RHENIUM

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In the past decade, the two most important uses of rhenium have been in platinum-rhenium catalysts and high-temperature superalloys. Platinum-rhenium catalysts are used to produce lead-free, high-octane gasoline. Superalloys are used for turbine engine components. Other applications of rhenium, primarily as tungsten-rhenium and molybdenum-rhenium alloys, are more diverse; these included thermocouples, heating elements, temperature controls, flashbulbs, vacuum tubes, x-ray tubes and targets, metallic coatings, and electrical contact points. Research by industry continued on the recovery of rhenium from ore and concentrate and the development of new catalysts and alloys.

In the United States, rhenium is a byproduct of molybdenite recovered as a byproduct of porphyry copper ore from six operating porphyry copper-molybdenum-rhenium mines in the Western States. Domestic mine production data for rhenium (table 1) were derived by the U.S. Geological Survey from reported molybdenum production at the mines. Domestic demand for rhenium metal and other rhenium products was met principally by imports, but also from domestic recovery and stocks.

Compared with that of 1999, 2000 rhenium consumption decreased by about 1.5%; imports of metal for consumption decreased by 16% and imports of ammonium perrhenate increased by 171% (table 1). The average prices for metal powder and ammonium perrhenate were $1,009 and $514 per kilogram, respectively.

Consumption

Rhenium is used in petroleum-reforming catalysts for the production of high-octane hydrocarbons, which are used in the production of lead-free gasoline. Bimetallic platinum-rhenium catalysts have replaced many of the monometallic catalysts. Rhenium catalysts tolerate greater amounts of carbon formation in making gasoline and make it possible to operate the production process at lower pressures and higher temperatures, which leads to improved yields (production per unit of catalyst used) and higher octane ratings. In 2000, catalytic uses comprised about 20% of rhenium consumption reported in table 1. Platinum-rhenium catalysts also were used in the production of benzene, toluene, and xylenes, although this use was small compared with that of gasoline production.

A significant property of rhenium is its ability to alloy with molybdenum and tungsten. Molybdenum alloys containing about 50-weight-percent rhenium have greater ductility and can be fabricated by either warm or cold working. Unlike other molybdenum alloys, this type of alloy is ductile at temperatures above 196° C and can be welded. Alloys of tungsten with 24-weight-percent rhenium have improved ductility and have lower ductile-to-brittle transition temperatures than pure tungsten. Rhenium improves the strength properties of nickel alloys at high temperatures (1,000° C). In 2000, metallurgical uses comprised about 75% of rhenium consumption. Other uses for these alloys, which collectively represented only 5% of total consumption, were in thermocouples, temperature controls, heating elements, ionization gauges, mass spectrographs, electron tubes and targets, electrical contacts, metallic coatings, vacuum tubes, crucibles, electromagnets, and semiconductors.

Foreign Trade

Imports for consumption of rhenium metal are listed in tables 1 and 2, and those of ammonium perrhenate are listed in tables 1 and 3. World production of rhenium in ore was estimated to be 28 metric tons (t); the quantity of rhenium recovered is

Rhenium in the 20th Century

Following the discovery of rhenium in 1925, the usual investigative work to isolate sufficient quantities, determine its properties, and locate adequate sources began. Rhenium remained little more than a curiosity until the latter half of the century.

In 1956, after several years of development, Kennecott Copper Corp. began producing rhenium at Washington, PA, where Molybdenum Corp. of America roasted Kennecott's Bingham Canyon Mine molybdenite concentrates. No more than 4,600 kilograms of rhenium was produced in the Western World between 1942 and 1965, with most used in research and development. Industrial use was small, mostly metallurgical, in high temperature thermocouples and some electronic uses.

In the late 1960s, the use of rhenium in catalysts began when both Chevron, Inc., and UOP, Inc., developed the bimetallic platinum-rhenium reforming catalysts. The first charge of catalyst was installed in Chevron's El Paso, TX, refinery. The price of rhenium escalated to $1,870 per kilogram in 1969 and to a high of $3,080 per kilogram in 1971. These high prices of 1971 and 1972 stimulated competition with rhenium in the form of indium and germanium catalysts. Rhenium prices have fluctuated widely since that time.

In 2000, metallurgical applications returned to being the major use because of usage by the turbine engine industry. The estimated U.S. consumption of rhenium in 2000 was about 32,000 kilograms of metal.

estimated to have been about 25 t, because not all concentrates were processed to recover the rhenium values. Rhenium was recovered from some byproduct molybdenite concentrates from porphyry copper deposits in Canada, Chile, China, Iran, Kazakhstan, Peru, Russia, and the United States. Rhenium metal and compounds were produced in Chile, France, Germany, Russia, the United Kingdom, and the United States.

World Review

World reserves of rhenium are contained primarily in molybdenite in porphyry copper deposits. U.S. reserves of rhenium are concentrated in Arizona, New Mexico, and Utah. Chilean reserves are found primarily at four large porphyry copper mines and in lesser deposits in the northern one-half of the country. In Peru, reserves are concentrated primarily in the Toquepala open pit porphyry copper mine and in about 12 other deposits in the rest of the country.

Other world reserves are in several porphyry copper deposits and sedimentary copper deposits in Armenia, northwestern China, Russia, and Uzbekistan and in sedimentary copper-cobalt deposits in the Congo (Kinshasa).

Technology Development

The feasibility of introducing rhenium as an in situ diffusion barrier to reduce the loss of aluminum from an aluminum diffusion barrier coating has been investigated by researchers at Hokkaido University, Sapporo, Japan. The results were reported at the NACE Corrosion 2001 conference in Houston, TX. Rhenium is added to superalloys to improve creep resistance. In addition, slow diffusion of rhenium has been shown to be responsible for slower coarsening kinetics in single crystals. In the study, a nickel-base single crystal superalloy containing rhenium was aluminum-diffusion treated, then oxidized in air at 1,373 K for up to 2.54 megaseconds under thermal cycling and isothermal conditions. The treatment was carried out in a mixture of FeAl and Al_2O_3 powder. It resulted in a triplex layer structure in the sequence beta NiAl/Re rich layer/Al diffusion zone (Narita, 2001).

Outlook

In the next 5 years, demand for rhenium metal was expected to follow the demand for turbine engines and petroleum. For the long term (10 to 20 years), recycling of rhenium-bearing waste and scrap was expected to increase. Identified U.S. resources are estimated to be about 7,000 t, and identified rest-of-world resources are estimated to be about 10,000 t.

Reference Cited

Narita, Toshio, 2001, Application of rhenium coatings as a diffusion barrier to improve high temperature oxidation resistance of nickel-based superalloys: Advanced Materials and Processes, v. 159, no. 5, May, p. 20-21.

GENERAL SOURCES OF INFORMATION

U.S. Geological Survey Publications

Rhenium. Ch. in Minerals Commodity Summaries, annual.
Rhenium. Ch. in Minerals Yearbook, annual.
Rhenium. Ch. in United States Mineral Resources, Professional Paper 820, 1973.

Other

Rhenium. Ch. in Mineral Facts and Problems, U.S. Bureau of Mines Bulletin 675, 1985.

TABLE 1
SALIENT U.S. RHENIUM STATISTICS 1/

(Gross weight, kilograms)

	1996	1977	1998	1999	2000
Mine production 2/	14,000	15,400	14,000	12,000	12,600
Consumption e/	24,100	17,900	28,600	32,500	32,000
Imports (metal)	10,800	8,510	14,200	12,800	10,700
Imports (ammonium perrhenate)	10,000	6,560	11,000	2,750	7,450

e/ Estimated.
1/ Data are rounded to no more than three significant digits.
2/ Rhenium contained in molybdenite concentrates, based on calculations by the U.S. Geological Survey.

TABLE 2
U.S. IMPORTS FOR CONSUMPTION OF RHENIUM METAL, BY COUNTRY 1/

	1999		2000	
Country	Gross weight (kilograms)	Value (thousands)	Gross weight (kilograms)	Value (thousands)
Austria	--	--	23	$24
Chile	10,100	$11,200	9,850	10,100
Estonia	31	15	40	32
Germany	1,650	1,990	300	260
Romania	--	--	22	13
Russia	785	516	136	83
Switzerland	--	--	36	38
United Kingdom	209	258	291	259
Total	12,800	14,000	10,700	10,800

-- Zero.
1/ Data are rounded to no more than three significant digits; may not add to totals shown.

Source: U.S. Census Bureau, with adjustments by the U.S. Geological Survey.

TABLE 3
U.S. IMPORTS FOR CONSUMPTION OF AMMONIUM PERRHENATE, BY COUNTRY 1/

	1999		2000	
Country	Gross weight (kilograms)	Value (thousands)	Gross weight (kilograms)	Value (thousands)
Chile	829	$689	--	--
China	270	71	--	--
Estonia	470	243	151	$61
Germany	--	--	183	129
Kazakhstan	1,070	610	6,100	2,970
Russia	109	61	--	--
United Kingdom	--	--	1,010	671
Total	2,750	1,670	7,450	3,830

-- Zero.
1/ Data are rounded to no more than three significant digits; may not add to totals shown.

Source: U.S. Census Bureau, with adjustments by the U.S. Geological Survey.

TABLE 4
RHENIUM: ESTIMATED WORLD MINE PRODUCTION, BY COUNTRY 1/ 2/

(Kilograms)

Country	1996	1997	1998	1999	2000
Armenia	NA	NA	1,000	700	700
Canada	1,500	--	2,200	1,600	1,600
Chile	2,600	2,500	2,500	2,400	2,200
Kazakhstan	200	1,800	2,400	2,400	2,400
Peru	2,000	2,000	2,300	4,800	4,800
Russia	500	NA	900	1,100	1,100
United States 3/	14,000	15,400	14,000	12,000	12,600
Uzbekistan	300	NA	NA	NA	NA
Other	100	5,000	3,200	3,000	3,000
Total	21,200	26,700	28,500	28,000	28,400

NA Not available. -- Zero.
1/ Data are rounded to no more than three significant digits; may not add to totals shown.
2/ Table includes data available through September 2001.
3/ Calculated rhenium contained in MoS_2 concentrates. Recovered quantities are considerably less and are withheld.