Bull. Mater. Sci., Vol. 19, No. 2, April 1996, pp. 179–199. © Printed in India.

An integrated approach to the optimum utilization of national tungsten resources: Technology gaps

S L N ACHARYULU and P RAMA RAO*
Defence Metallurgical Research Laboratory, P O Kanchanbagh, Hyderabad 500058, India
*Defence Research and Development Organization, Sena Bhavan, "B" Wing 156, New Delhi 110001, India

Abstract. A critical review of the current status of tungsten resources, of state-of-the-art processing technology and of product development in India vis-a-vis the world scenario is presented. An attempt has been made to identify technology gap areas requiring attention.

Keywords. Tungsten; scrap recycling; tungsten powder; solvent extraction; APT production; carbide scrap.

1. Introduction

Tungsten is one of the important metals for the modern industry due to its high density and high temperature properties, particularly hardness in the form of tungsten carbide. Tungsten found wide usage as a cutting tool (tungsten carbide) and as alloying element in steel during the rapid industrialization phase between the two world wars. Hard core tungsten penetrators using tungsten carbide for defeating frontal armour were developed during 1940's. The war efforts also led to a boost in tungsten consumption as a cutting tool for the manufacturing industry. As illustrated in figure 1 the demand for tungsten has been steadily growing. A sharp decline in tungsten prices is noted since the beginning of the eighties (Lenton 1987), as shown in figure 2. Considering the strategic importance of tungsten, particularly for a country like India deficient in tungsten resources, there is a need to work out a national policy towards the optimum utilization of tungsten resources available in the country. Some of the issues facing the national tungsten industry are discussed in this paper.

2. Indian scenario

With globalization of the world market, a new scenario is emerging with a dominant role being played by China in deciding the price and supply pattern of tungsten powder. This situation has compelled most of the tungsten-consuming countries to devise new strategies in order to assure supplies to meet domestic requirements. India needs to formulate a strategy to contend with the emerging scenario through an integrated approach to tungsten exploration, mining, beneficiation, processing, product development and application including recycling of scrap.

The present requirement of tungsten in India is met largely through imports of powder and ore concentrates. Domestic production of powder is about half of its total requirement. The production of ore concentrate is insignificant. The only source of tungsten, presently available in the country, is the Degana mine in Rajasthan owned by Hindustan Zinc Ltd., producing around 10 tons of concentrates. The indigenous ore concentrate has always been in short supply compared to what is required. Even so, the

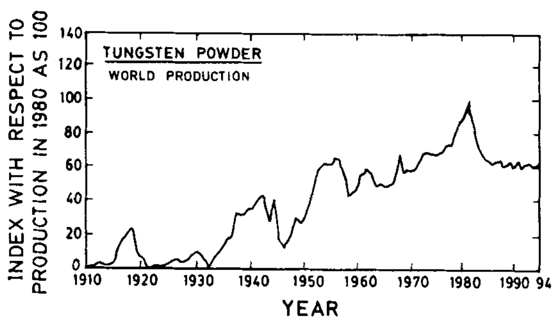

Figure 1. Growth in world production of tungsten powder.

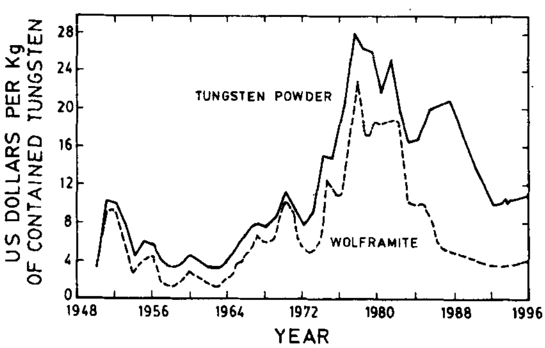

Figure 2. Price fluctuations in the cost of tungsten powder and wolframite (Lenton 1987).

Table 1. Demand in India for tungsten concentrate in tonnes (Anon 1991)

Application	1989-90	1994-95	1999-2000
Cutting tools	740	1100	1600
Steel	1090	1910	3484
Filament	122	216	382
Defence	1500	1500	1500
Total	3452	4726	6966

concentrates produced in India are not much in demand due to the high cost attributable to rather primitive methods of concentration, inconsistent supplies and inability to meet the stringent specifications comparable to imported concentrates. The low tenor of Degana ore deposit is the root cause of indifferent progress in the downstream processing of the ore.

The demand and production of tungsten ore concentrates are indicated in tables 1 and 2 respectively. India has proven reserves of 35,000 tonnes of tungsten concentrate in Rajasthan, Maharashtra, Bengal, Andhra Pradesh, Uttar Pradesh and Karnataka (Dhruva Rao 1987) (figure 3). Inspite of the vast potential reserves of tungsten in the country, economic recovery of the metal value poses problems. Recovery is complex due to the manner of its dissemination, low tenor of occurrence and its association with

Table 2. Production of tungsten concentrate in India.

Year	Karnataka		Rajasthan		West Bengal		Total	
	Quant.	Value	Quant.	Value	Quant.	Value	Quant.	Value
1980	—	—	40500	3240	3608	379	44108	3619
1981	3571	424	30371	3645	8466	974	42408	5043
1982	8362	843	47415	5690	5961	686	61738	7219
1983	13571	1211	31090	3762	820	75	45481	5048
1984	18210	2205	39396	4728	—	—	57606	6933
1985	20854	2318	30450	3743	—	—	51304	6061
1986	19350	1877	25908	3364	—	—	45258	5241
1987	19700	1459	31416	5027	—	—	51116	6486
1988	13050	963	25267	4674	—	—	38317	5637
1989	0	0	24215	4480	—	—	24215	4480
1990	0	0	22641	4189	—	—	22641	4189
1991	0	0	10863	2009	—	—	10863	2009

Quantity Unit: Kg Value Rs. in thousand

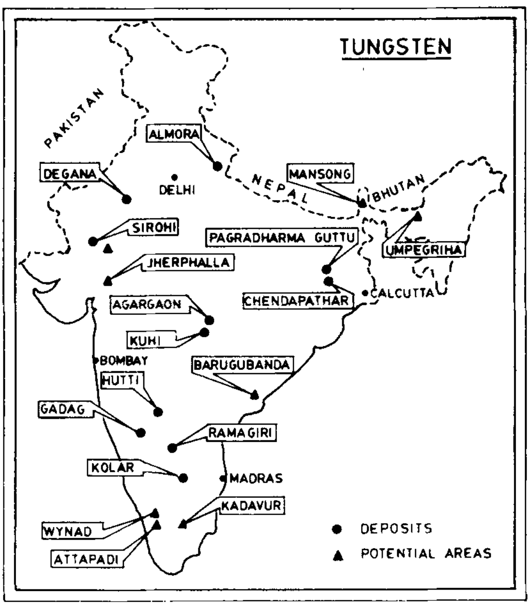

Figure 3. Distribution of tungsten resources in India (Dhruva Rao 1988).

various other elements. Consequently, the cost of indigenous concentrates is prohibitive at present (Krishna Rao 1996). Efforts need to be put in to developing a technological base for optimum utilization of tungsten resources available in the country. As an insurance against short fall, and uncertain demand/supply position, it is also necessary to create a stockpile to meet demands in critical situations.

There is no simple generic approach to reduce materials import vulnerability. An overall strategy to reduce the country's reliance on uncertain sources of supply of strategic materials should be based on a combination of the known approaches such as

Table 3. State-wise resource estimation of tungsten deposits in tonnes.

Place	Identified	Potential deposit over 0·1% WO_3	Potential deposit below 0·1% WO_3
Rajasthan			
Degana	284	—	6315
Sirohi	137	129	—
Maharashtra			
Agaragaon	—	—	1298
Khobna	—	8400	—
Kuhi	—	3170	—
West Bengal			
Chandapathar	—	214	—
Andhra Pradesh			
Burugubanda	—	2000	—
Karnataka			
KGF-Balaghat &	—	—	—
Walker	—	813	—
Hutti	—	205	—
Uttar Pradesh			
Almora	—	2250	10000
Total	1234	14318	17613

the following:

- increase the diversity of world supply of strategic metals through the development of promising deposits in countries having favourable political orientation, through exploration and operation of lease rights.
- decrease the demand of strategic metals through the implementation of improved manufacturing processes and recycling of the scrap and waste and identification of alternative materials.
- create strategic stockpiles.

2.1 *Resources assessment and prospects*

Most Indian deposits are of low grade ranging from 0·05 to 0·3% WO_3 (table 3). Each deposit has specific problems with regard to its nature of occurrence, association with other minerals and dissemination. Tungsten mining activity in the country is in a stage of infancy. There is a need for evolving scientific exploration, mining and beneficiation technologies (Anon 1988). The occurrence of associated high value elements of strategic or economic value should also play a decisive role in the development of these deposits. Some of these issues are discussed in the other papers included in this volume.

The mineral exploration activity in our country must encompass the following:

- Choice of favourable target areas on the basis of relevant geological modelling.
- Speedy publication of geological maps.

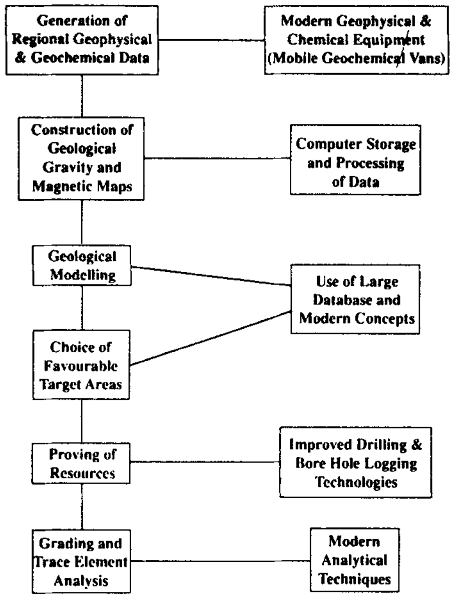

Figure 4. Strategy for exploration based on scientific inputs.

- Generation of regional geophysical and geochemical data; especially gravity and magnetic maps so that geological models become more relevant.
- Development of polymetallic deposits for extraction of major metals alongwith low content metals aggregating to economically workable levels.
- Application of modern exploration technologies like:
  - Introduction of rapid in-field analytical techniques such as portable XRF on a wider scale to speed up generation of geochemical data.
  - Computer processing of large geological and geophysical data already available and endowing geophysical instruments with greater capabilities for storage and interpretation of data.
  - Improved drilling and bore hole logging technology to generate a larger data base.

These essential features pertaining to scientific inputs in exploration are summarized in figure 4.

The present practice of mining has been to open the deposits by making adits and underground inclines. Stopes are formed between two levels driven at vertical intervals of 20 meters. The ore from stopes is taken off by drilling and blasting overhead. Loading is manual. Big boulders are normally rejected underground and the rest is transported out and dumped on the surface where hand sorting of tungsten ore portion is carried out based on visual inspection. Drilling and blasting operations have proved inefficient and sockets are left unexploited. As concentration is done by manual methods, it is labour intensive, less productive and covers only certain size fractions. In this process, only 40–50% of the run-of-mine ore reaches panning stage for higher concentration. The tungsten value lost in fines is quite significant as tungsten tends to concentrate in both fine as well as coarse grains. Explorations at Degana have indicated 'W' content of the order of 0·1 to 0·2% in granite reserves with the distribution pattern covering a wide area both in surface and

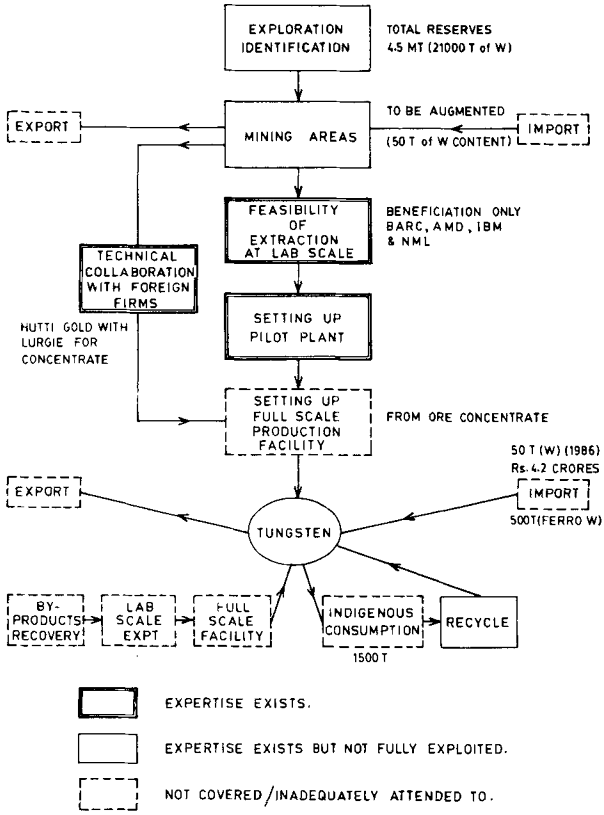

Figure 5. Indian current situation regarding tungsten.

depth (Patni *et al* 1987). In the light of homogenous and bulk occurrence of huge quantity, open cast mining with modern sorting techniques for beneficiation is essential. By adopting the latest technologies like automatic photometric ore sorting machine (Willey 1982), the mining activity could be attempted in a more cost effective way so that lesser amount of ore can be handled with better separation of gangue at mine site itself.

The need for intensive exploration and mining efforts is obvious in the case of tungsten. Increasing scientific inputs into our mineral exploration activities needs to be encouraged. Substitution and recycling are needed to be given priority to reduce imports. A status of the prevailing situation is presented in figure 5 which brings out the existing technology gaps.

Established R and D centres such as Ore Dressing Section of Bhabha Atomic Research Centre (ODS, BARC), Atomic Minerals Division (AMD), National Metallurgical Laboratory (NML), Jamshedpur, Regional Research Laboratory (RRL), Bhubaneshwar, Defence Metallurgical Research Laboratory (DMRL) and Tata Research Development and Design Centre (TRDDC), Pune have carried out extensive bench scale and pilot plant tests on the various tungsten ore deposits in the country (Krishna Rao 1996; Pradip 1996). Based on this work, there is a need to identify an appropriate flow sheet for economic exploitation of each tungsten ore deposit available

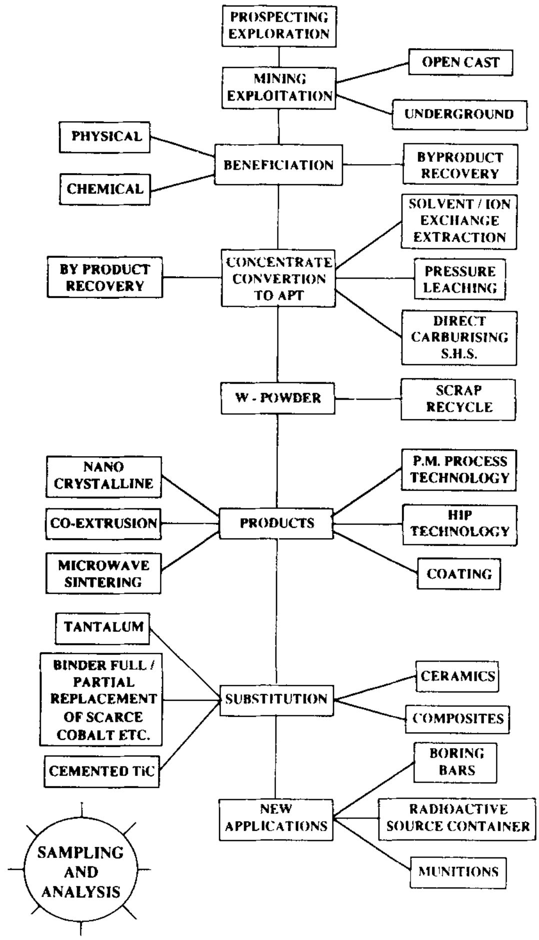

Figure 6. Strategy for integrated development of tungsten resources and applications.

in the country. Hindustan Zinc Ltd (HZL) are making sincere efforts for cost-effective utilization of Degana tungsten ore, including the possibilities of recovery of lithium, rubidium and caesium as byproducts (Jakhu and Ray 1996).

An integrated development strategy for better utilization of Indian ores including processing for higher yields alongwith extension of application areas is proposed in figure 6. Sampling and analysis using the latest techniques to deal with the irregularity of tungsten occurrence with unpredictable frequency and dimension in the host rocks is needed. These complexities of occurrence present a difficult scenario for assessment of tungsten content (Rama Rao *et al* 1987). Detailed sampling and analysis procedures have, therefore, to be specifically evolved. A group comprising representatives from Departments of Defence R and D, Scientific and Industrial Research, Atomic Energy and Mines in association with industries namely M/s Sandvik and M/s Widia have established, after assessing various methods on a round robin basis, a procedure to sample and analyse the Indian ores. Various techniques available and found effective in the analysis of low grade tungsten ores in India are also critically reviewed in this volume (Srivastava *et al* 1996).

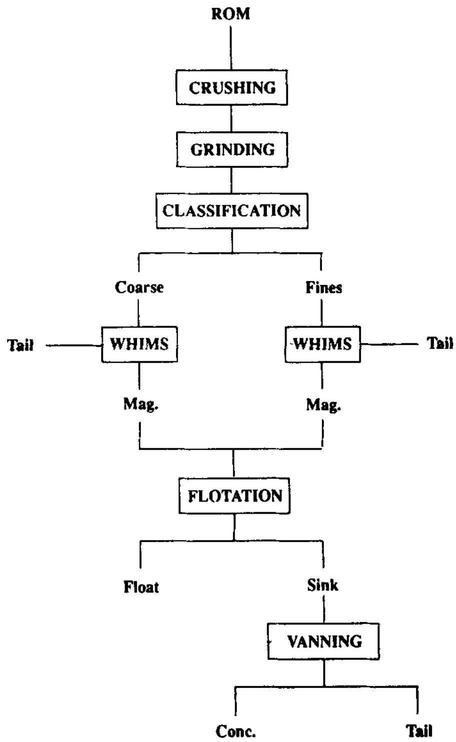

Figure 7. Schematic flowsheet for concentration of very lean ores from Degana, Rajasthan.

2.2 *Processing of tungsten ores*

Tungsten occurs in nature primarily in two ore forms viz. wolframite [$(FeMn)WO_4$] and scheelite [$CaWO_4$]. Both these forms are amenable to hydrometallurgical extraction of tungsten metal. Naturally occurring tungsten ores can occasionally contain upto several percent WO_3 content. But such rich ores are uncommon and are present in small tonnage. Generally, ores containing > 0·5% WO_3 are taken up for economical extraction.

Innovative techniques are being developed for achieving an enrichment ratio of 125:1 to produce commercial grade concentrate i.e. 65% WO_3 in wolframite and 70% in scheelite (Walery 1982). The beneficiation of tungsten ores containing wolframite and scheelite involves gravity concentration in jigs, tables followed by magnetic separation wherever necessary in order to produce a marketable grade of concentrate. For example, in India, a beneficiation plant is being commissioned by Hindustan Zinc Ltd (HZL) for the beneficiation of low grade Degana ore (Jakhu and Ray 1995). A typical flow sheet for the beneficiation of tungsten ores is shown in figure 7. Various processing routes have been devised for converting scheelite and wolframite ore concentrates to high purity tungsten powder (figure 8). However, the method to be preferred for a particular plant will depend on the raw material feed characteristics, notably, WO_3-content and purity of the ore concentrate and composition of gangue minerals (Lassner 1982). In general, pressure leaching has been the choice in all conversion plants constructed within the last 25 years.

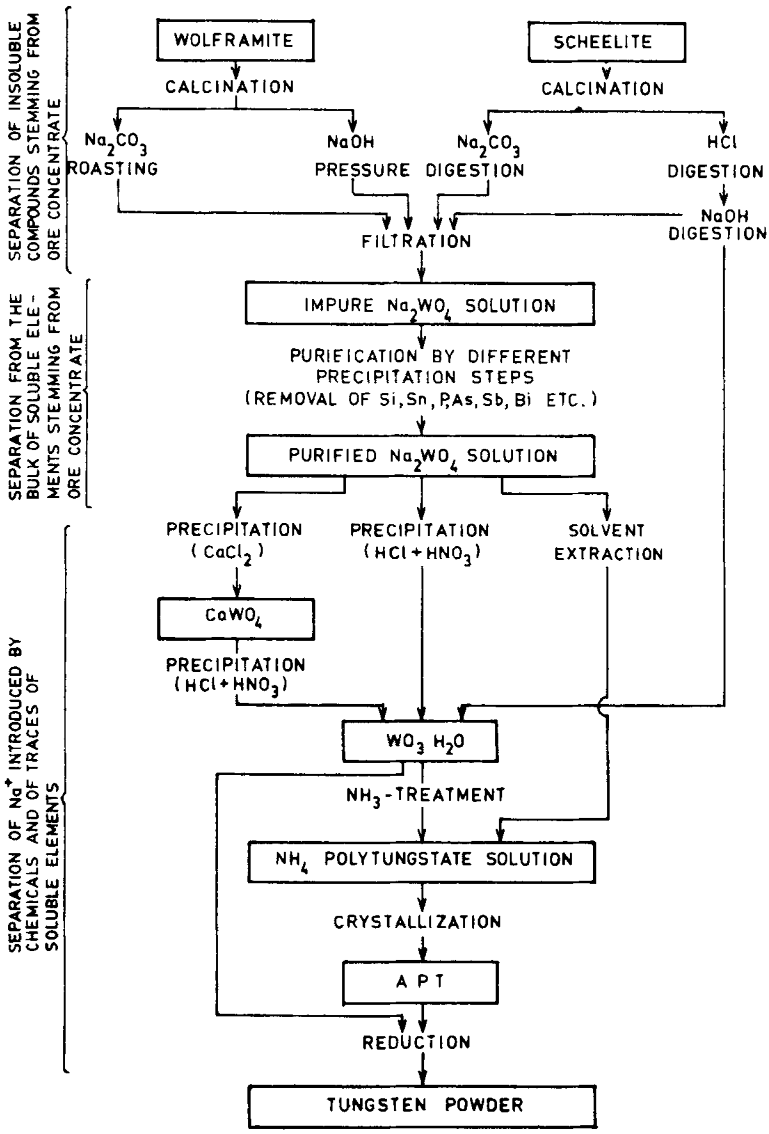

Figure 8. Flowsheet for the production of tungsten powder.

There are three main processing steps in ore conversion technology:

- Conversion of insoluble tungsten compounds to soluble sodium tungstate with separation of the insoluble gangue compounds.
- Purification of impure sodium tungstate solution by precipitation reactions.
- Production of a highly pure solid tungsten compound by conversion of sodium tungstate solution with emphasis on separation of traces of impurity elements.

Higher purity is achievable by adopting the APT route due to a slow crystallization phenomenon vis a vis the rapid precipitation techniques where impurity entrapment is more likely.

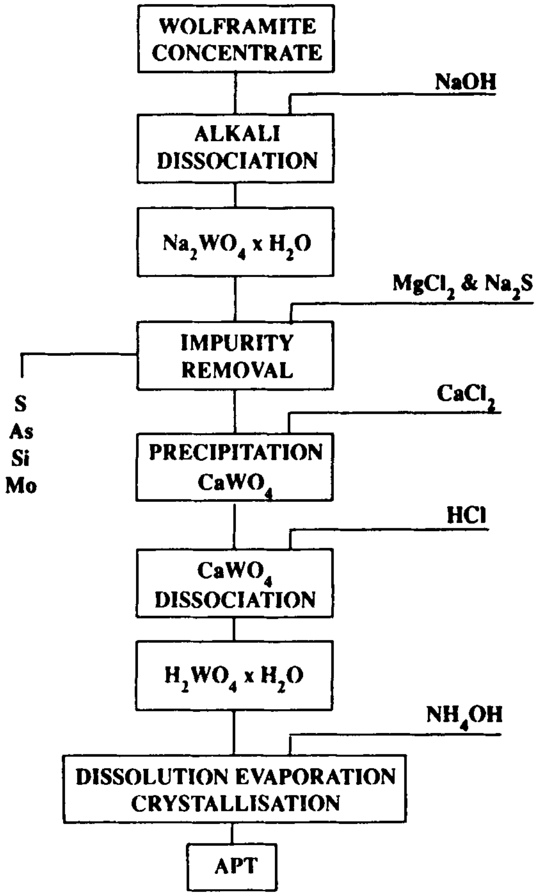

Figure 9. Flowsheet for APT technology with conventional technology.

2.3 *Processing to powder*

Based on the generic characteristics of ore concentrate, a conventional processing flow sheet is shown in figure 9. However, this processing route is only suitable for high grade ore concentrates. In the international scenario, most of the mining companies have started to look at low grade ore concentrate from the view point of converting it into APT by alternative processing techniques. This situation is warranted by the depletion of high grade ore and high cost of underground mining. The solvent extraction method and ion exchange techniques are being vigorously pursued by tungsten producers of China, Korea, etc. (figures 10 and 11). These processes have certain advantages in comparison to the conventional process with respect to better impurity level control, automation and capability to handle low grade ores. The major disadvantage is the problem of disposal of effluent liquids generated during the course of the conversion of ore concentrate to metal powder.

The relevance of solvent extraction/ion exchange processes is significant in the Indian context due to the low tenor of tungsten ore. A comprehensive approach is necessary for developing an appropriate process flow sheet for extraction from such

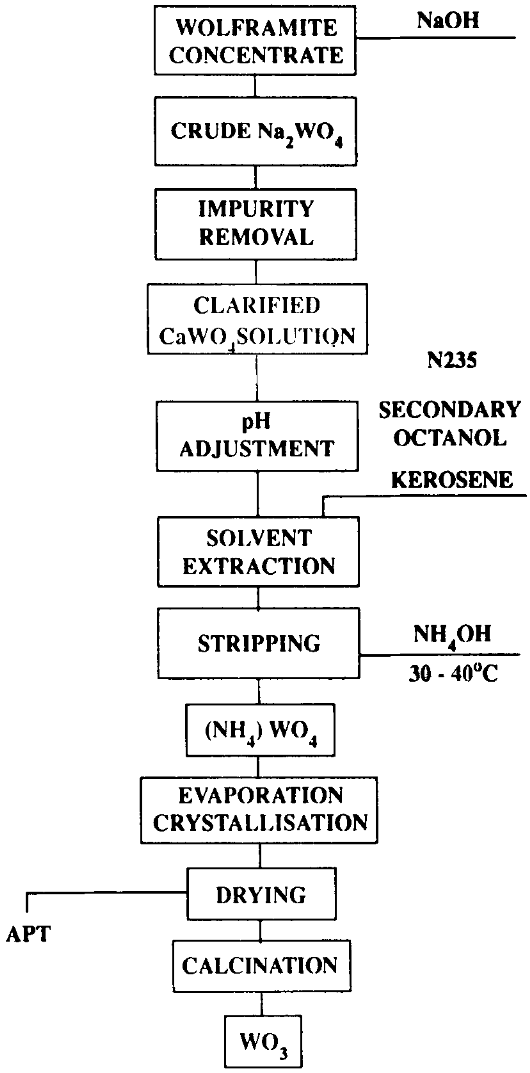

Figure 10. Flowsheet for solvent extraction process for APT production.

lean ores. Work carried out at the National Metallurgical Laboratory (NML), Jamshedpur, for example has clearly indicated the need to adopt a judicious combination of physical and chemical beneficiation so as to maximize the recovery of tungsten values from Degana tungsten ore (Premchand 1996).

2.4 *Powder processing*

The relative weightage of various cemented carbide cutting methods is: turning 33%, milling 17%, drilling 25%, tapping and reaming 13% and others 12%. Recent developments to improve the strength of cemented carbide has increased its use for

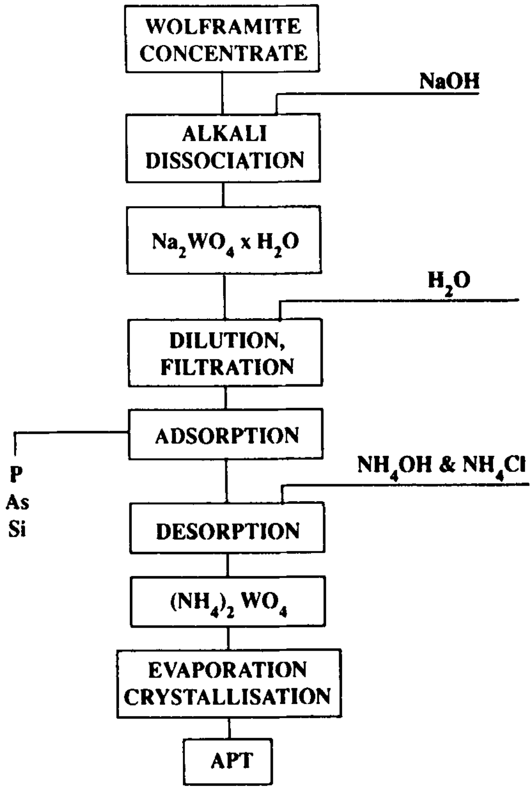

Figure 11. Flowsheet for APT production with ion exchange technology.

carbide tipped drills, solid drills and solid end mills. Such improvements have been brought about by reduction in defect levels in cemented carbides by application of the state of art technologies like hot isostatic pressing, pressure aided sintering and coating processes. These defect free cemented carbides find application in milling inserts, in more efficient cutting tools and even in dot matrix printer pins.

In India, cooperative efforts are in progress between Defence Metallurgical Research Laboratory (DMRL) and Sandvik Asia to introduce HIPing technology for cemented carbide for improving the performance in more aggressive situations. CVD and PVD techniques are also being studied and market evaluation is in progress.

A significant international trend is the development of more value added products directly from ore. GE, USA and CIS countries (Ruihe 1987) are attempting to directly produce tungsten carbide powder by adopting thermit-reduction principles. A schematic diagram is shown in figure 12. This approach is particularly relevant to the Indian industry because the consumption of W powder is predominantly for carbide manufacturing.

In general, tungsten powder is produced the world over by hydrogen reduction of WO_3 powder. This technology is well established in India by leading carbide manufacturers. The close interaction between R and D laboratories and user industries should result in establishing the latest solvent extraction technologies suited for our lean grade ores.

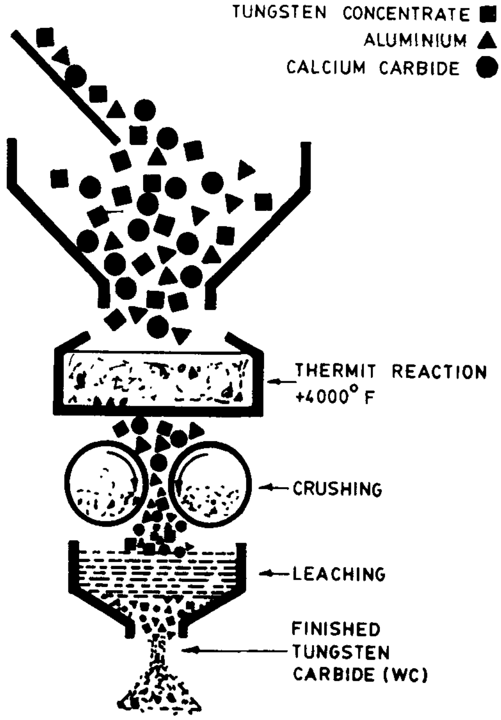

Figure 12. Production of tungsten carbide through thermit reduction process.

Table 4. India's consumption pattern of primary and secondary tungsten (tonnes of tungsten).

Type	1975	1981	1982	1983	1984
Consumption of tungsten ores and concentrates	9109	6642	5495	5834	7645
Consumption of secondary tungsten	3300	2600	2000	1800	2000
Total consumption	12409	9242	7495	7634	9645

3. Recycling of tungsten bearing scrap

Recycling of scrap is inevitable for all metals and materials, particularly in the context of present day concerns regarding environment, energy and resource conservation (Rama Rao *et al* 1987) (table 4). In the western world, much of the scrap is recycled. The recycling is approximately to the tune of 20% of total tonnage. Cemented carbide recycling, for instance in USA, is estimated to be 25–35% currently (figure 13). A typical melt for high speed steel manufacture contains well over 60–70% scrap. There is a low level of recycling, however, in such applications as lamp elements, welding electrodes, electrical contacts and chemicals. The extent of usage of secondary tungsten in any industry is not guided by availability of technology alone, but also depends on such economic factors, as market demand, production cost price of the ore as well as of the finished products. It is estimated that the present recycling process enables

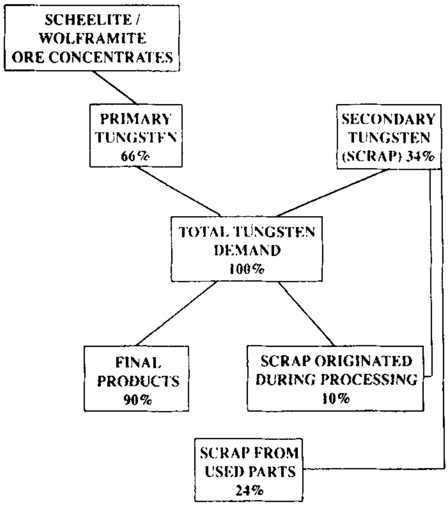

Figure 13. Tungsten scrap recycling pattern.

Table 5. Consumption and recycling pattern (total western world consumption of tungsten – 30,000 T/annum).

	Western Europe		USA	
	Consumption percent	Recycling percent	Consumption percent	Recycling percent
Cemented carbide	52	31	65	25–35
Steel industry	20	60–70	15	60–70
Pure metals	13	Low	10	Low
Chemicals	15	—	10	—

producers to save 20% of material cost in production of carbide. Table 5 shows the consumption mix in Western Europe.

3.1 *Scrap recycling practice*

Scrap is usually available in the following forms:

- Pure tungsten metal scrap
- Heavy alloy scrap
- Tungsten carbide scrap
- Tungsten containing steels

Each type of scrap has its own recycling scheme.

3.2 *Pure metal scrap*

Pure tungsten metal scrap recycling systems process scrap generated during the manufacturing of tungsten rod, tungsten wire and tungsten mill products. Figure 14

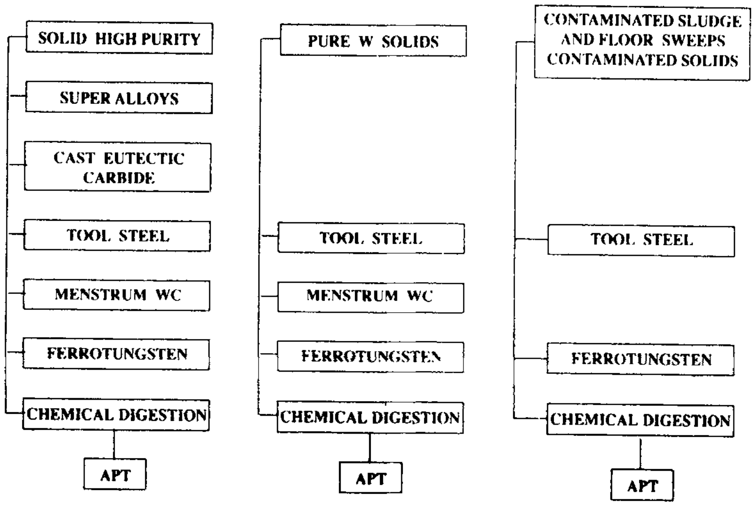

Figure 14. Flowsheet for the treatment of metal scrap.

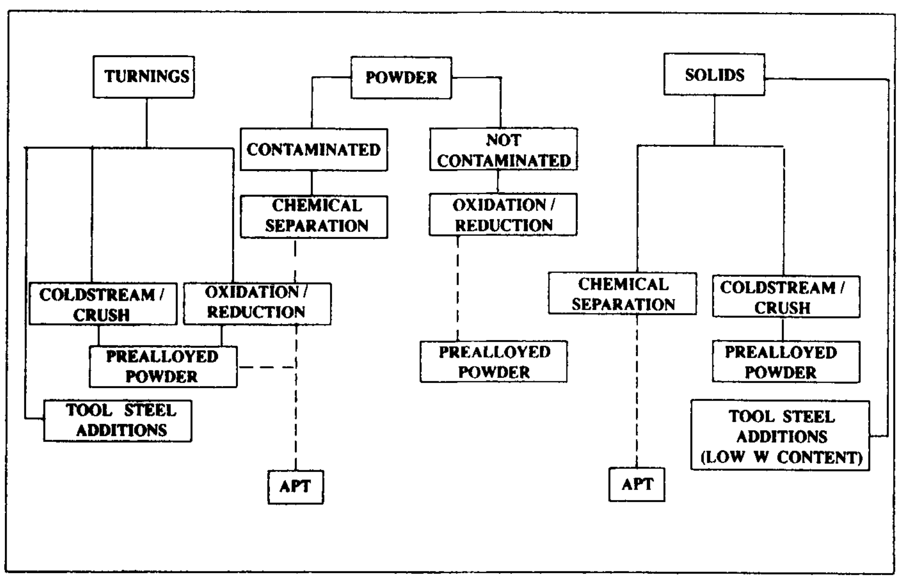

Figure 15. Flowsheet for tungsten recovery from heavy alloy scrap.

outlines the treatment of pure tungsten metal scrap. High purity tungsten metal is preferentially used as alloy addition in super alloys, and hence this scrap has the highest value. In the descending order of value, tungsten is used to make cast eutectic carbide (WC–W_2C), a hard-facing material, and for the manufacture of tool steel which has a higher tolerance for impurities in scrap. Alternatively, tungsten metal scrap may be used as feed material in the Menstrum process for the production of coarse WC or as ferro-tungsten. Least desirable application is its chemical conversion to synthetic scheelite, APT, or other tungsten chemicals.

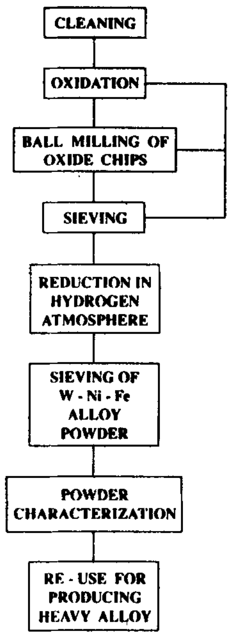

Figure 16. A process flowsheet for recycling of W–Ni–Fe heavy alloy scrap.

Tungsten sludges generated during the grinding of products, which generally contain silicon carbide or aluminium oxide as impurities, can be directly added to tool steel melts as a substitute for scheelite or ferrotungsten. They can also be used in the Menstrum process, and in the production of ferro-tungsten, which are desirable options. Again, the least desirable is chemical processing into synthetic scheelite or tungsten compounds. Sludges and floor sweeps which are slightly contaminated, or solids containing elements like thorium, zirconium or molybdenum, can either be added directly to tool steel melts for the production of ferro-tungsten, or treated by chemical processing.

3.3 *Heavy alloy scrap*

Heavy alloy scrap, in general, contains over 90% tungsten—the remainder being iron, copper, nickel and cobalt. Heavy alloys, so called because of their high density, have a wide range of applications, such as counter weights in aircraft, as radiation shielding material and as armour penetration projectiles in kinetic energy anti-tank weapon systems. A large quantity of scrap, especially in the production of penetrators, is generated. DMRL has established a Heavy Alloy Penetrator factory at Tiruchirapally. A large amount of scrap in the form of high quality turnings is generated in this plant. Figure 15 shows the flow sheet for the recovery of tungsten from heavy metal scrap. DMRL has established, on a laboratory scale, a direct process so that bulk of the scrap may be recycled for re-use within the product area (Subba Rao *et al* 1992). An oxidation/reduction process is the preferred method of recycling. Heavy metal turnings or scrap powders are oxidized at temperatures exceeding 850°C. After milling, the oxide is reduced in hydrogen at temperatures over 900°C, into metallic prealloyed powders suitable for addition to virgin powder mixes even upto 30%. The schematic flowsheet is shown in figure 16.

More costly and less efficient is the leach-milling process. The cold-stream process can be used for heavy metal alloys with binder contents of less than 3%. Small amounts of heavy metal scrap, especially large pieces, can be added to various tungsten containing steels. One must, however, be careful to account for the other metallics present in them. For example, nickel and copper are not desirable additions for tool steels and copper is not acceptable in superalloys. Small amounts of heavy metal scrap can be used to manufacture Fe–W melting base material. Contaminated powders, turnings and large pieces are chemically processed into APT or synthetic scheelite. The recycling of large pieces is a problem since the oxidation process is not economical. Na-nitrate/Na-carbonate fusion is the most commonly used process for chemical separation, although electrolytic separation offers an attractive alternative.

3.4 *Carbide scrap*

The greatest quantity of scrap available is in cemented carbide form. The most favoured process is the zinc process (Kiettor *et al* 1988). Cold stream process, the bloating process, and various other recycling processes are listed in table 6. Reclaimed powders from the above processes can be used directly for cemented carbide manufacture.

3.5 *Zinc process*

The zinc process is considered the most effective carbide scrap recycling process due to its higher recovery ($>95\%$) at lower cost with superior energy efficiency, when compared to the others listed in table 6. While the vessels are typically stainless steel, the material to be treated with zinc is contained in graphite. Argon is commonly used as a protective gas. Careful design will preclude the contact of molten zinc with structural members of the furnace. The condensed zinc can be recovered and re-used. The zinc employed must be very pure since it will transfer any metallic impurities to the scrap.

The reclaimed powders can be handled in a fashion similar to that of virgin powders. The product is slightly carbon deficient which has to be adjusted during the subsequent grading process. Proper process control can keep the iron pickup to a minimum, well within acceptable limits. The zinc process has a yield above 95%. The zinc process has a low energy consumption—approximately 4 KWh/kg as compared to the chemical process with consumption levels of 12 KWh/kg. The secondary carbide mix obtained by zinc process can be added to the primary mix upto an extent of 20% depending on the criticality of the finished product.

Strategic considerations make the zinc process very attractive. Countries which import tungsten, cobalt, tantalum and niobium can reduce their dependence on these imports. Commercial exploitation of the zinc process, can be judged from the fact that the process, which started in USA in 1975 with a capacity of 100 tonnes per annum, has today reached an installed capacity exceeding 1000 tonnes per annum. Several units, with a total capacity of 200 tonnes per annum, exist in several other countries.

3.6 *Indian scenario*

Technology for recycling of scrap by the chemical route is available in India and is being practised in small capacities by all carbide manufacturers having their

Table 6. Recycling processes for different application.

Recycle method	Product	High purity W	$WThO_2$ $WZrO_2$	cemented carbide	Heavy metal solids	Heavy metal turnings	W–Cu	W–Mo	W–Re	W–Ag
Melting	Super alloys	X								
	Stellites	*		*						
	Cast Eutectic Carbides	X								
	Menstrum WC for cemented carbide and hardfacing alloys			0	X	*	*			
	Tool steel	*	X		*	*		X		
	Ferro W(Mo)	*	*		*	*		*		
	Melting base	*	*	*	*	*		*		
Zinc process	Cemented carbide			X						
Bloating	Cemented carbide			X						
Leach milling	Cemented carbide			*						
Electro-lysis	Cemented carbide			0						
Cold stream	Cemented carbide and heavy metal	0		X		*				

Crushing	Hardfacing alloys W. granules	X		*						
Oxidation reduction	Heavy metal	0				X				
Vacuum distillation	Tool steel						*			*
Nitrate and on nitrate carbonate fusion	Tungsten chemicals (APT, WO_3 H_2WO_4, etc.)	0	0	0	0	0	X		0	X
Oxidation NaOH leach		0	0	0	0	0		0	X	
Electrolysis			0		0	0	X			*
Chlorination (Axel Johnson Process)		0	0	0	0	0	0	0	0	0

X, Best economic use; *, good economic use; 0, least economic use.

own chemical plant. They mostly recycle inhouse scrap by any of the following processes:

- Scrap bloating for large size scrap
- Nitride fusion for medium and small size scrap

Scrap bloating is done in an induction furnace by heating the scrap to over 2200°C in a graphite crucible. Cobalt melts, boils and oxidises and thus the scrap becomes easily crushable. This facility exists only with M/s Sandvik Asia, Pune and M/s Rapicut, Ankleshwar. M/s Sandvik have also put up a cobalt recovery plant with a capacity of 30 tonnes per annum. Others use fusion process where the resultant product consisting of tungsten and cobalt oxide are crushed and used as feed material along with the ore. DMRL has developed a direct oxidation process for both tungsten scrap and heavy alloy. Large size tungsten scrap is broken to about 1/2″ by thermal shock treatment and then roasted in an oxygen stream at 900°C for 8–12 h. Oxidized scrap could be directly ball milled to − 100 mesh size. Oxides from uncontaminated heavy alloy scrap can be reduced in hydrogen gas and reused successfully in heavy alloy production. However, tungsten grain size of heavy alloy thus produced is coarser. Oxidized and ground tungsten carbide scrap can be directly used in wolframite ore processing plants for recovery of tungsten.

Scrap utilization, in India, is mostly limited to the scrap generated in-house. Carbide scrap available from worn out tools and parts work out to about 200 tonnes, i.e. 35% of the total annual carbide production. There is no organized scrap collection activity. However, a recent survey indicated possible existence of an underground scrap collection activity for illegal export and improper use. The quantum and exact cost of such exports is not known. In many European countries there is legislation for accounting of carbide tools and wear parts to ensure proper use of scrap. It is felt that similar efforts should be made in India, making all large tool users (like railways, public sector undertakings, mining industry) accountable for collection of scrap, preferably gradewise. This should hopefully lead to more efficient recycling, progressively reaching the 35 percent level practised elsewhere in the world.

4. Concluding remarks

In India, the success of the tungsten alloy ammunition going into manufacture has provided an impetus to achieve backward integration with respect to tungsten resources development, an area that demands urgent attention. Hindustan Zinc Ltd (HZL) have recently taken over the Degana Mines in Rajasthan with a view of augment efforts for exploration, mining and processing of indigenous ore reserves. Appropriate beneficiation-cum-processing strategies including by-products recovery are yet to be established so as to optimally utilize the resources available within the country successfully. Recovery of byproducts like lithium, rubidium and cesium, known to occur at Degana, is expected to enhance the techno-economics of the project.

Tungsten products are almost always processed through the powder route. The present technology for the production of tungsten powder requires a tungsten concentrate with $> 65\%$ WO_3, which is processed to yield ammonium para tungstate (APT), an intermediate step in the conversion of concentrate to tungsten powder. There are technologies now being commercialized which manufacture APT even with ore concentrates as low as 30% WO_3. In view of the fact that the indigenous assaying tungsten deposits contain only 0·1 to 0·3% WO_3, such technologies for the production of APT need to be seriously taken up for development and application. Tungsten is amenable to recycling. In USA, as much as 30% of the tungsten requirements are met through recoveries from scrap. An organized national level effort is needed to encourage scrap utilization for recovery of tungsten values.

In view of tungsten being a strategic product in India, and its yet underdeveloped resource position, there is a strong case for stock-piling the raw materials needed through imports. The present time seems to be particularly opportune for this purpose, considering the low international price situation.

References

Anon 1988 *Material Policy for VIII Five Year Plan, Govt. of India*, Chapt. XIV

Anon 1991 *Report of the VIIIth Plan Working Group on Nonferrous Metals Minerals and Metals Review*, VXVII (4)

Bernhard F Kieffer and Erik Lassner 1987 *Tungsten 1987* (UK: MPR Publishing Services) p. 59

Dhruva Rao B K 1987 *National workshop on tungsten resource development* (Bhubaneshwar: DMRL and RRL) p. 165

Jakhu M R and Ray S 1996 *Bull. Mater. Sci.* **19** 313

Krishna Rao N 1996 *Bull. Mater. Sci.* **19** 201

Lassner E 1982 *Tungsten 1982* (UK: MPR Publishing Services) p. 71

Lenton W D 1987 *Tungsten 1987* (UK: MPR Publishing Services) p. 162

Patni S K, Lahiry A K and Bahree R C 1987 *National workshop on tungsten resources development* (Bhubaneshwar: DMRL and RRL) p. 41

Pradip 1996 *Bull. Mater. Sci.* **19** 267

Premchand 1996 *Bull. Mater. Sci.* **19** 295

Rama Rao P, Acharyulu S L N, Bhattacherjee G S, Bijoy Sarma and Bagchi T P 1987 *Development of tungsten resources management*, Technical Report, DMRL

Ruihe Z 1987 *Tungsten – 1987* (UK: MPR Publishing Services) p. 50

Srivastava S C, Bhaisare S R, Wagh D N and Iyer C P S 1996 *Bull. Mater. Sci.* **19** 331

Subba Rao K, Saibabu A, Bijoy Sarma and Maitra N 1992 *Transactions of PMAI, India* **19** 85

Walery R G 1982 *Tungsten 1982* (UK: MPR Publishing Services) p. 52

Willey G J 1982 *Tungsten 1982* (UK: MPR Publishing Services) p. 29