GOSPODARKA SUROWCAMI MINERALNYMI

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Boron mining and processing in Turkey

Introduction

Boron is the Group III A (13) element in the periodic table, occurs in borates and borosilicates in the earth crust. Boron has a chemical symbol of B and was discovered in l808 by French Chemist – Gay Lussac and English Chemist – Humphrey Davey. Boron containing minerals are called borates and were utilized by humans for thousands of years. Borates were used 300 years B.C. in Chinese Ceramics. It is also known that it was employed as melting agent in gold metallurgy in Babylonian Civilization. Marco Polo brought borax to Europe to start the usage in soldering and glazing of pottery.

Boron mining started in Turkey in 1861 by foreign companies. Later, mining exploitation rights were transferred to state sector, namely, Etibank. Turkey has 72% of the world reserves, but the figures are 35% in the production and trade.

1. Boron reserves and common minerals

1.1. World boron reserves

On the basic of equivalent B_2O_3 content, boron reserves are known as 1.176 billon tons. 72.2% of the reserves as 851 million tons are known to exist in Turkey. World boron reserves are given in Table 1.

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TABLE 1

The world boron reserves [million metric tons]

TABELA 1

Światowe rezerwy boru [mln ton]

Country Name	Region and type	Total Ore	Contained B_2O_3	B_2O_3 Reserve	B_2O_3 Reserve Base	B_2O_3 Total Reserve
Turkey	Bigadic-Balikesir (Ca-NaCa types)	935	330	(1030-360)		
	Emet-Kütahya (Ca-type)*	545	200	(890-310)		
	Kestelek (Ca-type)	7	3	(8-3)		
	Kırka (Na-type)	520	140	(519-130)		
	Subtotal	2007	673	227	624	851
USA	Boron-(Na-type)	113	26			
	(Ca-type)	198	20			
	Subtotal	311	46			
	Searles Lake, Death Valley, Hector, Owens Lake, Salton Sea, Four Corners, Muddy Mountains, etc.	255	77			
	Subtotal	566	123	40	40	80
Russia	Dalnegorsk, etc.	700	64	40	60	100
China	Liaoning, etc.	480	65	27	9	36
Mexico	Mesa del Amo, Vitro, Tubutama, etc.	140	13.5			
Argentina	Loma Blanca, Sijes, Tincalayu, Salars, etc.	100	20.5	2	7	9
Chile	Surire, Atacama, etc.	60	76	8	33	41
Serbia	Jarandol, Raska, etc.	40	8	3	–	3
Kazakhstan	Inder, Satimola, etc.	77	5	14	1	15
Bolivia	Salars, Uyuni, etc.	20	15	4	15	19
Peru	Salars de Salinas, etc.	20	5	4	18	22
Others	Iran, Germany, etc.	100	10			
General	Total	4310	1078	369	807	1176

(Roskill, 11. Edition 2006), (Lyday 2006)

In addition, the regional distribution of borates reserves of Turkey in Table 2 and the distribution in accordance with mineral kinds are given in Table 3. The map of Turkey with Borates regions are shown in Figure 1.

TABLE 2

The regional distribution of Turkish boron reserves

TABELA 2

Regionalny rozkład tureckich rezerw boru

Location	Proven reserve	Probable reserve	Possible reserve	Total reserve
Bigadiç	363.534.560	259.924.150	–	623.458.710
Emet	266.561.602	1.416.000.000	–	1.682.561.602
Kestelek	6.994.525	–	–	6.994.525
Kırka	171.971.373	201.350.000	377.299.000	750.620.373
Total Reserve	809.062.060	1.877.274.150	377.299.000	3.063.635.210

Reference: Eti Mining Company.

TABLE 3

Distribution of Turkish boron reserves according to mineral types

TABELA 3

Rozkład tureckich rezerw boru według rodzajów minerałów

Mineral type	Proven reserve	Probable reserve	Possible reserve	Total reserve
Kolemanit	600.648.707	1.663.972.350	–	2.264.621.057
Boraks (Tinkal)	171.971.373	201.350.000	377.299.000	750.620.373
Üleksit	36.441.980	11.951.800	–	48.393.780
Total Reserve	809.062.060	1.877.274.150	377.299.000	3.063.635.210

Reference: Eti Mining Company.

Fig. 1. The map of Turkey with borates regions

Rys. 1. Mapa Turcji z regionami występowania boranów

1.2. Boron minerals

Boron element exists in more than 250 rocks in the world. Most widely known economic boron minerals are shown in Table 4.

TABLE 4

The most common boron minerals and their properties

TABELA 4

Najczęściej występujące minerały boru i ich właściwości

Mineral Name/Property	Composition (Formula)	B_2O_3 [%]	H_2O [%]	Crystal structure	Hardness (Mohs)	Specific gravity
Borax (Tincal)	$Na_2B_4O_7\ 10H_2O$ $Na_2O\ 2B_2O_3\ 10H_2O$	36.51	47.24	monoclinic	2–2.5	1.711–1.715
Colemanite (Borocalcite)	$2CaO\ 3B_2O_3\ 5H_2O$ $Ca_2B_6O_{11}\ 5H_2O$ $Ca[B_3O_4(OH)_3]\ H_2O$	50.80	21.92	monoclinic	4–5	2.42–2.43
Ulexite (Borona-trocalcite)	$Na_2O\ 2CaO\ 5B_2O_3\ 16H_2O$ $NaCaB_5O_9\ 8H_2O$ $NaCa[B_5O_6(OH)_6]\ 5H_2O$	42.95	35.57	triclinic	2.5	1.955–1.961
Kernite (Rasorite)	$Na_2O\ 2B_2O_3\ 4H_2O$ $Na_2B_4O_7\ 4H_2O$ $Na_2[B_4O_6(OH)_2]\ 3H_2O$	50.95	26.37	monoclinic	2.5–3.0	1.906
Probertite (Kramerite)	$Na_2O\ 2CaO\ 5B_2O_3\ 10H_2O$ $NaCaB_5O_9\ 5H_2O$ $CaNa[B_5O_7(OH)_4]\ 3H_2O$	49.56	25.65	monoclinic	3–3.5	2.13–2.14
Datolite (Gadolinite)	$4CaO2B_2O_34SiO_22H_2O$ $Ca_2B_2Si_2O_9H_2O$ $Ca_4[B_4(SiO_4)_4(OH)_4]$	21.76	5.63	monoclinic	5–6	2.97–3.02
Sassolite (Natural Boric Acid)	$B(OH)_3$, $B_2O_33H_2O$ H_3BO_3	56.29	43.71	triclinic	1	1.48–1.50
Hydroboracite	$CaOMgO3B_2O_36H_2O$ $CaMgB_6O_{11}6H_2O$ $CaMg[B_3O_4(OH)_3]_23H_2O$	50.53	26.16	monoclinic	2–3	2.167–2.173
Szaibelyite (Ascharite)	$2MgO\ B_2O_3\ H_2O$, $Mg_2B_2O_5H_2O$ $Mg_2(OH)[B_2O_4(OH)]$	41.38	10.71	monoclinic	3–3.5	2.60–2.76
Boracite (Stassfurite)	$5MgO\ MgCl_2\ 7B_2O_3$, $Mg_3B_7O_{13}Cl$ $Mg_3[B_3O_5]_2[BO_3]Cl$	62.15	–	O.Rhombic cubic >265°C	7–7.5	2.89–2.87

2. Boron utilization

Boron is used in more than 200 fields of application. Principal utilized boron compounds are shown in Table 5 and Figure 2.

TABLE 5

Important boron products and their utilization areas

TABELA 5

Ważne produkty zawierające bor i dziedziny ich wykorzystania

Product	Utilization Areas
Colemanite	Textile quality fiberglass, Boron alloys, metallurgical slag formation agent
Ulexite and Probertite	Isolation fiberglass, Borosilicate glass, antiseptics, boron alloys, nuclear reactors, fire retarder, nylone, photography, textile, fertilizer, catalyst, glass, fiber glass, enamel, glaze
Anhydrous Borax	Fertilizer, glass, fiberglass, metallurgical slag former, enamel glaze, fire retarder
Sodium Perborate	Detergent and whiteness, textile
Sodium Metaborate	Detergent, agricultural medicine, photography, textile
Sodium Pentaborate	Fire retarder, fertilizer
Boric Acid	Glass, ceramic, glass fibre, as industrial and antiseptic use
Amorphous and Cyrstalline Boron Element	Military purpose, nuclear weapons and protector in nuclear reactors
Sodium Boron Hydride	Cleaning of metal surfaces, paper whitener and special chemical refining
Boron Alloys (Ferro bor, Nickel bor, cobalt bor)	Surface hardening of nucleus
Boron Nitride	Cubical boron nitride cutting tools in place of diamond
Boron Carbide	Abrasive material, manufacture of special hard protecting material and nuclear reactors
Boron Flammable	Composites for Aerospace, composites for sporting material
Boron Halides	Medicine Industry, catalysts, electronic pieces, boron filaments and fiber optics
Boron Esthers	Catalysts for polymerization reactions, fire retarder
Special Sodium Borates	Chemicals for photography, adhesives, textile, “finishing” compounds, materials of detergency and cleaning, fire retarder, fertilizer and agricultural medicines

Reference: Eti Mining Company.

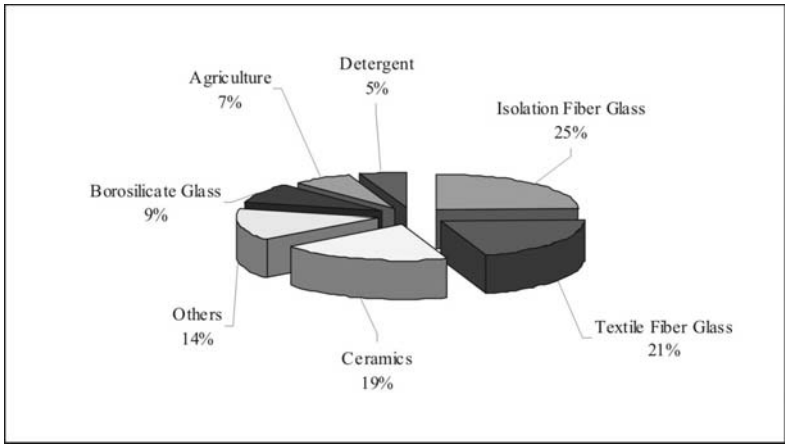

Fig. 2. The main consumption areas of boron products (Eti Mining Co.)

Rys. 2. Główne dziedziny zastosowania produktów zawierających bor (Eti Mining Co.)

3. Boron production and consumption in world and Turkey

Total world boron production is 5 575 000 tons as run of mine ore equivalent to 1 750 000 tons of B_2O_3. 35% of this total world production is contributed by Turkey as 1 735 000 tons of run-of-mine ore, equivalent to 607 000 tons of B_2O_3. Turkey is number one in the world production as indicated in Figure 3 and Table 6.

World boron consumption in 2005 is reached to 1 800 000 tons B_2O_3 (Table 7). Turkey in boron market offers boron concentrate, ground boron and refined boron products.

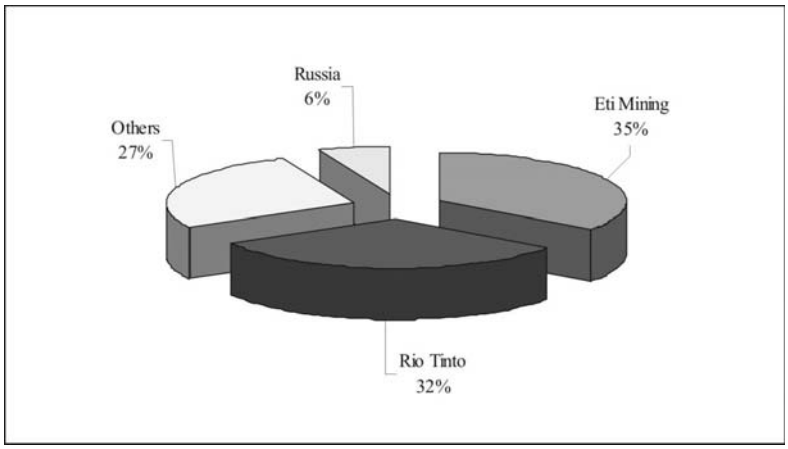

Fig. 3. The share of producer in world market (Eti Mining Co.)

Rys. 3. Udział producenta w rynku światowym (Eti Mining Co.)

TABLE 6

The world borate production in recent years [thousand tons of ore/contained B_2O_3]

TABELA 6

Światowa produkcja boranów w ostatnich latach [tysiące ton rudy/zawartość B_2O_3]

Country/Year	2000	2001	2002	2003	2004	2005
Turkey	1402/504	1493/517	1368/479	1399/490	1697/590	1735/607
Usa	1070/546	1050/536	1050/543	1150/605	1210/637	1230/657
Russia	850/85	719/85	757/97	963/109	1000/106	1000/110
Chile	338/57	328/56	431/73	401/68	400/68	600/102
Argentina	513/87	634/108	510/87	545/93	560/94	550/94
China	363/145	375/150	363/145	325/130	325/135	350/140
Bolivia	43/15	32/11	40/14	110/39	110/39	100/35
Kazakhstan	115/12	81/8	98/10	69/7	70/7	–/–
Peru	9/3	9/3	9/3	11/3	10/4	10/4
Iran	4/–	3/–	2/–	3/–	3/–	3/–

(Roskill, 11. Edition 2006), (Lyday 2006)

TABLE 7

The world borate consumption as B_2O_3 in recent years [thousand metric tons]

TABELA 7

Światowe zużycie boranów jako B_2O_3 w ostatnich latach [tysiące ton]

Region/Year	2001	2005
N.America	375	400
L.America	125	150
Europe	800	550
Asia	175	600
OTHERS	25	100

(Roskill, 11. Edition 2006)

4. Boron concentration and production of boron chemicals

4.1. Boron concentration

Main boron minerals in Turkey are Tincal (Na Borate) and Colemanite (Ca Borate). Main gang minerals in the ore deposit are determined as clay minerals, quartz, volcanic tuff, calcite, gypsum, biotite, chlorite and limonite.

In colemanite ores, concentration is carried out by disintegration, washing and classification in the size fractions In large sizes, colemanite concentrate is obtained through attrition tumbling, hand sorting. While in fines sizes (–6 mm), attrition scrubbing and classification in the size fractions are carried out. At Emet Colemanite Concentration plant at a capacity of 600,000 tons per year a colemanite ore of 27% B_2O_3 content is treated to produce a concentrate having 43% B_2O_3 at 300,000 tons per year. Flow sheet of the concentration plant is given Figure 4.

In tincal ores, two different flowsheets are applied. The flow sheet in Figure 5, attrition scrubbing to the ore is followed by classification by the use of screens and cyclone. Then concentrate is produced in –6 mm +0.1 mm fraction. As Na borate is soluble in water so that all the water is kept at near saturation with boron. At Kırka Concentration Plant, 1.2 million tons of tincal ore, having 26% B_2O_3 is treated to produce a concentrate of 34.5% B_2O_3 content with a total of 800,000 tons per year. In another process, where the effect of environmental impact is minimized, tincal ore is solubilized and solution is sent directly to produce boron salts. Solid waste is stored in a suitable area as indicated in Figure 6. In solubilization plant, the tincal ore having 26% B_2O_3 is treated at 200,000 tons per year.

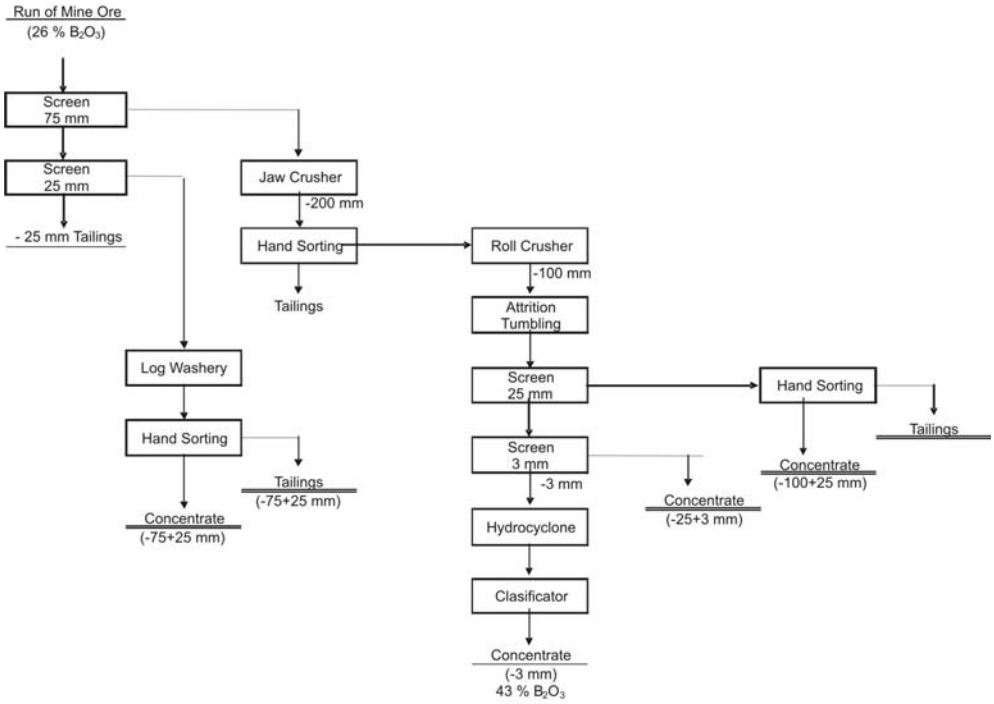

Fig. 4. The flow-sheet of Emet colemanite concentration plant

Rys. 4. Schemat technologiczny zakładu koncentracji kolemanitu Emet

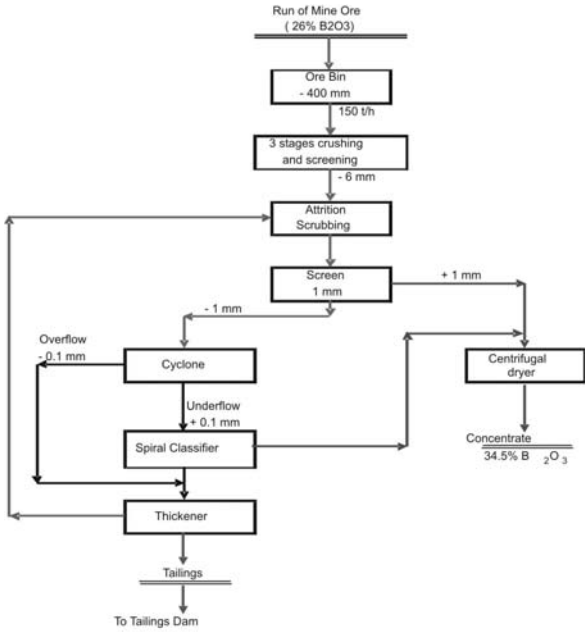

Fig. 5. Flow-sheet of Kırka tincal concentration plant

Rys. 5. Schemat technologiczny zakładu koncentracji tynkalu Kırka

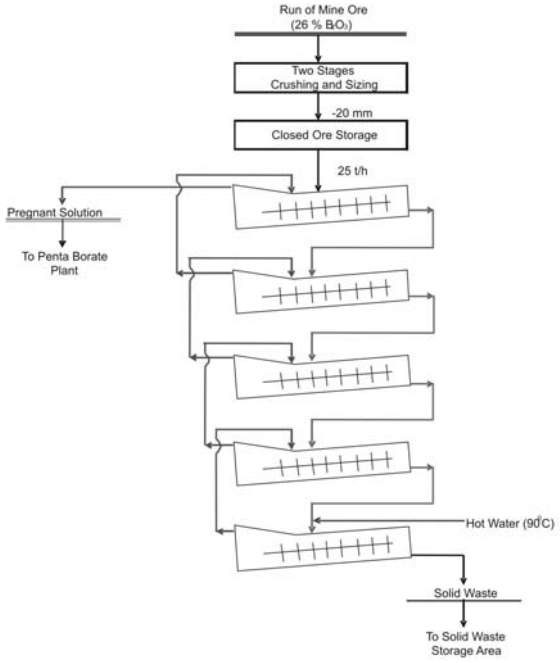

Fig. 6. The flow-sheet of Kırka solubilazation plant

Rys. 6. Schemat technologiczny zakładu solubilizacji Emet

4.2. Boron chemicals

Through the use of boron concentrates, boric acid, borax pentahydrate, borax decahydrate, sodium perborate (mono), sodium perborate (tetra), boron oxide, refined products are produced as shown in Table 8.

TABLE 8

Production of refined product in Turkey [tons]

TABELA 8

Produkcja rafinowanych produktów w Turcji [tony]

Products	2002	2003	2004	2005	2006
Boraks Dekahidrate	34.300	33.030	36.600	46.500	44.110
Boraks Pentahidrate	12.604	15.380	14.010	9.630	14.507
Boric Acid	83.606	91.100	152.842	183.899	195.769
Sodyum Perborata (Tetra)	8.670	26.300	29.411	29.420	14.167
Sodyum Perborata (Mono)	249	7.115	8.650	7.930	4.370
Boron Oxide				8	644
Boron Pentahidrat (Etibor 48)	253.566	283.663	376.617	497.154	552.774
Ground Colemanite	43.386	62.466	96.411	148.720	189.368
Refined Boron Product Total	392.995	456.588	618.130	774.541	826.341

Reference: Eti Mining Company

5. Environmental measures

Some environmental effects came about due to boron mining and processing on a large scale for a long time almost 50 years in Turkey. Tincal as a soluble mineral resulted in liquid waste encountered in Kırka region, which cover large areas. Environmental measures are focused in two directions:

— Solid waste instead of liquid one must be preferred.
— Present areas of wastes, can be treated to produce boron compounds and removed to solid storage area.

5.1. Solid waste storage

Plant utilizing direct solubilization process (Fig. 6) results in solid waste production which can be stored in open areas in open cast mine. In addition, solid wastes are produced from boron chemical plants, after filtration are stored in solid state.

5.2. Rehabilitation of existing tailings dams

In present tailings dams, there are 12 million m^3 solid waste and 6.5 million m^3 waste water, containing 3 g/L B_2O_3. When research work was carried out in order to recover boron, the product with 38% B_2O_3 was obtained with 95% recovery. Recycled clean water can be used agriculturally. At the end of application of this process, the areas occupied by effluents will be emptied. Then it will be possible to utilize this land for agricultural purposes.

Conclusions

1. 72.2% of World boron reserves exists in Turkey.
2. Turkey occupies the first place in boron production and trade with a share of 35%.
3. In boron processing, direct solubilization process results in solid waste to be stored easily.
4. Waste waters present in tailings dam can be treated to obtain clear water.
5. Through cleaning of tailings dam areas, it will be possible to realize important environmental rehabilitation.

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GÓRNICTWO I PRZETWARZANIE BORU W TURCJI

Słowa kluczowe

Bor, bor rafinowany, produkt końcowy, produkcja, konsumpcja

Streszczenie

Bor jest pierwiastkiem Grupy III A (13) w układzie okresowym pierwiastków, występującym w skorupie ziemskiej w postaci boranów i borokrzemianów, stosowanym przez człowieka od tysięcy lat. Bor ma ponad 200 rodzajów zastosowania. Turcja dysponuje 72% światowych rezerw boru. Z drugiej strony, Turcja pokrywa 35% produkcji i handlu.

Opracowanie ukazuje ogólny stan wiedzy na temat boru oraz górnictwa i przetwarzania boru w Turcji.

BORON MINING AND PROCESSING IN TURKEY

Key words

Boron, refined boron, final product, production, consumption

Abstract

Boron is the Group III A (13) element in the periodic table occurs in borates and borosilicates in the earth crust and had been employed by human kind for thousands of years. Boron has more than 200 kinds of use. Turkey has 72% of the world reserves. On the other hand, the Turkish figures are 35% in production and in the trade.

This paper covers a general knowledge about boron, boron mining and processing in Turkey.