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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 1.4.2020 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).

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.

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 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

Table – 1 : Reserves/Resources of Vanadium as on 1.4.2020 (P) (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	**0**	**0**	**0**	**0**	**276530**	**1720000**	**4108100**	**0**	**232000**	**18297225**	**0**	**24633855**	**24633855**
Contained V_2O_5	**0**	**0**	**0**	**0**	**1106.12**	**2835**	**6032.4**	**0**	**487.2**	**54133.29**	**0**	**64594.01**	**64594.01**
By States													
Karnataka													
Ore	0	0	0	0	0	500000	4000000	0	0	14884430	0	19384430	19384430
Contained V_2O_5	0	0	0	0	0	700	5600	0	0	43197.55	0	49497.55	49497.55
Maharashtra													
Ore	0	0	0	0	276530	0	108100	0	0	0	0	384630	384630
Contained V_2O_5	0	0	0	0	1106.12	0	432.4	0	0	0	0	1538.52	1538.52
Odisha													
Ore	0	0	0	0	0	1220000	0	0	232000	3412795	0	4864795	4864795
Contained V_2O_5	0	0	0	0	0	2135	0	0	487.2	10935.74	0	13557.94	13557.94

Figures rounded off

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 24 million tonnes of metal located mainly in China (40%), Australia (25%),Russia (21%),South Africa (15%) 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)	**24,000**
USA	45
Australia	6000
Brazil	120
China	9,500
Russia	5,000
South Africa	3,500

Source: *USGS, Mineral Commodity Summaries,2022*

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

The world production of vanadium in 2020 was 95,000 tonnes of metal content which was same as compared to the previous year. This includes vanadium in slag product and from refining and burning of heavy oils. Major producing countries were China (56%), Russia (21%) and South Africa (15%) (Table-3).

Remaining countries together contributed 8% 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	2018	2019	2020
World: Total (rounded off)	**79000**	**95000**	**95000**
China	40000	54000	53000
Russia	17052	18380	19530
South Africa	14904	14858	14421
Brazil	5505	5923	6622
Kazakhstan	1000	1000	1000
USA	-	460	170
India	442	400	400

Source: *BGS, World Mineral production, 2016-20*

A generalised view of the development in various countries with countrywise description sourced from latest available publication of Minerals Yearbook 'USGS' 2018 is furnished as below:

Australia

In November, Neometals Ltd. announced that it would update the 2009 Definitive Feasibility Study (DFS) of the salt roast-leach operation at its Barrambie vanadium-titanium-magnetite project, approximately 80 kilometers (km) northwest of Sandstone in Western Australia. The company had a mining permit for Barrambie and owned 100% of the project through its subsidiary Australian Titanium Pty Ltd. The DFS was expected to be complete in the second quarter of 2019 .

Brazil

Largo Resources Ltd.'s (Toronto, Ontario, Canada) Maracás Menchen Mine, located 813 km northeast of Brasilia, produced 9,830 tonnes of V_2O_5 in 2018, a 6% increase compared with the 9,300 tonnes of V_2O_5 produced in 2017.The company expected to produce between 10,000 and 11,000 tonnes/year of V_2O_5 in 2019. According to the company, the 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. This in turn was expected to lower operating costs and produce a superior high-purity concentrate.

Canada

In February, VanadiumCorp Resource Inc. announced that it filed for an international patent application to secure rights for the new VanadiumCorp-Electrochem Processing Technology (VEPT). According to the companies, VEPT efficiently recovers vanadium compounds including vanadium pentoxide, vanadyl sulfate, as well as others from a variety of feedstocks containing vanadium.

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 had a capacity of 5,000 tonnes/year of FeV and 7,500 tonnes/year 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 owing to local governments conducting environmental inspections following the discovery of polluted water in the Jinsha River in Panzhihua. Tighter environmental controls were also expected in other vanadium-producing regions. Pangang Group Vanadium Titanium & Resources Co., Ltd. continued to be the leading Chinese vanadium producer, with operations located in Panzhihua. The company had the capacity to produce approximately 24,000 tonnes/year of vanadium.

In February 2018, the Standardization Administration of China (SAC) released a new standard for high-strength rebar that would decrease the use of substandard steels in construction to make buildings in China more earthquake resistant. The implementation date for the new standard was November 1, 2018. The new rebar standard would eliminate the low-strength Grade 2 rebar, and the SAC authorized Grade 3, Grade 4, and Grade 5 high-strength standards. The newly authorized standards would have 0.03% vanadium in Grade 3, 0.06% vanadium in Grade 4, and more than 0.1% vanadium in Grade 5 rebar. The increase of vanadium in rebar was expected to increase the overall consumption of vanadium in China by approximately 10,000 tonnes/year. However, this consumption estimate was expected to vary depending on the enforcement of these new rebar standards.

In January 2019, China's State Bureau of Quality and Technical Supervision conducted quality inspections of rebar producers in small steel mills to ensure that they had adopted the new rebar standards. It was reported that approximately 30% to 40% of mills had not fully switched to the new standards. Many of the small mills could not afford to implement the technology needed to produce the upgraded rebar. At yearend 2017, five Government agencies, including the Ministry of Environmental Protection and the Ministry of Commerce, jointly issued an import ban on 24 types of solid waste, including vanadium slag. The ban on four types of vanadium slag imports was expected to reduce the amount of raw material available for V_2O_5 production in China. In April 2018, authorities issued an additional import ban on vanadium waste and scrap that would go into effect at yearend 2019. Additional measures to further restrict the import of solid waste were expected to be announced. Some of the China-based VRFB companies included Dalian Rongke Power Co. Ltd., Golden Energy Century Ltd., Golden Energy Fuel Cell Co. Ltd., Shanghai Shenli Technology Co., Ltd., and VRB Energy. According to the company, Shanghai Shenli Technology was funded by the Ministry of Science and Technology of China and was financially supported by the Shanghai municipal government.

In 2017, the China National Development and Reform Commission called for more investment in energy storage, specifically flow batteries. One such project underway was the 800-megawatthour vanadium energy storage project in Dalian in northern China. The project, built by UniEnergy Technologies LLC (Seattle, WA) and Rongke Power, was expected to come online in 2020. VRB Energy commissioned a 12-megawatthour energy storage project in Hubei Province. This demonstration project was expected to serve as an example for larger future projects.

Czechia

EVRAZ Nikom had one processing facility, which was used to process V_2O_5 from Russia and China and also vanadium trioxide from Bushveld Minerals Ltd.'s Vametco Mine into FeV. Nikom's FeV production capacity was 4,600 tonnes/year.

South Africa

With the closure of EVRAZ Highveld Steel and Vanadium Ltd.'s operations during 2016, Bushveld Minerals Ltd.'s Vametco vanadium mine and Glencore plc's Rhovan facility were South Africa's only active primary vanadium producers in 2018. Bushveld announced that its Vametco vanadium mine and plant in Brits, North West Province, produced 2,560 tonnes of contained vanadium in the form of vanadium nitride and vanadium oxide in 2018 compared with 2,650 tonnes of contained vanadium in 2017.The company attributed the slight decrease to the 37.5 days of stoppages at its plant. Labor grievances accounted for 22.5 days of the stoppages. Bushveld announced that it would produce more vanadium at Vametco in 2019 because it was not anticipating any more plant stoppages. The company had commenced a multiphased expansion project to increase annual production at Vametco. Phase II of the expansion project was completed in June, increasing capacity to 3,750 tonnes/year of vanadium. Vametco used the standard salt roast and leach process to produce a trademark vanadium carbon nitride product called Nitrovan. Glencore plc (Switzerland) announced that its Rhovan vanadium facility, 30 km northwest of Brits, produced 9,160 tonnes of V_2O_5 in 2018, a 3% decrease compared with 9,480 tonnes of V_2O_5 produced in 2017.

Kazakhstan.

Ferro-Alloy Resources Ltd. (FAR) (United Kingdom) announced that it had completed a feasibility study to develop its Balasausqandiq vanadium project in Kyzylordinskaya Oblast, in the south of Kazakhstan, and was expected to build a new processing facility in two phases. Phase 1 was expected to treat 1 million metric tonnes per year of ore to produce 5,600 tonnes/year of V_2O_5. Phase 2 was expected to increase the ore treated to 4 million tonnes/year, producing 22,400 tonnes/year of V_2O_5.

In addition to developing the Balasausqandiq vanadium project, FAR continued to produce approximately 125 tonnes/year of V_2O_5 equivalent in the form of ammonium metavanadate (AMV) at its existing processing facility from purchased concentrates and other vanadium containing materials. The company was expected to install equipment to convert AMV to V_2O_5 and increase capacity to up to 1,500 tonnes/year of V_2O_5.

FOREIGN TRADE

Exports

The Exports of ferro-vanadium decreased drastically by to 55%, 240 tonnes in 2020-21 as compared to 531 tonnes during the previous year. Exports were mainly to UAE (43%), Thailand (18%), Netherlands (17%), Oman (13%), Belgium (8%) and Brazil (1%) (Table-4).The exports of vanadium ore and concentrates were reported at Nil in 2020-21 which was 10 tonnes during last year (Table5).

Table – 4: Export of Ferrovanadium (By Countries)

Country	2019-20 (R)		2020-21 (P)	
	Qty (t)	Value (₹'000)	Qty (t)	Value (₹'000)
All Countries	**531**	**883571**	**240**	**346840**
UAE	103	140008	102	141985
Thailand	16	29814	42	64449
Netherlands	82	121635	40	55916
Oman	8	12390	32	49299
Belgium	225	398727	20	26199
Brazil	2	5191	2	3803
France	-	-	1	2162
Turkey	1	1832	1	1508
Indonesia	++	617	++	507
Malaysia	++	317	++	386
Other countries	94	173040	++	626

Figures rounded off

Imports

The Imports of ferro-vanadium were 480 tonnes during the year 2020-21 as compared to 595 tonnes during the previous year. The imports were mainly from Germany (39%), Japan (24%) and Korea, Rep.of (16%) (Table-6). The imports of vanadium ores and concentrates during 2020-21 decreased by massive 86% to 999 tonnes as compared to 7,006 tonnes in the previous year.The imports were mainly from Canada (38%), Mexico (20%) and UAE & Korea, Rep. of (15% each) (Table-7).

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

Country	2019-20 (R)		2020-21 (P)	
	Qty (t)	Value (₹'000)	Qty (t)	Value (₹'000)
All Countries	**10**	**10801**	-	-
Latvia	10	10801	-	-

Figures rounded off

Table – 6 : Imports of Ferrovanadium (By Countries)

Country	2019-20 (R)		2020-21 (P)	
	Qty (t)	Value (₹'000)	Qty (t)	Value (₹'000)
All Countries	**595**	**1143397**	**480**	**613762**
Germany	216	342960	188	260094
Korea, Rep of	56	151770	76	131424
Japan	124	224188	113	124205
Switzerland	10	13218	20	32604
Czech Republic	10	12928	30	29993
UAE	-	-	48	26724
Netherlands	33	107490	5	8711
UK	++	15	++	7
Russia	92	174162	-	-
China	14	78472	-	-
Other Countries	40	38194	-	-

Figures rounded off

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

Country	2019-20 (R)		2020-21 (P)	
	Qty (t)	Value (₹'000)	Qty (t)	Value (₹'000)
All Countries	**7006**	**349104**	**999**	**77967**
UAE	-	-	146	27377
Mexico	46	7924	200	14406
Canada	2762	100607	375	11608
Korea,Rep of	-	-	148	10560
Taiwan	19	10940	54	8045
Netherlands	66	17462	74	5613
USA	-	-	2	358
Kuwait	4113	212171	-	-

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. 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.