2015 Minerals Yearbook

BROMINE [ADVANCE RELEASE]

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Bromine

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The United States was one of four leading bromine producers in the world along with China, Israel, and Jordan. World production of bromine in 2015, excluding the United States, was estimated to be 342,000 metric tons (t) compared with 409,000 t in 2014 (tables 1, 6). In 2015, bromine sold or used in the United States decreased slightly compared with 2014, but data were withheld to avoid disclosing company proprietary data.

Bromine is one of two elements that are liquid at room temperature and is found principally as a dissolved species in seawater, evaporitic (salt) lakes, and underground brines associated with petroleum deposits. In addition, bromine is an essential element for life and is a requirement for tissue development (McCall and others, 2014). The primary uses for bromine compounds include, in descending order, brominated flame retardants (BFRs), intermediates and industrial uses, drilling fluids, and water treatment.

Production

Domestic production data for bromine were developed by the U.S. Geological Survey (USGS) from a voluntary canvass of the two U.S. producers—Albemarle Corp. and Chemtura Corp., both of which responded to the survey, representing 100% of total production. Production data collected by the USGS were withheld to avoid disclosing proprietary information, but capacity data for both producers were provided (table 2).

In the United States, bromine was recovered from brine wells in Arkansas, where bromine is found in the Smackover Formation at a depth of about 2,400 meters with concentrations of 3,000 to 5,000 parts per million (ppm) bromine; by comparison, seawater contains about 60 to 70 ppm bromine (Turekian, 1968, p. 92; Albemarle Corp., 2013, p. 8; Arkansas Geological Survey, undated).

After bromine processing, the spent brine is returned underground into the production formation by class V injection wells that are regulated by the U.S. Environmental Protection Agency (EPA). The chemical composition of the spent brine is generally similar to that of the original, except that the concentration of the target elements (such as bromine and magnesium) is reduced and the concentration of other elements (such as calcium) may have increased through substitution (U.S. Environmental Protection Agency, 1999, p. 1–2, 5).

Environment

Methyl bromide, a broad-spectrum pesticide used in the control of nematodes, pathogens, pest insects, rodents, and weeds, is the leading bromine-containing pesticide in the world, but its use has been declining owing to the ban imposed by the Montreal Protocol, which classified it as a class I ozone-depleting substance. As part of the Montreal Protocol, developed countries were to stop using the pesticide by 2005; however, the United States has received annual exemptions for crops and other critical uses. The critical-use exemption is for applications where no technically or economically feasible alternatives to methyl bromide exist. For 2015, the EPA authorized use of 377 t, or 1.5% of the historic 1991 baseline consumption of methyl bromide, for approved critical uses. This was a decrease from the 2014 authorized use of 442 t (U.S. Environmental Protection Agency, 2014, p. 44305). Use of methyl bromide was also allowed through a quarantine and preshipment exemption for agricultural commodities and lumber. Methyl bromide has proven to be difficult to replace because of its low cost and usefulness against a large variety of agricultural pests. Alternatives to methyl bromide exist but vary by the benefits needed for a particular crop. The U.S. Department of Agriculture researched environmentally, technically, and economically feasible alternatives (U.S. Department of Agriculture, 2011).

In August, the production of hexabromocyclododecane (HBCD) reached its sunset date in the European Union (EU), when production was required to cease unless specifically authorized by the EU. HBCD was primarily used as a flame retardant in polystyrene building insulation foams and had been found to likely "lead to significant adverse effects on human health and/or the environment" (United Nations, 2011, p. 7, 24). However, authorizations were approved for 13 facilities in the EU to continue production of HBCD flame retardant polystyrene foams until August 2017 to allow for production of sufficient quantities of alternative materials (Official Journal of the European Union, 2015). Although the EPA had not banned the production of HBCD in the United States, Chemtura Corp. announced plans to permanently discontinue the production of HBCD-based flame retardants by the end of 2015 (Chemtura Corp., 2015a). Both U.S. manufacturers, Albemarle and Chemtura, were producing alternative BFRs to replace HBCD-based products (Albemarle Corp., 2015a).

Recycling

Some bromide solutions were recycled to obtain elemental bromine and to prevent the solutions from being disposed of as hazardous waste. Hydrogen bromide is emitted as a byproduct from many organic reactions such as a result of the reaction between an alkane and bromine (Weizmann Institute of Science, undated, p. 173). This byproduct waste is recycled with virgin bromine brines and is a source of bromine production. Plastics containing BFRs can be safely incinerated as a solid organic waste, and the bromine can be recovered (Frim and Ukeles, 2007). Additionally, the stability of BFRs reduces or eliminates the need for incorporating additional flame retardants to new products made from recycled plastics, which had previously contained a BFR (Bromine Science and Environmental Forum, undated).

Consumption

The USGS did not collect consumption data on bromine compounds. Apparent consumption of bromine in the United States, calculated by the USGS as production plus imports minus exports, decreased slightly in 2015. In 2015, the leading global applications of bromine were for the production of BFRs (41%), intermediates and industrial uses (29%), clear brine fluids (19%), and water treatment (6%) (Israel Chemicals Ltd., 2016, p. 41).

BFRs are commonly used in many household and industrial appliances; electronic equipment, such as cases for computers, mobile telephones, and televisions; and other items, such as furniture, insulation boards, mattresses, and textiles. About 90% of all electrical components contain BFRs.

Bromine compounds are widely used in the agricultural, chemical, and pharmaceutical industries. Applications include dyes, perfumes, photographic chemicals, and zinc-bromine batteries. In particular, bromide compounds are especially effective pesticides, used as soil fumigants in agriculture, particularly in fruit growing, and as fumigants to prevent pests from attacking stored grain and fresh produce. World trade in agricultural goods depends on the use of bromine compounds to ensure compliance with mandatory quarantine rules.

Calcium bromide, sodium bromide, and zinc bromide, collectively referred to as clear brine fluids, are used in the oil- and gas-well-drilling industry for high-density, solids-free completion, packer, and workover fluids to reduce the likelihood of damage to the well bore and productive zone. These high-density fluids also help to prevent migration of fluids between underground formations through the well bore.

Another major use of bromine is as a water purifier and disinfectant, as an alternative to chlorine. Brominated compounds are used for water treatment in hot tubs and swimming pools and to control algae and bacterial growth in industrial processes.

Bromine and bromine compounds are also used to remove mercury from flue gas emissions at coal-fired electric powerplants (Vosteen and others, 2005). Inorganic bromine compounds, such as calcium bromide, when mixed with coal at powerplants, react with mercury in combustion zones, forming mercury compounds that are captured in scrubbers, removing up to 90% of mercury liberated during combustion (Fielding, 2012). Southern Research Institute (Birmingham, AL) developed a system that converts calcium bromide to bromine gas. The bromine gas then reacts with mercury in coal-fired powerplant flue gas to form mercuric bromide, which is captured and retained in the powerplant's wet scrubbers (Southern Research Institute, 2010).

Transportation

Bromine is transported in bulk quantities in the United States in 7,570- and 15,140-liter (L) lead-lined pressure tank railcars or in 6,435- to 6,813-L nickel-clad pressure tank trailers. The trailers must be at least 92% full to prevent inertia effects of the heavy liquid while on the highway. Dry nitrogen gas is recommended for use in pressurizing bromine during transfer, although dry air may be used. The gas used must be absolutely dry or severe corrosion results. When exposed to a high-humidity atmosphere, the water content of bromine can exceed 300 ppm. If the water content exceeds 70 ppm, the corrosiveness of bromine to many metals increases (Frim and Ukeles, 2007).

Prices

The price for purified, bulk, 99.95% bromine on an ex-works U.S. basis, as reported by Industrial Minerals, ranged from $1.55 to $1.70 per pound (about $3,400 to $3,700 per metric ton) from January through April 2015. In May through July 2015, prices ranged from $1.60 to $1.75 per pound (about $3,500 to $3,900 per metric ton). In August through December, prices ranged from $2.00 to $2.45 per pound (about $4,400 to $5,400 per metric ton). Price trends in Europe mirrored those in the United States. The European cost, insurance, and freight (c.i.f.) ex-works value of purified, bulk, 99.95% bromine ranged from $1.60 to $1.80 per pound (about $3,500 to $4,000 per metric ton) from January through July 2015. By the latter half of 2015, August through December, European prices had increased to $1.76 to $1.98 per pound (about $3,900 to $4,400 per metric ton). Actual prices for bromine are negotiated on long- and short-term contracts between buyers and sellers.

Because the bromine industry has few producers, published price lists of elemental bromine and bromine compounds from producers were not available. Although companies typically announce price increases by percentage increase, they normally do not publish actual price data. In February 2015, Chemtura announced a price increase of up to 20% for elemental bromine for its customers in the Asia Pacific region (Chemtura Corp., 2015d). In March, Albemarle increased its global price for elemental bromine and bromine derivatives by 30%, not including clear brine fluids (Albemarle Corp., 2015c). Chemtura increased its prices in April for all regions of up to $0.90 per kilogram for selected BFRs and brominated performance products (Chemtura Corp., 2015b).

Foreign Trade

In terms of bromine content, exports of bromine and bromine compounds in 2015 increased by about 22% to 25,000 t compared with 20,600 t in 2014 (table 3). Calcium bromide and sodium bromide, commonly used as drilling fluids in the oil- and gas-drilling industries, were the dominant exported products, accounting for 53% of exported materials in 2015. The leading recipient of exported calcium bromide in 2015 was the United Arab Emirates, which accounted for 44% of exports in this category. The amount of exported sodium bromide, in particular, almost tripled in 2015 compared with the amount exported in 2014. Mexico was the leading recipient of methyl bromide, an ozone-depleting pesticide, receiving 65% of the total amount of methyl bromide exported by the United States in 2015.

Imports of bromine and bromine compounds increased slightly during the same period, with a 6% increase in value compared with that in 2014 (table 4). Imports of the combined category of ammonium, calcium, and zinc bromide remained the dominant imported bromine product, in terms of quantity, accounting for 74% of imported materials in 2015. Although the amount of ammonium, calcium, and zinc bromide increased

only slightly in 2015, the average unit value increased by 14%. The increase in the average unit value of total imported bromine materials and bromides of ammonium, calcium, or zinc, in particular, reflected the global price increases bromine experienced during 2015.

World Review

The U.S. share of world bromine production has decreased as other countries have strengthened their positions as world producers of elemental bromine. In 2015, China, Israel, Jordan, and the United States led in bromine production capacity (tables 2, 5). Actual production did not necessarily reflect capacity (tables 5, 6).

China.—In China, bromine operations were located in Shandong Province. Although the Shandong Provincial government and the Government of China require companies to purchase licenses for the extraction of bromine, many small unlicensed facilities continue to operate (Gulf Resources, Inc., 2015, p. 9).

Because bromine production capacity was available for only one company, estimated production listed in table 6 is substantially higher than the capacity listed in table 5. Gulf Resources, Inc., one of the leading bromine producers in China, had a combined production capacity of about 47,300 metric tons per year (table 5). In 2015, Gulf Resources produced approximately 18,900 t of bromine, an 11% decrease compared with 2014 production of approximately 21,300 t (Gulf Resources, Inc., 2016, p. 46). Although bromine prices increased in 2015, decreased sales volume and a 10% decrease in bromine net revenue was attributed to economic policies implemented by the Government of China (Gulf Resources, Inc., 2016, p. 7, 44).

Israel.—Israel Chemicals Ltd. (ICL) (Tel Aviv) remained a world leader in bromine production with a maximum annual production capacity of 280,000 t at operations on the Dead Sea (table 5). In 2015, ICL produced 116,000 t of elemental bromine compared with 174,000 t produced in 2014 (table 6) (Israel Chemicals Ltd., 2015, p. 47; 2016, p. 45). The approximately 33% decrease in production was primarily the result of a workers' strike at ICL's subsidiary, Bromine Compounds Ltd., during the first half of 2015 (Israel Chemicals Ltd., 2016, p. 45).

Jordan.—Jordan produced an estimated 100,000 t of bromine in 2015 (table 6). Jordan Bromine Co. Ltd. (a joint venture between Albemarle and Arab Potash Co.) also processed brines from the Dead Sea, which contain more than 10,000 ppm of bromine, a much higher concentration than the next richest source found in U.S. brine wells, which contain 5,000 to 6,000 ppm (Albemarle Corp., 2013, p. 8).

Outlook

Because of domestic and international fire safety standards regulating the flammability of construction, home furnishing, and electronic products, BFRs account for the largest consumption of bromine worldwide. However, environmental and toxicological concerns regarding particular BFR products, such as HBCD, continued to be assessed in 2015. Balancing fire safety with environmental and human health concerns is expected to continue, with regulatory demands likely leading to the continuing development and production of alternative BFR products.

Bromine use in clear brine drilling fluids is dependent on fluctuations in the business cycle for the oil- and gas-well-drilling industry. However, although the average annual number of active drilling rigs in the United States and Canada decreased by approximately 48% in 2015 compared with that in 2014 and by 13% internationally, the decrease in the demand for brine fluids was less than expected (Syrett, 2015; Baker Hughes Inc., 2016a). In particular, U.S. exports of sodium bromide, predominantly used as a drilling fluid, more than tripled in 2015 (table 3). In the United States and Canada, the decline in the number of active drilling rigs was more pronounced in onshore drilling (48% decrease) than offshore drilling (36% decrease) (Baker Hughes Inc., 2016b). Because of the high capital expenditures associated with offshore drilling platforms, companies continued to drill in spite of decreased oil prices (Syrett, 2015). Globally, long-term growth in the use of clear brine fluids for offshore natural-gas- and oil-drilling is expected (Albemarle Corp., 2015b, p. 11; Chemtura Corp., 2015c, p. 9).

Use of bromine in chemical water treatment is expected to show modest growth during the next several years. Bromine has been determined to be safer than its substitutes in sanitary preparations and has a higher biocidal activity level for the same volume of product. The use of bromine compounds is expected to continue to increase in the hot tub, spa, and swimming pool sector as a gentler disinfectant than chlorine. Global demand for water treatment products is projected to increase in developing markets, such as China and India, as a result of continued industrial expansion and increased efforts to expand access to safe water supplies.

The market for bromide-based technologies to remove mercury emissions at coal-fired powerplants is an area of potential growth for the industry. Using bromide compounds for abatement of mercury emissions appears to be more cost-effective compared with other materials, such as chlorine-, fluorine-, or iodine-based compounds. In recent years, U.S. and international regulations have called for reductions in mercury emissions. These include the Mercury and Air Toxics Standards (MATS) published by the EPA in 2012 as well as the United Nations Environment Programme's Minamata Convention on Mercury in 2013 (U.S. Environmental Protection Agency, 2012; United Nations, 2013, p. 20). Although the U.S. Supreme Court blocked the enforcement of MATS in June 2015, ruling that the EPA failed to take cost into consideration, in December, the EPA proposed a supplemental finding that cost does not alter the appropriateness of the EPA to regulate air toxics, in accordance with the Clean Air Act of 1990 (U.S. Environmental Protection Agency, 2015, p. 75025). Although mercury control regulations have yet to be confirmed, significant growth potential for bromine compounds exists if mercury reductions become mandated.

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TABLE 1
SALIENT BROMINE STATISTICS[1]

(Metric tons and thousand dollars)

	2011	2012	2013	2014	2015
United States:					
Bromine sold or used:[2]					
Quantity	W	W	W	W	W
Value	W	W	W	W	W
Exports:[3, 4]					
Quantity (Br equivalent)	13,200 r	13,000 r	18,200 r	20,600 r	25,000
Value	45,500 r	48,600 r	61,200 r	67,100 r	79,900
Imports for consumption:[5, 6, 7]					
Quantity (Br equivalent)	45,100 r	53,400 r	36,300 r	57,700 r	58,000
Value	100,000 r	120,000 r	88,000 r	118,000 r	124,000
Apparent consumption	W	W	W	W	W
World, production[e, 8]	380,000 r	357,000 r	389,000 r	409,000 r	342,000

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data.
[1]Data are rounded to no more than three significant digits.
[2]Elemental bromine sold as such to nonproducers, including exports, or used by primary U.S. producers in preparing bromine compounds.
[3]Export values are free alongside ship.
[4]Includes bromine compounds that were not included in the 2014 Minerals Yearbook and earlier editions.
[5]Sources: U.S. Census Bureau and PIERS.
[6]Import values are cost, insurance, and freight.
[7]Calcium bromide reported by PIERS is not included to avoid double counting.
[8]Does not include U.S. production.

TABLE 2
ELEMENTAL-BROMINE-PRODUCING PLANTS IN THE UNITED STATES IN 2015

State and company	County	Plant	Production source	Capacity[1] (thousand metric tons)
Arkansas:				
Albemarle Corp.	Columbia	Magnolia South	Well brines	NA
Do.	do.	Magnolia West	do.	NA
Do.	Union	Satellite plants	do.	NA
Total				148 [2]
Chemtura Corp.	do.	El Dorado Central and El Dorado South	do.	71 [3]
Do.	do.	Marysville West	do.	59
Grand total				278

Do., do. Ditto. NA Not available.
[1]Actual production capacity is limited by brine availability.
[2]Total capacity of Magnolia South, Magnolia West, and Satellite plants.
[3]Total capacity of El Dorado Central and El Dorado South plants.

TABLE 3

U.S. EXPORTS OF BROMINE AND BROMINE COMPOUNDS[1]

Compound[2]	HTS[3] code	2014 Gross weight (metric tons)	2014 Br equivalent (metric tons)	2014 Value[4] (thousands)	2015 Gross weight (metric tons)	2015 Br equivalent (metric tons)	2015 Value[4] (thousands)	Principal recipients in 2015
Elemental bromine	2801.30.2000	3,420	3,420	$8,890	3,960	3,960	$8,850	Canada, 35%; China, 28%; Belgium, 14%.
Inorganic bromine compounds:								
Calcium bromide[5]	2827.59.2500	15,000	12,000	36,800	11,300	9,030	27,700	United Arab Emirates, 44%; Trinidad and Tobago, 26%.
Potassium bromide[5, 6]	2827.51.0000	35	23	61	13	9	23	Colombia, 60%; China, 25%; Republic of Korea, 15%.
Sodium bromide[5, 6]	2827.51.0000	1,520	1,180	2,660	5,570	4,330	9,750	Singapore, 37%; Ghana, 31%; Angola, 22%.
Organic bromine compounds:								
Ethylene dibromide	2903.31.0000	135	117 r	526	685	592	4,130	Belgium, 90%.
Methyl bromide	2903.39.1520	4,590	3,870 r	18,200	8,460	7,120	29,400	Mexico, 65%.
Total		24,700 r	20,600 r	67,100 r	30,000	25,000	79,900	

[r]Revised.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Includes compounds not previously listed.

[3]Harmonized Tariff Schedule of the United States.

[4]Declared cost, insurance, and freight valuation exports are free alongside ship.

[5]Source: PIERS.

[6]Potassium bromide and sodium bromide import data are reported under a common HTS code.

Source: U.S. Census Bureau.

TABLE 4

U.S. IMPORTS OF BROMINE AND BROMINE COMPOUNDS[1]

Compound[2]	HTS[3] code	2014 Gross weight (metric tons)	2014 Br equivalent (metric tons)	2014 Value[4] (thousands)	2015 Gross weight (metric tons)	2015 Br equivalent (metric tons)	2015 Value[4] (thousands)	Principal sources in 2015
Elemental bromine	2801.30.2000	2,050	2,050	$6,160	2,530	2,530	$7,270	Israel > 99%.
Inorganic bromine compounds:								
Ammonium, calcium, or zinc bromide	2827.59.2500	52,300	42,700	69,500	52,900	43,200	79,500	Israel, 75%; Jordan, 18%.
Potassium bromate	2829.90.0500	34	16	213	52	25	317	China > 99%.
Potassium bromide[5, 6]	2827.51.0000	1,380	926	2,380	761	511	1,310	China, 90%.
Sodium bromate	2829.90.2500	1,140	601	4,540	758	402	2,190	China > 99%.
Sodium bromide[5, 6]	2827.51.0000	11,200	8,690	19,300	11,800	9,160	20,300	Israel, 78%; China, 19%.
Organic bromine compounds:								
Decabromodiphenyl oxide and octabromodiphenyl oxide	2909.30.0700	506	410 r	2,260	846	685	4,220	China, 91%.
Dibromoneopentyl glycol	2905.59.3000	935	543 r	4,950	427	248	2,360	China, 54%; Israel, 46%.
Ethylene dibromide	2903.31.0000	36	31	255	22	19	167	China, 76%; India, 24%.
Hydrobromic acid	2811.19.3000	1,050	1,040	2,810	584	577	2,360	Israel, 52%; Netherlands, 38%.
Methyl bromide	2903.39.1520	172	145	859	109	92	731	Israel, 99%.
Tetrabromobisphenol A	2908.19.2500	889	523	4,540	1,040	610	3,480	Israel, 52%; Jordan, 29%; China, 19%.
Total		71,700 r	57,700 r	118,000 r	71,900	58,000	124,000	

[r]Revised.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Calcium bromide reported by PIERS no longer listed to avoid double counting.

[3]Harmonized Tariff Schedule of the United States.

[4]Import values are cost, insurance, and freight.

[5]Source: PIERS.

[6]Potassium bromide and sodium bromide import data are reported under a common HTS code.

Source: U.S. Census Bureau.

TABLE 5

SELECTED WORLD BROMINE ANNUAL PLANT CAPACITIES AND SOURCES AS OF DECEMBER 31, 2015[1]

Country and company or plant	Location	Capacity (metric tons)	Source
China, Gulf Resources, Inc.	Shandong	47,300	Underground brines.
India:			
Hindustan Salts Ltd.	Kharaghoda	900	Seawater bitterns from salt production.
Solaris ChemTech Industries Ltd.	Khavda	NA	Do.
Tata Chemicals Ltd.	Mithapur	150	Do.
Israel, ICL Industrial Products	Sodom	280,000	Bitterns of potash production from surface brines.
Japan, Tosoh Corp.	Tokuyama	24,000	Seawater.
Jordan, Jordan Bromine Co. Ltd.	Safi	100,000	Bitterns of potash production from surface brines.
Turkmenistan:			
Cheleken Chemical Plant	Cheleken region	NA	Seawater.
Nebitdag Iodine Plant	Vyshka	NA	Underground brines.
Ukraine, Perekop Bromine Plant	Krasnoperekopsk	NA	Do.

Do. Ditto. NA Not available.

[1]Does not include U.S. production capacity.

TABLE 6

BROMINE: ESTIMATED WORLD PRODUCTION, BY COUNTRY[1, 2]

(Metric tons)

Country[3]	2011	2012	2013	2014	2015
Azerbaijan	-- r	-- r	-- r	-- r	--
China	100,000	105,000	110,000	110,000	100,000
Germany[4]	1,600	1,600	NA r	NA r	NA
India	1,600	1,700	1,700	1,700 r	1,700
Israel[5]	202,313	173,940	172,341 r	173,796 r	116,000
Japan	20,000 r	20,000 r	20,000 r	20,000 r	20,000
Jordan	50,000	50,000	80,000	100,000	100,000
Turkmenistan	460	480	500	500	500
Ukraine	4,100	4,100	4,100	3,500	3,500
United States	W	W	W	W	W
Total[6]	380,000 r	357,000 r	389,000 r	409,000 r	342,000

[r]Revised. NA Not available. W Withheld to avoid disclosing company proprietary data; not included in total. -- Zero.

[1]World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]Includes data available through April 22, 2016.

[3]In addition to the countries listed, several other nations, including Iran, were thought to produce bromine, but output data were not reported; available general information is inadequate to formulate reliable estimates of output levels.

[4]Includes bromides and oxides.

[5]Reported figure.

[6]Does not include U.S. production.