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GOVERNMENT OF INDIA
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19 Vanadium

Vanadium was discovered in 1801 by a Mexican Mineralogist 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 the order of 1700^0 c. Vanadium metals and its compound 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 cacnotite. 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, 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 supports fuel efficiency mandates 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 ferro-magnesian-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 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 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 hybride green process to extract vanadium from gasifier slag. The green process is being scaled up from 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. Lanjigarh Alumina has developed an in-house process for extraction of V_2O_5 (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% V_2O_5, Hindalco's Renukoot plant 18.2% V_2O_5 and Muri and Belgaum plants 6 to 20% V_2O_5.

EXPLORATION & DEVELOPMENT

The exploration and development details, if any, are given in the review of "Exploration & Development" in "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

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

in the Steel Industry in the manufacture of 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 contains 0.15% to 0.25% vanadium and high speed tool steels (HSS) have a vanadium content 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 a super conductive magnet 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 aerospace titanium alloys.

WORLD REVIEW

The world reserves of vanadium were about 20 million tonnes of metal located mainly in China, Russia, South Africa, Australia and the USA and are expected to last till next century at the current rate of consumption (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)	**20,000**
USA	45
Australia	2,100
Brazil	130
China	9,500
Russia	5,000
South Africa	3,500

Source: *Mineral Commodity Summaries,2019*

The world production of vanadium in 2017 was 85,842 tonnes of metal content which marginally increased from 85,347 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 (50%), Russia (21%) and South Africa (21%) (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)

(In tonnes of metal content)

Country	2015	2016	2017
World: Total (rounded off)	**83000**	**85000**	**86000**
Brazil	3254	4461	5206
China[e]	45000	45000	43000
Kazakhstan[e]	1000	1000	1000
Russia	16196	16886	18636
South Africa	17788	18000[e]	18000[e]

Source: *World Mineral production, 2013-17*
e. estimated

To give a generalised view of the development in various countries the country-wise description is sourced from latest available publication of Minerals Year Book 'USGS' 2016 is furnished below:

Brazil

Largo Resources Ltd's (Toronto, Ontario, Canada) Maracas Menchen Mine, located 813 kilometers (km) northeast of Brasilia, produced 8000 t of V_2O_5 in 2016. In the second quarter of 2016, the company produced 2311 t of V_2O_5 compared with 1169 t of V_2O_5 in the first quarter of 2016. Production capacity was expected to be 9600 t/yr of V_2O_5 (Largo Resources Ltd.). According to the company, the vanadium is contained within a massive titaniferous magnetite deposit that has much higher grades of both V_2O_5 and iron than any other vanadium project in the world.

Canada

VanadiumCorp Resource Inc. signed a memorandum of understanding (MoU) with C-Tech Innovation Ltd to collaborate on the development of a vanadium electrolyte plant in Canada. Under the MoU, a test plant capable of producing battery-ready electrolyte would be established in Quebec. C-Tech was also expected to collaborate with VanadiumCorp on a commercial-scale Vanadium electrolyte plant. VanadiumCorp's Lac Dore project in northern Quebec was in the development stage, with a estimated resources of 280000 t of V_2O_5 contained in magnetite ore (VanadiumCorp Resources Inc., 2017).

Russia

EVRAZ Nizhny Tagil Metallurgical plant (NTMK), an intergrated 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, uses low-cost, highly efficient technology to process the vanadium slag produced by NTMK Vanady Tula has capacity of 500 t/yr of FeV and 7500 t/yr of V_2O_5 in its electrometallurgical and hydrometallurgical plants. Vanady Tula produced 8500 t of vanadium-containing products in 2015. EVRAZ announced that it expected to maintain 2015 production levels for 2016.

China

In December, many vanadium producers in the Panzhihua vanadium and titanium high-tech industrial devlopment zone were forced to suspend vanadium production owing to the local government conducting environmental inspections caused by polluted water in the Jinsha River. State owned producer, Panzhihua Iron and Steel Group (Pangang), was expected to reduce its V_2O_5 output by 200 tonnes per month. It was unclear how long production would be suspended. However, tighter environmental controls were also expected in other vanadium-producing regions.

Pangang stopped selling vanadium slag to the spot market and was using it for its own vanadium production. Chengde Iron and Steel Group was reportedly also not selling vanadim slag and it resorted to importing slag from New Zealand to decrease costs.

China-baseds VRB companies included Dalian Rongke Power Co. Ltd, Golden Energy Century Ltd., Golden Energy Fuel Corp., Pu Neng Energy, and Shanghai Shen-Li High Tech Co. Ltd. According to the company Shanghai Shen-Li High Tech Co. Ltd was heavily funded by the Ministy of Science and Technology of China and financially supported by the Shanghai municipal government.

UniEnegy Tecnologies (Seattle, Washington) and Rongke Power were expected to deploy an 800-megawatt hour vanadium flow battery on the Dalian Peninsula in northern China. The China National Energy Administration approved the application of the battery into the utility grid owing to its competitive price, lack of emmissions, and operational flexbility.

Czechia

Nikom (part of EVRAZ plc) had an FeV production capacity of 4940 t/yr. Nikom has one processing facility, which is used to process V_2O_5 from Russia and China and also vandium trioxide from Vametco into FeV.

South Africa

On April 13, 2015, EVRAZ Highveld Steel and Vanadium Ltd were placed under business rescue procedures to avoid liquidation. The rescue procedures were expected to either result in Highveld being refinanced or restructured or, if that was not possible, to undergo liquidation under the supervision of a business rescue practitioner to maximize the return to creditors.

Vanchem Vanadium Products Pty Ltd (eMalahleni) stopped production in May 2015 after its raw material suppplier, the Mapochs Mine, went into business rescue along with its owner, EVRAZ Highveld. However, at the end of 2015, Vanchem went into business rescue again when its raw material supply from the Mapochs Mine ended. Vanchem, part of Switzerland-based Duferco S.A, produced approximately 5000 t/yr of vanadium products prior to being in business rescue. In 2016, EVRAZ Highveld decided to close the company completely, which could invlove selling the company in one piece, selling parts of it, or selling off its assets.

In 2016, Bushveld Mineral Ltd agreed to purchase EVRAZ's 78.8% holding in Strategic Minerals Corp., which owns the Vametco vanadium mine and plant in Brits, North West Province. Vametco Alloys Ltd produced 2419 t of vanadium in 2015 in the form of Vanadium Nitride and Vanadium Oxide. Its plant has a capacity of 2750 t/yr which could increase to 3340 t/yr through some plant improvements.

Bushveld Minerals was also developing its Mokopane vanadium project in Limpopo Province. The company announced it would be focussed on the growing interest in the usage of VRBs. However, as of May 2016, Bushveld Minerals announced that $7.7 millions would be needed to complete further technical studies, and with current market conditions, a strategic partner involvement did not appear forthcoming.

Glencore Xstrata plc (Baar, Switzerland) announced that its Rhovan Vanadium facility, 30 km northwest of Brits, produced 9570 t of V_2O_5 in 2016, a slight increase compared with 9480 t of V_2O_5 produced in 2015.

FOREIGN TRADE

The exports of ferrovanadium decreased sharply to 213 tonnes in 2017-18 as compared to 460 tonnes during the previous year. Exports were mainly to Netherlands (37%), Belgium (23%), Oman (19.7%), and USA (9%) (Table-4). No exports and imports of vanadium ore and concentrates were reported in 2017-18 (Table-5). On the other hand, the imports of ferrovanadium were 718 tonnes during the year 2017-18 as compared to 311 tonnes during the previous year. The imports were mainly from Korea, Rep. of (27%), China (16%) and Japan (18%) (Table-6). The imports of vanadium ores and concentrates during 2017-18 increased to 491 tonnes as compared to 268 tonnes in the previous year (Table-7).

Table – 4: Exports of Ferrovanadium (By Countries)

Country	2016-17		2017-18	
	Qty (t)	Value (`'000)	Qty (t)	Value (`'000)
All Countries	**460**	**493144**	**213**	**410524**
Netherlands	180	198865	80	189130
Belgium	170	177534	50	88803
Oman	10	9936	42	64473
USA	23	25046	20	41069
UAE	20	20298	15	18264
Turkey	1	984	2	3253
Pakistan	++	594	1	1296
Bangladesh	-	-	1	1094
Mauritius	5	5186	1	1081
Malaysia	1	808	1	799
Other countries	50	53893	++	1262

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

Country	2016-17 Qty (t)	2016-17 Value (`'000)	2017-18 Qty (t)	2017-18 Value (`'000)
All Countries	**++**	**25**	-	-
USA	++	25	-	-

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

Country	2016-17 Qty (t)	2016-17 Value (`'000)	2017-18 Qty (t)	2017-18 Value (`'000)
All Countries	**268**	**15868**	**491**	**89745**
Netherlands	52	6749	208	48934
Chinese Taipei/ Taiwan	-	-	133	22841
Vietnam	-	-	130	10273
Mexico	24	814	18	7614
Korea, Rep. of	-	-	2	83
Belgium	47	4386	-	-
Germany	145	3919	-	-

Table – 6 : Imports of Ferrovanadium (By Countries)

Country	2016-17 Qty (t)	2016-17 Value (`'000)	2017-18 Qty (t)	2017-18 Value (`'000)
All Countries	**311**	**372113**	**718**	**1489369**
Korea, Rep. of	32	41615	194	484485
China	149	179779	113	251126
Japan	81	106324	132	239479
Russia	-	-	88	127134
Latvia	9	7637	58	99121
South Africa	-	-	32	87014
Netherlands	-	-	20	56525
Czech Republic	8	12896	16	44306
Switzerland	-	-	16	43529
Chinese Taipei/ Taiwan	-	-	13	33893
Other countries	32	23862	36	22757

FUTURE OUTLOOK

The worldwide demand for vanadium is directly related to the demand for steel specially with demands 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 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.