

VANADIUM MARKET IN THE WORLD

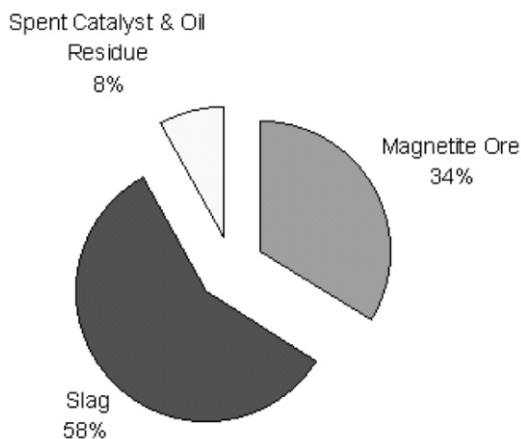
Present Status, Price Trends & Future Prospects

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Introduction :

Vanadium is a brittle, very hard metal, light silvery in colour which is stable in dry air at room temperature and oxidizes at high temperatures. It is the seventeenth most available element in the earth's crust with content of 0.015%. However, it is considered as a rare element since it is very much dispersed and the available mining techniques are costly enough to extract it. The element is found in a large number of minerals of which the most important are carnotite, roscoelite, vanadite, mottramite and patronite in concentrations that would be uneconomical to mine. Consequently, it is recovered as a by-product or co-product and is generally sourced in its primary state from deposits of titaniferrous magnetite, phosphorous ores, uranium ores, iron sands, oil, oil shale, tar sands and vanadiferrous clays. It can also be sourced by recycling spent Ni-Mo and Co-Mo refinery catalysts in petrochemical industry and ash produced by combustion of oil emulsion in power stations. The most important sources of vanadium are listed in Fig.1 which reveal the dominant role of vanadium bearing slag & magnetite ore for production of vanadium.

FIG.1. SOURCES FOR VANADIUM PRODUCTION



About 100 M/T of magnetite ore is required to produce 1.5 M/T of V₂O₅. Here, the normal mining cost is associated with open cast mining and is highly sensitive to transportation cost

due to low % V in ore (0.3%-2% V₂O₅) which necessitates the proximity of mines & plants for economic production. V₂O₅ containing slag (17% - 22% V₂O₅) & Spent catalysts/Oil residue is sold by steel producers to interested converters in various parts of the world as vanadium bearing ore on a formula linked to published vanadium prices. It is to be noted that the cost of converting these three types of vanadium sources to saleable V₂O₅ flake is very similar once material is delivered to conversion facilities.

Vanadium is introduced in steels as ferro-vanadium. About 1.5 M/T of V₂O₅ is required to produce 1 M/T of ferro-vanadium. Globally, about 87% of the vanadium consumption is in steel industry. Hence, the fortune of the vanadium market is linked to the growth of the steel industry.

Vanadium Deposits :

The total reserves of vanadium in the world is about 63 million tons. Out of this, only 13 million tons are exploitable and 38 million tons are in the reserve base as on 2004. A list of economic and reserve base of vanadium in the world is shown in Table 1.

COUNTRY	ECONOMIC RESERVE	BASE RESERVE
CHINA	5 Million tons	14 Million tons
SOUTH AFRICA	5 Million tons	12 Million tons
RUSSIA	5 Million tons	7 Million tons
U.S.A.	4500 tons	4 Million tons
OTHERS	--	1 Million ton
TOTAL WORLD	13 Million tons	38 Million tons

Table 1. Economic and Base Reserve of Vanadium in the World

South Africa, Russia and China constitute majority of the reserves playing a dominant role in vanadium production. It is anticipated that the reserve base in U.S.A. and Australia would become important in the near future.

South Africa :

Vanadium occurs in seams of titaniferrous magnetite situated in Bushveld complex having an average of 1.5% V₂O₅. The estimated 12.5 million tons of contained vanadium



to a depth of 50 mts in South Africa represent the world's largest reserves. The production comes from Anglo American's HighVeld Steel and Vanadium Corporation [HighVeld], Vametco Minerals Corp. [Vametco], Vanadium Technologies [Vantech] and Rhombus Vanadium Holdings Ltd. [Rhovan].

HighVeld which is the largest producer of vanadium in the Western World operates the Mapochs mine in the north eastern province of Mpumalanga where it extracts vanadium rich titaniferrous magnetite. It also produces vanadium rich slag and oxides from two plants at its works in Witbank. Slag is recovered from HighVeld steel works and is processed with ore at the Vantra plant which has 8170 tons per year of vanadium content roasted capacity for production of vanadium pentoxide. It is then converted to ferro-vanadium through aluminothermic and electric arc furnaces.

Vametco is a subsidiary of Strategic Minerals Corp. [Stratcor] of U.S.A. which has scaled down its mining operation and switched to use of vanadium bearing slags from South African steel producers. This plant has a capacity of 6000 tons per year of vanadium content involving in production of ferro-vanadium and proprietary nitrogen containing Nitrovan alloys.

Xstrata AG, a Swiss based mining group owned 41% by Glencore International AG possess Vantech and Rhovan plants for vanadium production. These two operations supply about 15% of the world vanadium production. While Vantech operates Kennedy's Vale vanadiferrous magnetite in Mpumalanga province with rated capacity of 6000 tons per year of V₂O₅ and 2400 tons per year of ferro-vanadium. However, the plant was closed down in early 2004. Rhovan facility has Ba Magopa mine in the north west province producing V₂O₅ from vanadiferrous magnetite with rated capacity of 7000 tons per year of V₂O₅. The mining operation located near Brits in Bophuthatswana has proven and probable reserves of 90.6 million tons grading V₂O₅ down to a depth of 60 mts. Xstrata commissioned a 6000 tons per year aluminothermic ferro-vanadium facility to convert V₂O₅ on site.

Russia :

The installed capacity in this country is about 20000 tons per year of V₂O₅. However, it is reported to run at less than 50% of the capacity. V₂O₅ production is mainly from titanomagnetite and ilmenite deposits located around Kachkanar and Sverlov in Ural mountains and in Kola peninsula. Vanadium is mined from Mount Kachkanar, Gusevogorsk and Pervouralsk. The ore containing 0.5% V₂O₅ is used for making pig iron at the Nizhny Tagil Iron and Steel

Works as well as at Chusovskoy Metallurgical Works which is further treated to produce slags having 17% to 21% V₂O₅. These slags are then processed at Tulatchermet [near Moscow] and Chusovsky plants for production of 50% and 80% ferro-vanadium.

China :

Vanadium is produced from mining of titaniferrous magnetite deposits located in Sichuan and Anhui provinces in central and eastern China as well as from slags imported from Russia, South Africa and New Zealand. Panzhihua iron ore mine in Sichuan is reported to possess reserves estimated to be 1.2 billion tons with 33.2% Fe₂O₃, 11.6% TiO₂ and 0.3% V₂O₅. Vanadiferrous slags are also recovered from Maanshaan complex in Anhui province and from iron works in Hubei and Chengde provinces. The slags are then processed in about seven plants for production of V₂O₅ with total capacity of 8500 tons per year out of which four plants possess facilities to convert them to ferro-vanadium having total capacity of 4000 tons per year.

United States of America :

The production of vanadium is about 4000 tons per year of vanadium content that comes from eight firms located in Arkansas, Louisiana, Texas and Utah. These plants produce vanadium pentoxide, ferro-vanadium, vanadium chemicals and vanadium metal by processing vanadium bearing iron slags, fly ash, petroleum residues and spent catalysts. Strategic Minerals Corp. is the largest producer of V₂O₅ and Shieldalloy Metallurgical Corp. is the biggest producer of ferro-vanadium in U.S.A.

Australia :

The Windimurra mine run by Xstrata AG is reported to be the largest primary producer of vanadium pentoxide in the world. The mine is located near Mount Magnet in the Murchison district of Western Australia with deposits of vanadiferrous magnetite ore. The reserves are estimated to be 106 million tons grading 0.47% V₂O₅. Presently, it is operating at about 7800 tons per year of V₂O₅. Clough Resource Coates Ridge vanadium project near Wundowie in Western Australia possess vanadiferrous magnetite ore deposit which was closed in 1985 after production of 300 tons of V₂O₅. There is also, Julia Creek Oil shale deposit in north eastern Australia's Queensland province.

Production Processes :

Vanadium Pentoxide

Magnetite Ore Reduction :

- a) The titaniferrous magnetite ores having 0.3% - 2% V₂O₅ is used for smelting pig iron to produce hot metal containing

0.5% - 1% vanadium. The hot metal is transferred to shaking ladles, transfer ladles and BOF/Bessemer/Open Hearth furnaces depending on the facilities available in the steel plant involving oxidation of vanadium and thus capturing in the slag. About 90% of the vanadium in the pig iron is reverted to slag as $\text{FeO.V}_2\text{O}_3$. In terms of V_2O_5 , the total content of V_2O_3 and V_2O_5 comes to about 10% - 25%. The converter slag is crushed and milled in ball mills and the magnetic particles are eliminated by magnetic separation. The slag is then mixed with sodium sulphate or sodium carbonate and heated in kiln in an oxidising atmosphere for production of calcine containing sodium vanadate. The calcine is cooled and sodium vanadate is leached from it using water. This solution is then treated with ammonium sulphate to precipitate ammonium polyvanadate. The ammonium polyvanadate is filtered from the barren solution, dewatered and heated to remove ammonia leaving V_2O_5 . A significant quantity of V_2O_5 produced is further reduced to V_2O_3 for assisting in conversion to ferro-vanadium. Vanadium units are produced through this process and the below mentioned process widely in China, Russia and South Africa.

- b) Another process is to recover vanadium directly by chemically processing the ores without smelting vanadium bearing iron. This direct treatment is carried out similarly as mentioned in the processes above through roasting and leaching methods for production of vanadates and oxides. This is economical only when V_2O_5 in the ore is in excess of 1.5%. These methods are used in South Africa and Australia.

Vanadium Bearing Slag Reduction :

The converter slag obtained during steel making process is crushed and subjected to magnetic separation. The transfer of vanadium to soluble compounds is affected by the oxidising roasting of the slag at 770°C - 820°C with alkaline additions. Sodium chloride and silvinit are used as alkaline additions, the amount averaging 10% - 12% of the slag weight. The mixture is roasted in rotating kilns. This results in oxidation of V_2O_3 to V_2O_5 and combines with alkaline additions producing compounds soluble in water i.e. sodium vanadates. The roasted slag is then leached and insoluble particles are filtered. The filtrate containing sodium and potassium vanadates are acidified with sulphuric acid and heated to produce 80% - 90% V_2O_5 . This precipitate is filtered, dried and melted in dry hearth furnaces at 700°C to 750°C . The liquid vanadium pentoxide is poured onto a massive iron disc where it solidifies in the form of platelets. So, the recovery of vanadium averages 80% - 85%.

Reduction of Oil Residues / Spent Catalysts :

Reclamation of vanadium contained in ash from power plants as well as from oil burnt from spent catalysts and other residues. These are subjected to roasting and leaching process as mentioned above to form vanadates and vanadium oxides. In case of spent catalysts, recovery of vanadium takes place along with Mo, Co and Nickel. This method is more popular in North America and Japan.

Ferro - Vanadium :

Silicothermic Reduction :

The manufacture of ferro-vanadium by the reduction of the oxides with carbon has not found wide application because vanadium is a carbide forming element and the resulting alloy can contain carbon up to 6% which cannot be used for melting low carbon steels where ferro-vanadium is commonly used. Therefore, ferro-vanadium is produced by the reduction of vanadium pentoxide by silicon and aluminium. The best method for bulk production of ferro-vanadium is the silicothermic process. This process is carried out in electric smelting furnaces. The raw materials required are melted vanadium pentoxide, ferro-silicon, soft iron cuttings and lime. Firstly, the estimated amount of iron cuttings are charged into a well heated bath and as iron melts down, a mixture of vanadium pentoxide with silicon and lime are added wherein the ferro-silicon amount added is in excess required. As soon as the mixture melts, the heat is killed for the process to complete. During this period, the slag is drained out. The silicon content of the alloy at the end of the reduction period reaches about 15%. After slagging off, the alloy is refined with silicon and this requires charging of vanadium pentoxide and lime. The vanadium pentoxide contained in the slag attacks the alloy silicon and as a result, vanadium is reverted to the slag while the silicon content in the alloy decreases. At the end of the refining period, the alloy is sampled. A small amount of aluminium is added to promote full reduction of vanadium contained in the slag. The vanadium content in the slags have to be carefully controlled when smelting ferro-vanadium in electric furnaces. Intermediate de-slagging can be done if vanadium pentoxide content in the slag is below 0.5%. Ferro-Vanadium produced is teemed into vertical moulds and after cooling, it is dressed and packed in cases or metallic drums.

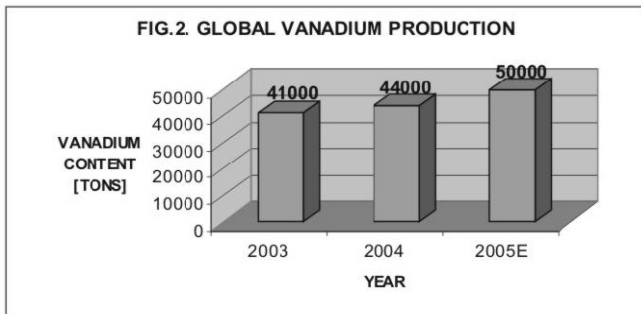
Aluminothermic Reduction :

Ferro-Vanadium is smelted with bottom priming which ensures uniform flow of the process wherein 200kg-400kg of the prepared mixture (it constitutes of a mixture containing pure vanadium pentoxide along with aluminium, iron cuttings with additions of lime and spar as flux) is charged onto the shaft bottom and ignited by means of a priming mixture

composed of sodium nitrate, aluminium powder and electron turnings or fused barium pentoxide, aluminium/magnesium powder which is ignited by red hot iron rod or electric spark. After the beginning of the aluminothermic process, the remaining mixture is charged at a uniform rate from a hopper. This process is capable to produce ferro-vanadium with vanadium content up to 97%.

Global Vanadium Production :

The global total vanadium content production has shown a growth of 7.3% in 2004 over 2003. This high level of production took place in 2004 despite the closure of depleted and inefficient facilities in the world in recent years. It has been observed that, in 2004, capacity utilization levels of various vanadium sources for vanadium production were excellent. The capacity utilization of steel slags was to the tune of 80%, vanadium ore about 80%, oil residues about 82% and spent catalysts to the tune of 63% for the production of vanadium. This enables one to understand the dominant role of secondary materials especially steel slags, oil residues and spent catalysts. Vanadium production in the world from 2003 onwards is illustrated in Fig.2.

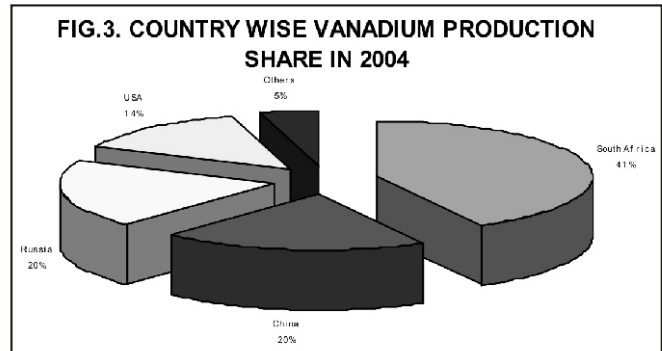


As vanadium occurs widely as a by product or co-product, the production increase is due to the same economic driving forces that led to increased demand for vanadium. This is because, increased steel production globally has generated larger volumes of vanadium bearing slag. Also, the growing demand for energy paved way towards generation of huge volume of vanadium bearing oil residues and stimulated the production of vanadium co-products from uranium operations. There exists still spare capacity in all vanadium sources. Therefore, the strong pricing and demand is expected to stimulate increased production from these sources in future.

A look at country wise production reveals that South Africa remains as the largest producer of vanadium despite the closure of Vantech plant of Xstrata around the beginning of 2004. The Xstrata Rhovan facility increased its output in 2004 to partially offset the reduction at Vantech. Production at HighVeld also increased and the overall vanadium production in South Africa reached a new high of 35000 tons of vanadium pentoxide. Country wise vanadium production share in 2004 is shown in Fig.3. Vanadium production in Russia which was low

at 9000 tons in 2003 reached levels of 16650 tons of vanadium pentoxide. The actual production might probably be augmented by some ferro-vanadium releases in early 2004 from governmental stockpiles.

Surging domestic demand for vanadium led to sharp rise in Chinese production. Chinese output rose by 60% between



2001 and 2003 and expected to continue this strong upward trend for the coming two to three years. In 2004, the production in China was 16650 tons of vanadium pentoxide. Production elsewhere in the world also rose by 10% in 2004 compared to 2003 largely due to modest increase in U.S.A. production.

In India, the total capacity of ferro-vanadium production stands at about 1075 tons in 2005-06. This is produced through aluminothermic reduction of vanadium pentoxide. Vanadium pentoxide availability in India is as a by product of the aluminium manufacturing industry. The more the production of aluminium, the higher is the availability of vanadium pentoxide. However, the price of vanadium pentoxide available to the Indian ferro-vanadium producers is as per the international rate of this substance. Ferro-Vanadium production in the country stands at an excess of 900 tons in 2005-06 and the production has been growing at a mammoth 11.62% per annum from 2002-03 onwards.

World wide vanadium pentoxide build up which was to the tune of 22500 tons started liquidation from 2003 onwards which reduced to levels of 6750 tons in 2004 is expected to result in no stock pile in 2005. Hence, expanded world wide production of vanadium would be needed to satisfy the needs of the market from 2005 on. With China already increasing the trend of vanadium production from magnetite ore, steel slag, oil residues and spent catalyst, the start of vanadium production from unused vanadium bearing slags in Russia in 2005 coupled with restart of production from uranium and vanadium co-ores from 2005 onwards in U.S.A. considering the high prices of uranium/vanadium is expected to increase vanadium production even with continued production rationalization in South Africa and Australia.

(To be concluded in next issue...)