569	19	10940
Mexico	121	43855	46	7924
Vietnam	219	26290	-	-
USA	20	9148	-	-
UAE	10	4093	-	-
Iran	19	2135	-	-
Germany	++	4	-	-

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 steels and tool steel 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 ferro-vanadium.

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.