MINISTRY OF ENERGY AND MINERAL RESOURCES
Mineral Status and Future Opportunity

BENTONITE

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CONTENTS

List of Contents	**I**
List of Figures	**II**
List of Tables	**II**
List of Appendices	**III**
1. Introduction	**1**
2. Locations	**1**
2.1. Al Azraq Area	**1**
2.1.1. Q'a Al Azraq	**1**
2.1.2. Ein Al Bayda Area	**1**
2.2. Al Yamaniyya Area	**2**
3. Geology	**5**
4. Thickness and Overburden	**5**
5. Reserves	**5**
6. Bentonite Properties	**5**
6.1. Mineralogical Properties	**6**
6.1 1.Crystal Structure	**7**
6.1.2. Exchangeable Cations	**7**
6.1.3. Colloidal Properties	**7**
6.1.4. Crystal Size and Surface Area	**7**
6.1.5. Dehydration and Rehydration	**7**
6.2. Chemical Properties	**8**
6.3. Engineering Properties	**10**
6.3.1. Improvement of Physical Properties	**10**
7. Processing of Bentonite	**11**
8. Background	**12**
9. World Reserves of Bentonite	**12**
10. Consumption of Bentonite	**14**
10.1. USA	**14**
10.2. Prices	**14**
11. Investment Opportunities	**15**
11.1. Bleaching of Edible Oil	**15**
11.2. Drilling Mud	**17**
11.3. Green Moulding Sand	**18**
11.4. Attenuation of Dissolved Heavy Metal Ions	**20**
11.5. Feeding Farm Animals	**21**
11.6. Examination of Absorption	**21**
11.6.1. Water Absorption (Pet Litter)	**21**
11.6.2. Absorption Results of Lubricating Oil	**22**
11.6.3. Adsorption of Water Vapour (Desiccants Properties)	**23**
11.6.4. Attrition Resistance of Clay Granules	**24**
11.7. Wastewater Treatment	**24**
11.7.1. Effluent Treatment of Irbid and Ramtha Sewage Treatment Plants by Bentonite	**24**
11.7.2. Low Cost Treatment of Olive Oil Mill Wastewater	**24**
11.7.3. Low Cost Treatment of Textile wastewater	**25**
11.8. Locally Status	**25**
12. References	**26**

List of Figures

Figure (1): Location map of the bentonite deposits in Jordan. 3

Figure (2): Distribution of bentonite boreholes in Al Azraq Area. 4

Figure (3): XRD trace of Q'a Al Azraq bentonite and Wyoming bentonite (Nawasreh, 2001). 6

Figure (4): SEM micrographs of bentonite samples from Q'a Al Azraq. 6

Figure (5): World Mine Production, Reserves, and Reserve Base: Reserves and reserve base are large in major producing countries, but data are not available (USGS mineral survey). 12

Figure (6): Flow chart of acid activation and bleaching process of bentonite (Nawasreh, 2001). 16

Figure (7): Water vapour absorption of clay samples. 23

Figure (8): Treatment of TWWs using optimum dose of Azraq bentonite after (Al Sghireen, 2006). 25

List of Tables

Table: (1): Particle size distribution (Wt %) (Nawasreh, 2001 and Ala'li, 1993). 8

Table (2): Physical properties of bentonite (Nawasreh, 2001). 8

Table (3): Physical properties of Azraq clays and Bulgarian, Turkey and Iraqi reference samples (Sallam, 1993). 8

Table (4): Chemical properties of bentonite (Nawasreh, 2001; Ala'li, 1996 and Ibrahim & Abdulhamid 1991). 9

Table (5): Chemical analyses of clay size fraction of three channel samples, three references and spot samples (Sallam, 1993). 9

Table (6): Chemical comparison between Jordanian bentonite and Wyoming bentonite after (Nawasreh, 2001). 9

Table (7): Comparison of chemical composition of Azraq clays and other clay deposits (Khoury, 2002). 10

Table (8): Results of engineering properties (Malak, 1995). 10

Table (9): Size analysis of classified products of bentonite sample using an 11 mm apex aperture hydrocyclone (Nawasreh, 2001). 11

Table (10): Physical properties of surface bentonite samples before & after upgrading. 11

Table (11): The hydrocyclone and physical results of Al Azraq bentonite (Salam, 1993). 11

Table (12): Bentonite; world production by country (USGS). 13

Table (13): Bentonite consumption by use. 14

Table (14): Evaluation of Ein Al Bayda clays for drilling mud compared with OCMA specifications and Bulgarian clays. 17

Table (15): Rheological properties of activated samples (3.5% Na2CO3) (Malak, 1995). 17

Table (16): Rheological properties of treated samples with H.V.C.M.C (Malak, 1995). 18

Table (17): Technical results on sand mixtures containing Raw Azraq clay (Salam, 1993). **18**
Table (18): Technical results on sand mixtures containing Bulgarian clay (Salam, 1993). **19**
Table (19): Results of sand mixture containing concentrated clay samples (Salam, 1993). **19**
Table (20): Properties of gray iron casting mould using Azraq clays (Salam, 1993). **20**
Table (21): Attenuation of heavy metal from nitrate solution (mg/gm clay) (Nawasreh, 2001). **20**
Table (22): Adsorption properties of lead by Ein Al Bayda clay (Baker, 1993). **21**
Table (23): The Water Absorption Results of Bentonite granules (Nawasreh, 2001). **22**
Table (24): Commercial Types of Cat Litter Examined (AFNOR, 1990). **22**
Table (25): The Oil Absorption Results of Bentonite Granules (Nawasreh, 2001). **23**
Table (26): Removal of NH+4, PO4+3 and K+ (Bakheet, 2002). **24**
Table (27): Treatment of Dajani OMW using different concentration of Azraq bentonite and commercial bentonite (Rababah, 2005). **25**

List of Appendices

Appendix (1): Absorption of β-Carotene by Acid Activated of Azraq Bentonite during the Bleaching Process of Crude Rape Seed Oil (Nawasreh, 2001). **31**
Appendix (2): Absorption of β-Carotene by Acid Activated of Azraq Bentonite during the Bleaching Process of Crude Rape seed Oil (Sample 2) (Nawasreh, 2001). **31**
Appendix (3): Absorption of β-Carotene by Standard Commercial Samples (TONSIL Bleaching Earth) provided by the Süd- Chemie Company (Acid Activated Bentonite and Thermal activated Palygorskite samples) During the Bleaching Process of Crude Rape seed Oil (Nawasreh, 2001) **31**

Bentonite

1. Introduction

The term bentonite was first suggested by Knight (1898), followed by Ross and Shannon (1926) who proposed that bentonite is a rock term for a clay deposit composed essentially of crystalline clay like mineral formed by alteration of glassy igneous materials either tuff or volcanic ash. Grim (1968) considered that bentonite is a clay deposit consisting essentially of smectite minerals usually dominated by montmorillonite which has a very wide range of industrial applications.

Among the smectite group, Montmorillonite is the most important commercially, with two main types:

Na-Bentonite (Swelling Bentonite): characterized by expansion up to 15 times of original volume when immersed in water.

Ca-Bentonite (Non-Swelling Bentonite): characterized by the adsorption property but do not show expansion when mixed with water. It has the ability to disperse in water and has very wide spread in nature.

2. Locations

The main two areas containing bentonite deposits are Al Yamaniyya and Al Azraq areas. Al Azraq area was divided into two parts; Q'a Al Azraq and Ein Al Bayda areas based on the conducted exploration studies.

2.1. Al Azraq Area

2.1.1. Q'a Al Azraq

Q'a Al Azraq (mud flat) is located about 110 km northeast of Amman, which represents a closed basin and covers about 350 Km2. It has a low relief, almost flat surface, oval shape and the elevation is about 510 m above sea level in the centre of the mud flat. Sixty five (65) boreholes were drilled within the Q'a Al Azraq. The spacing between the boreholes ranged from 2-3 km and at closer spacing in some places. The investigation revealed the presence of illite/smectite of different expendabilities, montmorillonite, palygorskite and kaolinite as clay minerals, while diatomite, evaporates (halite, gypsum with bassanite and anhydrite), quartz, dolomite, feldspar and calcite as non-clay minerals (Al'ali, et al., 1993).

2.1.2. Ein Al Bayda Area.

The Ein Al Bayda area represents the northern of Azraq depression. It is bounded by the Neogene-Quaternary basalt and volcanic tuff from the north and northeast and by the Al-Bayda Fault from the south. The area was studied extensively and about 17 boreholes were drilled in the area (10 km2). The inter-distance between boreholes was ranging between 500-1000m.

Ein Al Bayda is considered a promising area for bentonite deposits for the following reasons:

Location, grade and volume of the reserves.
The homogeneity of the deposits.
Thin overburden ranged from zero to 20 m with an average 10.6 m.
Low stripping ratio compared to international ratios for similar deposits.
Water table is 2-12m deep.
No mixing between the fresh water with the saline water.
The area is easily accessible all time of the year.

2.2. Al Yamaniyya Area

It is located about 10 km south of Aqaba, extending for a distance of 7 km along Aqaba coast with an average width of 6 km. Bentonite deposits are found within the Pleistocene sediments just near the shore lines. Three main clayey layers were identified ranging in thickness from 0.2m to 3m with alternating lenses of silt and sandstone. The overall thickness is around 8m. The percentages of the clay varied greatly horizontally and vertically based on the presence of the silt and sand lenses. The color of these deposits is greenish gray and yellowish brown.

The mineralogy of the deposits revealed the presence of montmorillonite and kaolinite clays in addition to illite/smectite mixed layer as the main constituent with expandable value up to 90% (Ibrahim and Abdulhamid, 1991). Chemical analyses of three samples conducted in Britain showed that the main mineral constituents are smectite, quartz, feldspar, kaolinite, and mica, and the smectite percentage ranges from 39-56% using the surface area calculation method.

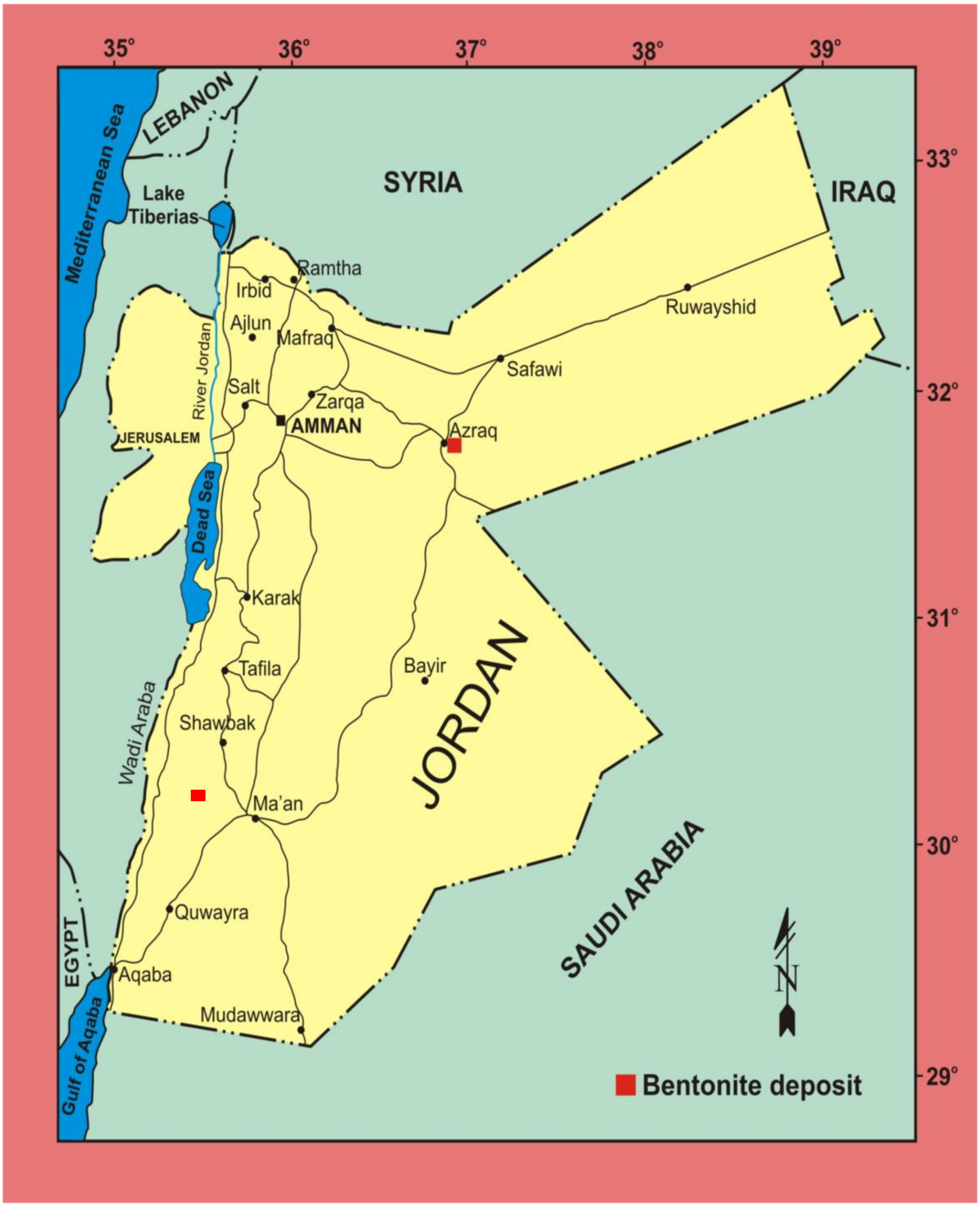
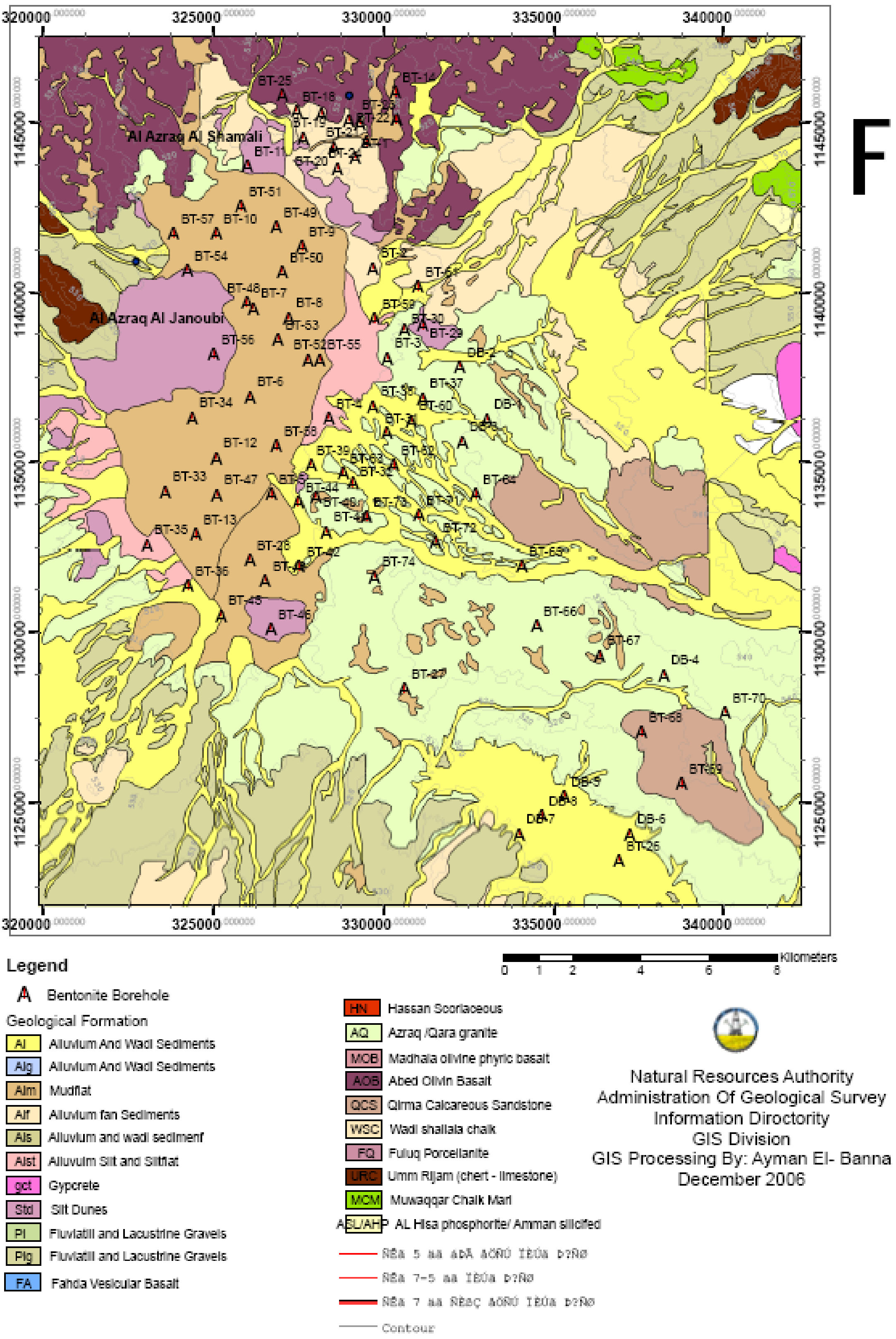


Figure (1): Location map of the bentonite deposits in Jordan.

Figure (2): Distribution of Bentonite Boreholes in Al-Azraq Area



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3. Geology

The Azraq Basin is asymmetric in shape, being approximately 50 km long and 30 km wide. It is located between the central Jordanian limestone province in the west and the Harrat Ash Shaam in the east. In the north it is bound by the Fuluq Fault and in the south by the Siwaqa Fault. The Basin is occupied in part by the Q'a Al Azraq (Mudflat) and an area called Ein Al Bayda.

Baker and Harza (1956) suggested that the Q'a al Azraq was a lake originally formed in the post Miocene time, and the clastic sediments, evaporates and Wadi sediments were accumulated and deposited in the lake. The low water supply and high rate of evaporation during the summer seasons are responsible for the dryness of the lake. The sediments penetrated in the drilled boreholes are composed of clay, silty clay, marly clay, sand, diatomite, evaporates and intercalations of lacustrine carbonates. Clays characterized by plastic appearance, gray to greenish gray changes to brown and reddish brown in color. The mineralogical constituents of the clay are Ca/Mg divalent smectite, random illite/smectite as the main clay minerals and kaolinite, palygorskite and mica as minor clay minerals, in addition to quartz and plagioclase as secondary non clay minerals.

Bentonites beds that originated as an alteration of water lain volcanic ash, deposited in either fresh or saline water, are commercially the most important source of this resource. These beds vary in thickness from a few centimeters or lenticular deposits, up to 10 meters in thickness which may in some cases extend over hundreds of sq km. The clay deposits belong to the Azraq Formation (Pliocene to Pleistocene in age).

4. Thickness and Overburden

Bentonite deposits in Ein Al Bayda present as lenticular in shape and the thickness ranged between 1.5-15.8 m based on the drilled boreholes data. The overburden in Al Azraq Area composed of silt, clays, chert fragments, carbonates, basalt fragments and volcanic tuff. Thickness of overburden ranges from zero to 20 m with an average of 10.6 m. The stripping ratio is considered to be economical and low compared to international deposits. The overburden of Al Yamaniyya is ranging between 20-25m and found to be unconsolidated and easy to be removed.

5. Reserves

The reserves in Ein Al Bayda area was 104.6 million ton, while the Q'a Al Azraq and Al Yamaniyya areas are not determined yet.

6. Bentonite Properties

Many researchers were studied the physical and chemical properties of Al Azraq bentonite. These important properties make bentonite of special interest for industrialists, environmentalist, agronomists, mineralogists and engineers. Some of the important properties are listed in tables 1, 2 and 3.

6.1. Mineralogical Properties

Al Azraq clay composed mainly of smectite, mixed layer illite/smectite, palygorskite and kaolinite forming the major constituents of clay minerals, whereas quartz, feldspar and calcite are present as impurities (non clay minerals). Comparative XRD traces of commercial bentonite sample (Wyoming bentonite), with concentrated bentonite samples from Q'a Al Azraq indicated that mineralogically were compared well but not necessary all the physical properties figure (3).

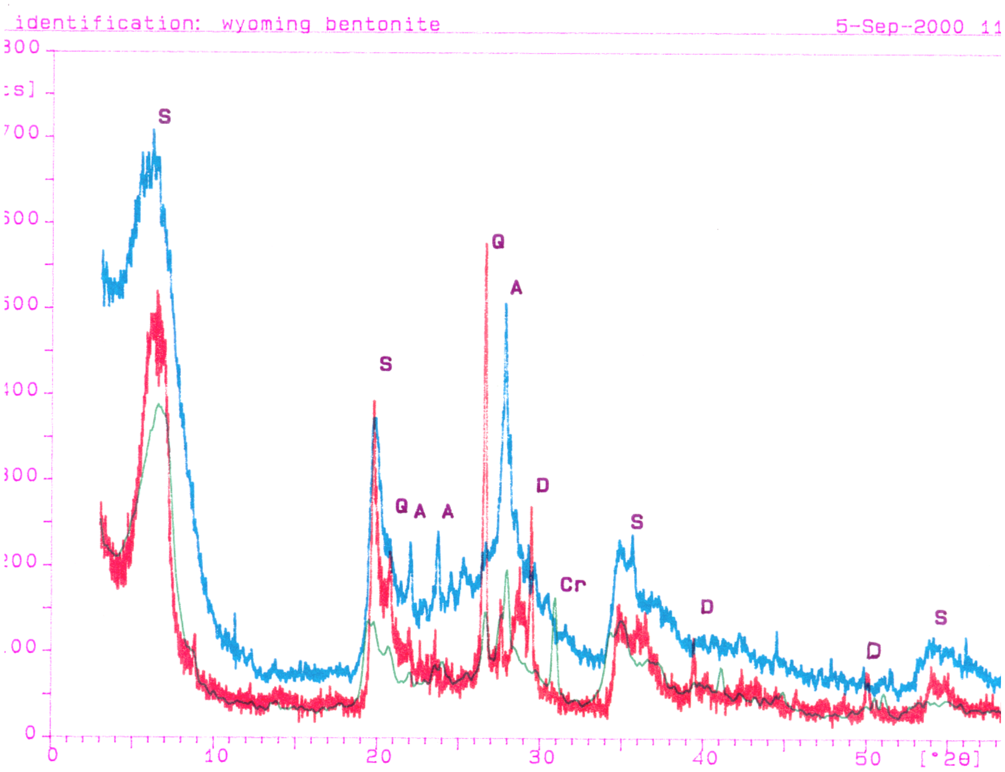


Figure (3): XRD trace of Q'a Al Azraq bentonite and Wyoming bentonite after Nawasreh, 2001).

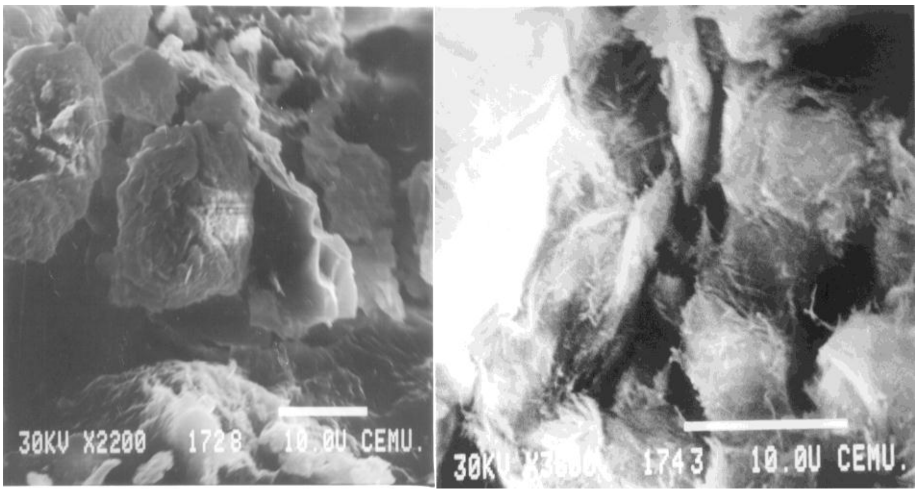


Figure (4): SEM micrographs of bentonite samples from Q'a Al Azraq.

6.1.1. Crystal Structure

The smectite clay structure consists of negatively charged layers within which several types of positively charged cations are fixed in specific positions. Each layer is composed of two silica tetrahedral sheets and one octahedral sheet. The 2:1 structural units are separated by layers of loosely held hydrated cations. The interlayer cations are present to balance the negatively charged structure that results from internal substitution of trivalent ions for silica in the tetrahedral sheet and divalent ions for aluminium in the octahedral sheet. The basal X-ray diffraction reflection expands to 17 Å after treatment with glycol and decrease to 10 Å on heating to about 200 °C. Mixed layered between illite and smectite sheets resulted from mixing different charged 2:1 units in the same crystal structure.

6.1.2. Exchangeable Cations

The presence of exchangeable cations is considered to be the most unique property of smectite minerals that are primarily adsorbed on the sheet surfaces. The cation exchange capacity (CEC) of pure smectite clays ranges between 70-130 meq/100g (Table 2). The exchangeable cations are easily and reversibly replaceable. The addition of soda ash (Sodium Carbonate) or other sodium compounds is common practice in industry to produce sodium smectite or clay with a high Na/Ca ratio.

6.1.3. Colloidal Properties

Once smectitic clays are added to a small amount of water, the small crystals disperse and separate as a result of their chemical and hydration properties. The electric potential causes the small particles to repel each other and stay in suspension as a colloid. The addition of more clay to the water causes the liquid to become viscous. The most viscous smectites are Na-montmorillonites which have the ability to become highly viscous and develop thixotropism. Thixotropy results because the negatively charged basal surfaces and the positive charges present on the crystal edges attract each other.

6.1.4. Crystal Size and Surface Area

Smectite crystals range in size between 2 microns and 0.2 microns with an average size of about 0.5 microns (Table 2). The morphology of the crystallites is lath shaped, but hexagonal and fibrous varieties are also recorded (Figure 3). The surface area of bentonite depends on the smectite percentage and grain size. Smectitic clays have the smallest crystal size, but the largest surface area (Table 2).

6.1.5. Dehydration and Rehydration

Smectites are hygroscopic and they adsorb large amounts of water from air. Heating of smectites will cause loss of water in two forms, adsorbed and crystalline. Adsorbed water is lost on temperatures from 100–200 0C. Crystalline water (OH) needs higher temperatures from 550–750 0C. Rehydration might occurs based on the relative humidity level and the type of the inter layer cation. Ca and Mg smectites rehydrate rapidly at lower humidity level (Table 2).

Table (1): Particle size distribution (Wt %) (Nawasreh, 2001 and Ala'li, 1993).

Grain size	+1000 µ		1000-63µ		63-2 µ		- 2 µ	
	Min.	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
Q'a Al Azraq1	0.13	0.41	2.71	4.93	42.14	44.77	49.89	55.02
Ein Al Bayda1	0.1	0.5	4.42	10.17	15.15	39.67	55.91	74.68
Ein Al Bayda2	0.12	49.49	0.06	54.89	12.28	66.96	14.69	96.62

Table (2): Physical properties of bentonite (Nawasreh, 2001).

Property	Location	
	Q'a Al Azraq1	Ein Al Bayda1
Specific gravity	2.64-2.72	2.49-2.58
Specific surface area m2/g	112.79-468.34	370.30-487.40
Smectite %	64.93	63.56
CEC Meq/100g	20.56-87.00	18.28-53.18
Oil absorption% by wt	60.70-87.20	70.0-74.0
Water absorption% by wt	143.50-185.50	106.5-207.0
Attrition resistance %	80-95	80-83.5
Adsorption of water vapor %	11	17

Table (3): Physical properties of Azraq clays and Bulgarian, Turkey and Iraqi reference samples (Sallam, 1993).

Sample Location	surface area Ethylene Glycol M2/g	Mont. %	Gel Index %	blue methylene adsorption Mg/g	CEC * blue-methylene Meq/100g	CEC A.A Mg/100g	Exchange. Cations Meq/100g				Na:Ca:Mg ratio
							Na	Ca	Mg	K	
Ein El-Bayda	314.60	42.00	11.00	167.70	52.50	56.00	9.00	7.00	6.00	2.00	45:85:20
	245.90	33.00	10.00	154.80	50.00	58.70	16.00	5.00	5.00	2.00	62:19:19
Al-Q'a	49.10	7.00	8.00	71.90	22.50	27.00	21.00	21.00	6.00	4.00	44:44:12
Reference Sample	B. 651.90	87.00	51.50	279.60	87.50	88.37	12.00	29.00	4.00	0.40	27:64:09
	T. 500.00	66.90	29.00	247.60	77.50	82.36	25.00	9.00	5.00	2.00	64:23:13
	I. 244.30	32.60	8.00	154.80	50.00	60.00	33.00	16.00	1.40	1.30	65:32:03
Pure Mont.	750.00	-	-	>200	-	80-120	-	-	-	-	-

CEC: Cation Exchange Capacity. B: Bulgarian T: Turkey q: Iraqi Mon.: Montmorillonite

6.2. Chemical Properties

The chemical analysis of some bentonite samples from the areas is shown in the following tables:

Table (4): Chemical properties of bentonite (Nawasreh, 2001; Ala'li, 1996 and Ibrahim & Abdulhamid 1991).

Oxides%	**Location**			
	Q'a Al Azraq1	Ein Al Bayda (bulk)1	Ein Al Bayda2	Yamaniyya 3
Na2O	0.13	1.12	0.01-4.99	0.49-3.26
MgO	3.47	10.75	1.06-12.8	0.91-3.92
Al2O3	20.08	10.7	2.02-21.76	12.95-17.33
SiO2	55.67	50.8	7.94-52.68	45.61-62.09
K2O	2.45	2.75	0.19-3.8	0.1-2.23
CaO	2.15	4.9	0.63-4.28	0.51-4.97
TiO2	2.54	0.9	0.06-1.57	0.54-1.65
Fe2O3	1.47	6.9	0.97-9.14	5.52-8.44

Table (5): Chemical analyses of clay size fraction of three channel samples, three references and spot samples (Sallam, 1993).

Oxides	**Ein El Bayda aver.(spot sample)**	**Q'a Al Azraq aver.(spot sample)**	**Channel Samples**			**Reference Samples**		
			MB1	**MB4**	**MB6**	**Bulgarian**	**Turkey**	**Iraq**
SiO2	55.10	51.59	52.85	57.50	47.95	54.59	58.00	60.83
Al2O7	11.62	11.97	13.11	14.74	13.51	11.75	12.34	10.93
Fe2O3	11.80	2.09	7.81	6.96	9.25	6.27	8.25	3.95
MgO	3.52	5.88	5.30	3.36	5.62	2.86	2.51	4.72
CaO	0.74	4.17	3.64	1.57	3.59	4.10	1.36	4.00
Na2O	0.96	3.42	0.82	1.79	0.59	2.22	2.02	0.71
K7O	1.85	3.31	1.79	2.28	1.89	0.39	1.35	0.35
TiO7	2.76	0.31	0.07	1.29	1.92	1.83	1.87	0.82
LOI	10.92	14.31	13.09	9.67	15.37	10.00	11.00	12.50
Total	**99.27**	**97.05**	**98.48**	**99.16**	**99.69**	**94.01**	**98.70**	**98.81**

Table (6): Chemical comparison between Jordanian bentonite and Wyoming bentonite (Nawasreh, 2001).

Location	**Na2O %**	**MgO %**	**Al2O3 %**	**SiO2 %**	**K2O %**	**CaO %**	**TiO2 %**	**Fe2O3 %**
Bentonite/Azraq	0.13	3.47	20.08	55.67	2.45	2.15	2.54	13.47
Bentonite (Wyoming)/USA	ND	1.92	22.84	66.11	0.56	1.32	0.55	6.51

Table (7): Comparison of chemical composition of Azraq clays and other clay deposits (Khoury, 2002).

Oxides %	Wyoming montmorillonite	California montmorillonite	Wyoming bentonite	Ein Al Bayda deposits	Q'a Al Azraq deposits	Purified Azraq Clay
SiO2	62.9	52.40	66.12	51.59	43.32	66.33
TiO2	0.16	0.33	-	1.71	0.59	-
Al2O3	19.3	15.0	17.01	16.70	12.59	17.07
Fe2O3	3.97	1.76	2.46	9.19	5.95	8.85
MnO	0.01	0.16	-	0.05	-	-
MgO	2.80	6.68	1.51	4.30	4.99	4.63
CaO	1.80	0.81	1.37	0.46	9.59	0.59
Na2O	1.54	1.21	2.02	0.93	2.25	3.08
K2O	0.56	0.33	0.54	2.46	2.89	2.62
LOI	5.1	19.5	7.3	12.40	17.41	-

6.3. Engineering Properties

Four clay rich samples were chosen for engineering tests. Samples 1 from borehole BT.19 (12.5-15.5m) is composed of mixed layer illite/smectite (70% expandability), palygorskite and kaolinite. Sample 2 from borehole BT.19 (25.5-27.5m) is composed of mixed layer illite/smectite (65% expandability), kaolinite and illite. Sample 3 from borehole BT. 15 (1.5-3.0 m) is composed of mixed layer illite/smectite (70% expandability), palygorskite, kaolinite and illite. Sample 4 from borehole BT. 17 (1.5-5m) is composed of mixed layer illite/smectite, kaolinite and illite. The clay content of four samples is 83%, 81%, 67% and 80% respectively.

Table (8): Results of engineering properties (Malak, 1995).

	Specific gravity	liquid limit	Plastic limit	Plasticity index	Shrinkage limit	CEC meq/100g
Sample 1	2.54	118	42.57	70.43	12.1	42.3
Sample 2	2.56	112	45.54	66.46	12.2	36.9
Sample 3	2.67	113	40.08	72.92	16.29	40.9
Sample 4	2.59	107	39.71	67.29	13.15	-

6.3.1. Improvement of Physical Properties

The quality of clay samples can be improved in a number of ways including physical upgrading. Physical improvement consists of removing non clay minerals in order to concentrate clay mineral particles together with their desirable properties. With this fact in mined the size fractionation of many samples was performed using a hydrocyclone. The results obtained are listed in (Table 11). The effect of upgrading of bentonite samples by remove coarse non clay minerals produced an enhancement of the clay minerals content and improved physical properties as illustrated by the results of surface area and cation exchange capacity (Table 10).

Table(9): Size analysis of classified products of bentonite sample using an 11 mm apex aperture hydrocyclone (Nawasreh, 2001).

Aperture (11mm)	+63 (µm) Weight %	-63+20 (µm) Weight %	-20 (µm) Weight %
Feed	2.45	-	-
Overflow 1	-	0.62	64.87
Overflow 2	-	-	15.64
Overflow 3	-	-	5.93
Underflow	-	6.49	4.00
Total	2.45	7.12	90.43

Table (10): Physical properties of surface bentonite samples before & after upgrading.

	Sample	0.5 µm % by wt	CEC meq/100 gm	Surface area m2/gm	smectite %
Before	1	38.42	83.31	454.02	60.54
	2	55.16	52.37	366.00	48.80
	3	23.62	20.56	112.79	15.04
AFTER	1	65.30	102.30	567.00	75.60
	2	70.96	85.59	457.50	61.00
	3	73.64	56.78	354.00	47.20

Table (11): The hydrocyclone and physical results of Al Azraq bentonite (Salam, 1993).

Sample location	S No.	Over flow aperture	Over flow % weight	Surface area m2	smectite %	Blue methylene absorption mg/g	CEC meq/100g	Apparent Viscosity*CP
Ein Al Bayada	MB1	8	60.92	528.8	70.5	296.2	75	4.0
		11	65.66	566.3	75.5	316	80	6.0
		14	77.39	453	60.4	296	75	5.0
Q'a Al Azraq	MB6	8	43.51	102	13.6	159.7	50	2.0
		11	45.8	152.3	20.3	173.7	55	2.0
		14	69	75	10	159.7	50	2.0
Reference	-	-	95.9	87	279.5	52	87	21.15

Apparent viscosity @ 6.4% concentration.

7. Processing of Bentonite

Bentonite is rarely used in its raw form, both drying and processing are usually essential to modify its properties for specific industrial applications. The processing techniques involve drying the bentonite in order to remove water and other volatile matter then grinding to suitable sizes. Approximately 10 to 15% of the moisture is removed from bentonite using rotary dryers and the finished product usually has a moisture content of 7 to 10% by weight. The raw material is then passed through a slicer to breakup the large chunks before drying. The temperature in dryers processing bentonite is 800oC at the inlet, 100- 200oC at the outlet, and 400-500oC in the main drying zone. The bentonite itself is kept at a temperature of less than 150oC. The dried clay is ground and sized using roll and hammer mills or pulverisers before screening. Once bentonite is delivered from the rotary dryer it is processed into either a fine powder or granulated into small particles or flakes. Most bentonite is ground to approximately 90% finer than 75μm. Granules are sometimes lightly calcined to make them water-stable and the granular grades are sold as absorbent products. Activation of bentonite for special industrial use (e.g. refining oil) is usually carried out by treatment of the clay with hydrochloric or sulphuric acids (HCl or H2SO4).

8. Background

Bentonite deposits were first reported in Q'a Al Azraq by Haddadin in 1974. After that many authors and researchers have studied bentonite ores in Jordan. They concluded the presence of illite/smectite mixed layer, palygorskite, montmorillonite and kaolinite in Q'a Al Azraq (Jaser, 1978, Khoury, 1980, Faraj, 1988, Qa'dan, 1992, Nawasreh, 1998 and 2001).

NRA set a project for mineral exploration and evaluation of clay deposits in Q'a Al Azraq and Ein Al Bayda areas during 1991-1993. Al'ali, and Abu Salah, 1993 found that the major constituent of the clay minerals are mixed layer illite/smectite, montmorillonite, palygorskite and kaolinite. Dwairi and Salam, 1994 indicated the use of Ein Al Bayda bentonite as binding agent in foundry sand. Geoindustry, 2000 recommended as favorable use for Jordan bentonite is in the sewage water treatment according to laboratory tests. Bleaching capacity of bentonite for edible oil after acid activations, water, oil and heavy metals absorption were evaluated by Nawasreh, 2001.

Ibrahim and Abdulhamid, 1991 indicated that the clay deposit of Al Yamaniyya area is composed mainly of illite/smectite, montmorillonite and kaolinite.

9. World Reserves of Bentonite

Figure (5) and table (12) show the producers and produced amounts world wide.

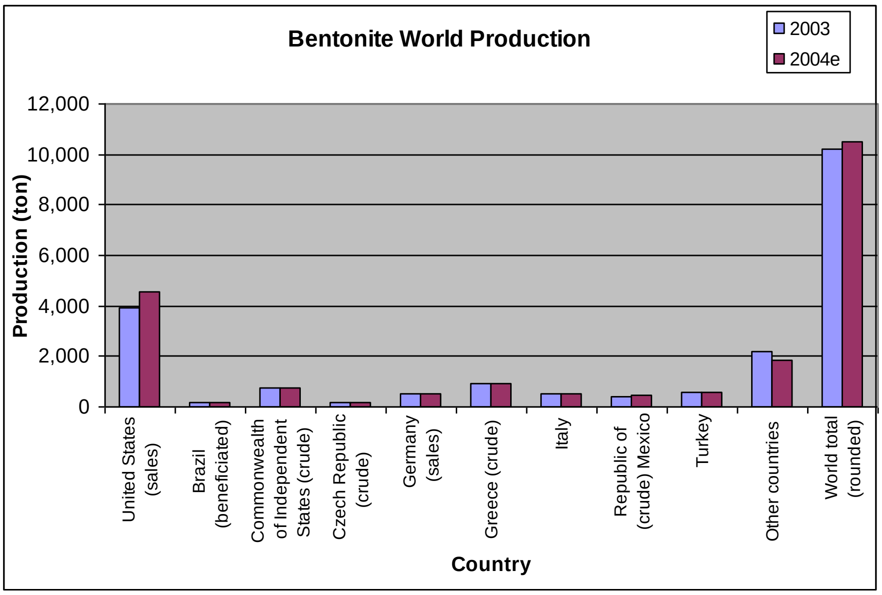


Figure (5): World Mine Production, Reserves, and Reserve Base: Reserves and reserve base are large in major producing countries, but data are not available (USGS mineral survey).

Table (12): Bentonite; world production by country (USGS).

(Metric tons)

Country[3]	2007	2008	2009	2010	2011[e]
Algeria[4]	32,600	30,600	31,000	34,000 [r]	34,000
Argentina	250,000	256,000	148,000	204,000 [r]	200,000
Armenia[e]	1,130 [5]	1,100 [r]	1,000 [r]	1,400 [5]	1,400
Australia[e, 4]	255,000	250,000	240,000	230,000	230,000
Azerbaijan[e]	50,500	40,700	10,600	18,100	20,000
Bolivia	--	1	323	440	591
Bosnia and Herzegovina	32,900	30,500	16,000	314 [r]	--
Brazil, beneficiated	330,000	340,000	264,000	532,000 [r]	532,000 [p]
Bulgaria	99,000	178,000	108,000	100,000 [r, e]	100,000
Burma[6]	971 [5]	1,000	1,000	1,000	1,000
Cyprus	150,000	150,000	150,000	150,000	150,000
Czech Republic, includes montmorillonite clays[e]	335,000	235,000 [r]	177,000 [r]	183,000	160,000
Egypt[e]	29,800 [5]	32,000 [5]	32,000	27,000 [r]	32,000
Georgia[e]	5,000	5,000	5,000	5,000	5,000
Germany	385,000	414,000	326,000	363,000 [r]	350,000
Greece[e]	950,000	1,500,000	845,000 [5]	850,000	850,000
Guatemala	23,600	62,700	14,300	22,400	20,000
Hungary	5,400 [r]	5,000 [r]	5,300 [r, 5]	3,000 [r]	3,000
Indonesia[e]	5,500	6,000	6,000	6,500	6,500
Iran[6]	254,000	358,000	387,000 [r]	400,000 [e]	400,000
Italy[e]	306,000	281,000	146,000	111,000	110,000
Japan	430,000	435,000	432,000	430,000	425,000
Macedonia[e]	35,200	22,900	15,400	12,800 [r]	14,500 [5]
Malawi	2,080	7,020	8,050	1,020	1,000
Mexico	614,000	375,000	511,000	591,000 [r]	53,800 [5]
Morocco	81,000	80,000	80,000	80,000	80,000
Mozambique	10,500	17,700	7,390	6,990 [r]	24,000
New Zealand, processed[e]	6,150	753	880	1,220 [r]	1,000
Pakistan	32,400	31,500 [r]	33,500 [r]	35,000	36,000
Peru	21,500	31,600	119,000 [r]	119,000 [r]	27,500 [5]
Philippines	1,150	1,420	1,410	1,480 [r]	1,500
Poland[7]	1,300 [r]	3,000 [r]	3,000 [r]	3,000 [r, e]	3,000
Romania	16,900	16,600	13,800	14,000	14,000
Slovakia	149,000	145,000	109,000	110,000	110,000
South Africa[8]	45,800	44,100	40,300	54,300	61,000
Spain[e]	155,000	155,000	155,000	155,000	155,000
Turkey	1,740,000	1,550,000	932,000	900,000 [r, e]	1,000,000
Turkmenistan, includes bentonite powder[e]	50,300 [r]	50,300 [r]	50,300 [r]	50,300 [r]	50,300
Ukraine[e]	300,000	200,000	195,000	185,000 [r]	185,000
United States	4,820,000	4,910,000 [r]	3,650,000	4,600,000 [r]	4,810,000 [5]
Uzbekistan[e]	15,000	15,000	15,000	15,000	15,000
Zimbabwe[8]	100	100	-- [e]	-- [e]	--
Total	12,000,000 [r]	12,300,000 [r]	9,280,000 [r]	10,600,000 [r]	10,300,000

[e]Estimated. [p]Preliminary. [r]Revised. -- Zero.

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

[2]Table includes data available through July 26, 2012.

[3]In addition to the countries listed, Canada and China are thought to produce bentonite, but output is not reported, and available information is inadequate to make reliable estimates of output levels.

[4]Includes bentonitic clays.

[5]Reported figure.

[6]Year beginning March 21 of that stated.

[7]Montmorillite type bleaching clay.

[8]May include other clays.

10. Consumption of Bentonite / Globally

10.1. USA

Table (13): Bentonite consumption by use.

	Thousand Metric Ton	
Use	**2010**	**2011**
Domestic:		-
Pet waste absorbents	961	1.110
Adhesives	8	9
Animal feed	64	36
Ceramics (except refractories) 2	-	-
Drilling mud	1.040	1.160
Filler and extender applications 3	104	68
Filtering, clarifying, decolorizing	-	-
Foundry sand	534	592
Pelletizing (iron ore) 4	586	649
Miscellaneous refractories	-	-
Miscellaneous 5	245	96
Waterproofing and sealing	103	181
Total	**3645**	**3901**
Exports		
Drilling mud	136	289
Foundry sand	135	158
Other 6	472	337
Total	**743**	**784**
Grand total	**4388**	**4685**

1. Data are rounded to no more than three significant digits, may not add to totals shown.
2. Includes catalysts and pottery.
3. Includes asphalt tiles (2003), cosmetics, ink, medical, miscellaneous fillers and extenders applications, paint, paper coating, paper filling (2003), pesticides and related products (2003), pharmaceuticals, and plastics.
4. Excludes shipments to Canada. Total sales in North America were 603,000 metric tons (t) in 2003 and 600,000 t in 2004.
5. Includes chemical manufacturing, heavy clay products, and other unknown uses.
6. Includes absorbents, fillers and extenders, miscellaneous refractories, pelletizing, and other unknown uses.

10.2. Prices (in the United States)

The average unit value reported by domestic producers for nonswelling bentonite was $76 per ton in 2012 compared with $73 per ton in 2011. The average value for swelling bentonite was $62 per ton compared with $61 per ton in 2011. The average value for all bentonite was $62 per ton in 2012 compared with $61 per ton in 2011. The average f.a.s. value of exported bentonite was $159 per ton.

11. Investment Opportunities

The bentonite deposits are open for investment. Mining and exploration companies are invited on the basis of detailed exploration, evaluation and exploitation. The purity of these clay deposits have been found to vary as a result of coarse mineral impurities, but several samples were found to be of sufficient purity to represent possible commercial sources of clay mineral which could also be upgraded by size fractionation if required. The suitability of number of samples from the Q′a Al Azraq and Ein Al Bayda areas for industrial uses have been investigated by means of number of standard tests to characterize the commercial properties of these materials (Nawasreh, 2001).

11.1. Bleaching of Edible Oil

Bentonite samples from Q’a Al Azraq area were subjected to hydrocyclone to reduce the impurities and then activated by acid using HCl (Figure 6). The result of oil bleaching experiments is given in appendix. Due to the differences in mineralogy and chemistry between bentonite samples two samples were chosen to be representative of most of the Q’a Al Azraq bentonite samples. Different combinations of acid strength and contact time were used to activate samples. They both displayed high bleaching capacities and produced colour changes in excess of 93% giving results similar to those obtained with industrial products.

A comparison of oil treatment results for the Q′a Al Azraq bentonite samples with standard commercial (215 FF and 110 FF Tonsil Bleaching Earth) samples provided by Süd Chemie Ltd Company are contained in Appendices (1, 2 & 3). It can be seen from the results that acid activated Jordanian bentonite samples produced very similar results to commercial available samples. Treatment of raw rape seed oil samples with activated clay samples gave products with properties identical to those of commercial refined rape seed oil.

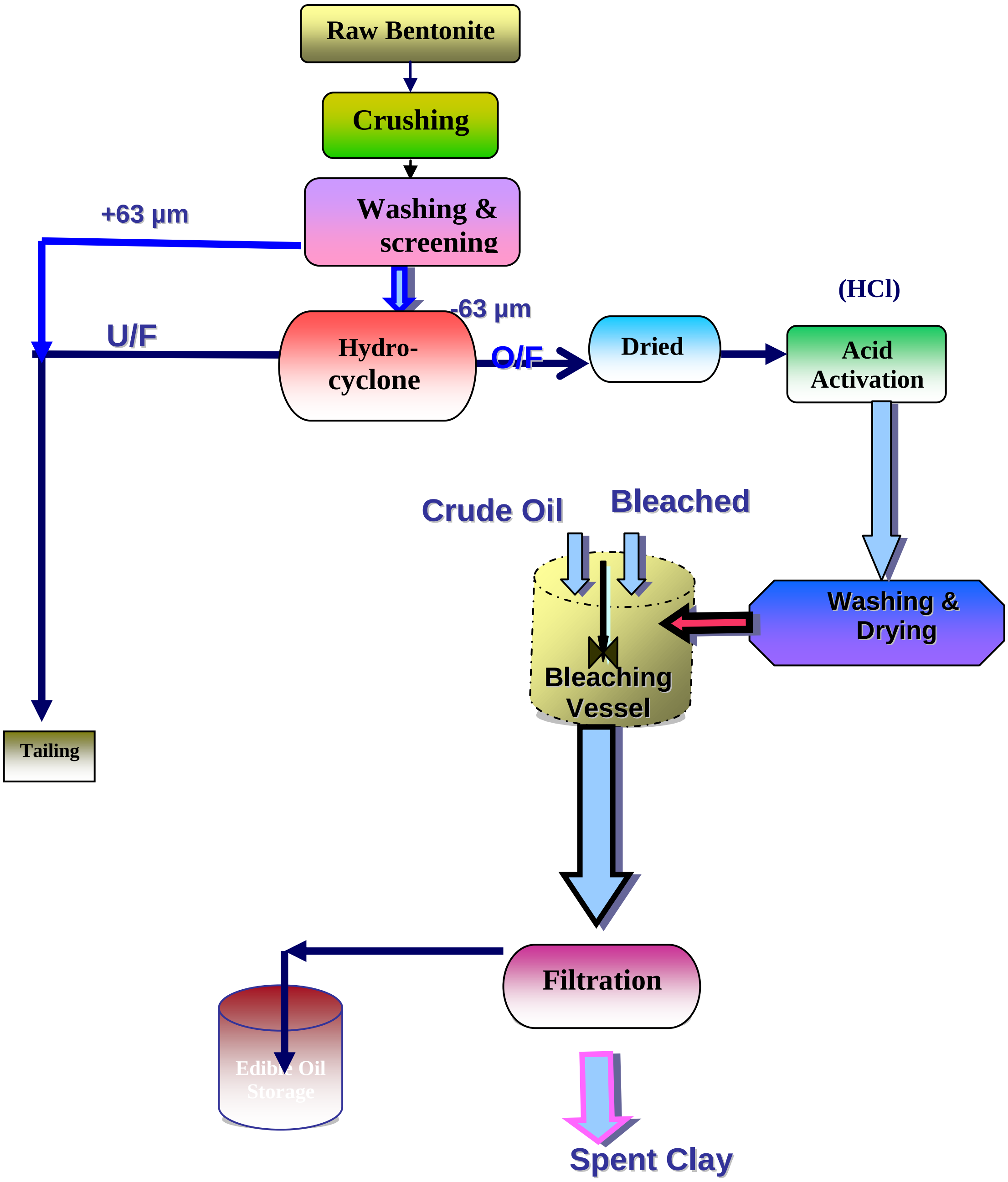


Figure (6): Flow chart of acid activation and bleaching process of bentonite (after Nawasreh, 2001).

11.2. Drilling Mud

Four bulk composite bentonite samples of Ein Al bayda area were evaluated by Salam, 1993 and Malak, 1995 for use as drilling mud with reference to OCMA and Bulgarian bentonite as seen in Table (14).

Table (14): Evaluation of Ein Al Bayda clays for drilling mud compared with OCMA specifications and Bulgarian clays

	Sample No.					
Test	BT.19	BT.19	BT. 15	BT. 17	Bulgarian	OCMA Specification
+200 sieve %	0		0	0	0	2.5% Max.
Yield No. (US bbls/2000lbs)	Out of range	Out of range	Out of range	Out of range	10.42	92 Min. 144.9 Max.
Filtrate loss (ml)	62	54.5	58.4	38.1	10.5	15 Max.
Moisture content	11	8.5	8.5	7	13	15 Max.
PH	7	7	7	7	10	Not defined

The activation of Ein Al Bayda samples with 3.5% Na2CO3 has slightly improved the rheological properties (Table 15).

Table (15): Rheological properties of activated samples (3.5% Na2CO3) (Malak, 1995).

	Sample No.				
Test	BT.19	BT.19	BT. 15	BT. 17	OCMA Specification
Yeild No. (US bbls/2000 lbs)	91.4	86.2	94.3	92.8	92 Min. 144.9 Min.
Filtrate loss(ml)	12.5	11.3	15.4	10.9	15 Max.
PH values	10	10	10	10	Not defined

The treatments of Ein Al Bayda samples with different concentrations indicated that the addition of 9-10% of cellulose improved the rheological to meet with lower limit for OCMA specifications (Table16). Salam, (1993) and Malak, (1995) concluded that the Ein Al Bayda clays are not suitable for use as drilling mud neither raw nor activated with sodium carbonate. They added that the clays gave better results when mixed with 9-10% high viscosity carboxyl methyl cellulose.

Table (16): Rheological properties of treated samples with H.V.C.M.C (Malak, 1995).

	Sample No																
	Sample 1				Sample 2				Sample 3				Sample 4				OCMA Sp.
Test	2%	5%	7%	10%	2%	5%	7%	10%	2	6%	8%	9%	2%	6%	7%	9%	
Yeild No. (US bbls/2000 lbs)	O.R	79.8	87.4	120.1	O.R	O.R	78.4	93.4	O.R	88.7	100.6	112	O.R	84.1	90.1	112	92 Min. 144.9 Max.
Filtrate loss(ml)	26.7	18.2	15.9	10.2	21.6	15.2	10.5	9	28	21.8	16.1	13.2	18.6	14.2	11.3	10.4	15 Max.
PH values	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Not def.

O.R out of range

11.3. Green Moulding Sand

Some bonding tests were carried out on Azraq clays as raw and activated with Na2CO3 by Salam, (1993) and compared with reference sample (Bulgarian). Her results show decreasing in the permeability as the clay and water contents are increased. The green compressive strength, shatter index and compatibility values increase with the increase of the clay and water content. The flowability shows a variable behavior as the clay and the clay and water content increase. Generally the obtained results by using Azraq clays indicate low technical values as compared with the Bulgarian clays. The activation of concentrated clays from Al Azraq by Na2CO3 show increase in the permeability and green compression strength. The shatter index, Flowability and compactability show a variable behavior as the clay and water content increase in the mixture. The technical results of Salam, (1993) are listed in tables 17 - 20.

Table (17): Technical results on sand mixtures containing Raw Azraq clay (Salam, 1993).

		Clay %				
Test	Water %	3%	5%	7%	9%	11%
	3	N.D	N.D	N.D	N.D	N.D
	5	130	116	115	119	115
Permeability	7	130	113	106	106	108
	9	110	98	80	80	65
	11	95	70	63	57	20
	3	V.L	V.L	V.L	V.L	V.L
Green	5	18	29	48	49	88
Compression	7	17	30	49	69	84
strength KN/m2	9	16	29	45	43	76
	11	11	29	39	46	73
	3	N.D	N.D	N.D	N.D	N.D
	5	38	41	68	78	87
Shatter index %	7	46	44	63	80	95
	9	47	51	58	69	96
	11	41	56	74	86	98
	3	N.D	N.D	N.D	N.D	N.D
Flowability %	5	99	80	79	66	88
	7	94	89	90	74	81
	9	95	93	97	97	94
	11	80	88	78	60	80
	3	N.D	N.D	N.D	N.D	N.D
Compactability	5	47	51	52	57	58
No.	7	46	52	59	62	64
	9	45	52	55	61	63
	11	45	49	55	59	56

N.D not detected V.L very low

Table (18): Technical results on sand mixtures containing Bulgarian clay (Salam, 1993).

		Clay %				
Test	Water %	3%	5%	7%	9%	11%
Permeability No.	3	151	144	146	132	127
	5	144	125	124	119	122
	7	119	104	102	100	96
	9	105	85	77	75	99
	11	85	63	55	58	62
Green compression strength KN/m2	3	22	49	69	103	122
	5	24	74	65	85	95
	7	29	48	71	83	198
	9	26	47	61	80	99
	11	21	39	63	79	93
	3	31	40	53	62	78
	5	43	55	69	75	84
Shatter index	7	44	60	62	77	88
%	9	46	65	80	82	92
	11	48	60	78	87	91
Flowability %	3	86	95	94	83	81
	5	80	90	91	77	95
	7	98	96	95	82	80
	9	97	84	79	95	92
	11	89	78	91	79	93
	3	45	48	52	46	45
	5	48	51	54	55	54
Compactability	7	49	55	58	58	60
No.	9	49	54	58	59	61
	11	49	52	56	59	63

Table (19): Results of sand mixture containing concentrated clay samples (Salam, 1993).

Location	**Aperture (mm)**	**Permeabilty Permeability No.**	**Green compression strength KN/m2**	**Shatter index %**	**Flowability %**	**Compactibilty Compact No.**
Ein Al Bayda MB1	8	100	52	70	99	58
	11	98	55	82	92	57
	14	95	52	68	82	58
Raw MB1	103	39	54	84	84	56
Ein Al Bayada MB4	8	95	30	71	94	50
	11	95	35	65	90	52
	14	94	29	57	89	49
Raw Ein Al Bayda MB4	93	17	47	87	87	47
Concentrated MB6	8	122	18	46	93	47
	11	105	22	46	98	49
	14	125	20	46	90	50
Raw Q'a Al Azraq MB6	112	12	46	87	83	42
Bulgarian		102	71	62	95	58

Table (20): Properties of gray iron casting mould using Azraq clays (Salam, 1993).

Condition	Mould properties*
Sand fineness number **	47
clay content	9%
Water content	7%
Permeability (Permeability No.)	118
Green strength KN/m2	69
Shatter index %	71

* Obtained from Royal Scientific Society
**Standard sands have fineness No. 50

11.4. Attenuation of Dissolved Heavy Metal Ions of Q'a Al Azraq bentonite

The result of the adsorption of heavy metals by treated and untreated clay samples from Q'a Al Azraq is listed in (Table 21). These results are expressed in terms of milligrams of metal per gram of clay adsorbed. It can be seen that monovalent cation sample was capable of removing more lead and nickel from solution than other samples. The activation of bentonite using hydrochloric acid reduced the ability of the clay cations to exchange due to the substitution of the interlayer cations by hydrogen ions (Nawasreh, 2001).

Retention values of heavy metals from monometallic solutions were higher than those from mixed metal solutions. This difference of adsorption is related directly to the competition between cations for adsorption sites on the clay particle surfaces. These heavy metal adsorption values provide useful information when considering the use of clay samples for the formation of pollutant barriers in landfill sites where the migration of the heavy metals needs to be contained (Nawasreh, 2001).

Table (21): Attenuation of heavy metal from nitrate solution (mg/gm clay) (Nawasreh, 2001).

Sample	Cr	Zn	Cu	Ni	Pb+2
Adsorption From Single Metal Solutions					
1	9.70	5.77	9.80	8.99	9.82
Acid activated 1	2.22	ND	1.70	0.60	2.84
2	8.09	2.16	8.27	3.77	8.71
Acid activated 2	1.53	ND	0.71	0.40	2.80
Palygorskite	0.50	0.22	1.00	0.04	0.06
Thermal activated	0.60	0.30	1.40	0.10	0.60
Adsorption From Mixed Metal Solutions					
1	6.93	3.70	7.63	3.63	8.69
2	3.71	3.11	4.10	3.57	4.53

A composite sample from Ein al Bayda smectitic clay was used to investigate its potential for lead adsorption by Baker, (1993). She found that the ability of clay to remove lead from the solutions is high and could be related to the high porosity table (22).

Table (22): Adsorption properties of lead by Ein Al Bayda clay (Baker, 1993).

Time minutes	Ct/Co
0	1.0
5	0.34
10	0.36
15	0.35
20	0.34
25	0.35
30	0.33
60	0.33
120	0.33
240	0.35
480	0.36
1440	0.4

Mass of adsorbent =1.79
Volume of solution =1.7dm3
Stirring speed =300 RPM
pH =6
Particle size =<53 microns

Bulk density of the sample =0.710 g/cm3
Porosity of the sample =0.708
Specific surface area for <5 micron of 1.7 g = 5.9 cm-1
Initial lead concentration =50 mg.dm-3

11.5. Feeding Farm Animals

A composite ground smectitic clay sample (<150mm) from Ein Al Bayda was used in feeding animals and poultry (Nawar et al, 1993). Fattening rations were formulated by adding 9.5% and 5% of the clay. Each ration was fed to 8 Awassi (averaging 21 kg weight) lambs for 8 weeks. At the end of the experiment, samples of blood and feces were collected from randomly chosen five animals. Four animal of each group were slaughtered. Blood samples were subjected to hematological assay, determination of the serum components, enzyme activity and serological examination. Feces were subjected to parasitological examination. The rations containing 5% clays gave significant increase in digestibility, live body weight and gain improvement of feed efficiency and nitrogen utilization, increase ($P<0.05$), in absolute weighs of the carcass, Hb% (<0.05), WBC's count ($P<0.01$) and serum cholesterol ($P<0.01$) and a decease in HCL % ($P<0.01$), serum total protein and globulin. The results indicated also an increase in serum GOT ($P<0.01$) and decrease in serum LDH ($P<0.01$). No clear change in each of serum Ca+2, Na+, K+ and (PO4) +3 and no effect on liver kidney functions and parasitological and serological examination were noticed (Khoury, 2002).

11.6. Examination of Absorption

11.6.1. Water Absorption (Pet Litter)

The ability of bentonite to absorb water or the retention capacity of water in their internal structure (pores and between the inter layer) is considered to be the most significant property. Water retention capacity is defined as the mass of water absorbed by a given mass of material (Nawasreh, 2001). The water absorption values of bentonite granules are listed in Table 23.

Table (23): The Water Absorption Results of Bentonite granules (Nawasreh, 2001).

Sample No.	Water Absorption (% by Wt)
1	207.00
2	158.00
3	107.50
4	115.62
MNJ 4	185.50
MNJ 5	143.50
MNJ 6	184.50
MNJ 3	106.50
MNJ 2	192.00

The water absorbency percentages varied from one sample to another and ranged from 107% for samples from Mallahat area to 207% for the divalent cation samples of the Q'a Al Azraq area.

Generally, the bentonite samples showed little variation in the amount of absorbency, and the low value for sample MNJ 3 may possibly be due to loss of clay materials from the apparatus during saturation of the sample with water (Nawasreh, 2001). Azraq bentonite samples showed larger absorption values than those obtained in the literature, as shown in Table 24.

Table (24): Commercial Types of Cat Litter Examined (AFNOR, 1990).

Clay Type	Country of Origin	Water Absorption (% by Wt)
Molar clay	Denmark	90
Sepiolite	Spain	90
Bentonite	Bulgaria	115
Attapulgite	Senegal	90
Attapulgite	USA	90
Bentonite	Indonesia	115
Bentonite	England	115
Marl	Spain	80
Fine Bentonite	USA	115

11.6.2. Absorption Results of Lubricating Oil

The use of clay granules, either bentonite or palygorskite or both, to absorb lubricating oil, grease and chemical spillage and other undesirable substances on the floor of factories, hangers, filling station, has led to an increase in the demand for clay granules to be used as absorbent materials. The oil absorption results of bentonite granules are listed in Table 25. The oil absorption values of bentonite range from 61% to 87%. The variation in oil absorption did not show a very large difference between the samples. The minimum value of oil absorption by bentonite is 60% by weight (US Federal Specifications for oil and water absorption, 1976). Most of the samples produced values above the minimum specified for absorption. Comparison between Jordanian bentonite granules with commercial granules for oil absorption capacity (the latter sold as absorbent granules of an unknown source which is currently used in the workshop of Cardiff School of

Engineering) showed all of the local granules have absorption percentages higher than the commercial absorbent granules which occur in the lower of the minimum margin of oil absorption value.

Table (25): The Oil Absorption Results of Bentonite Granules (Nawasreh, 2001).

Sample No.	Oil Absorption (% by Wt)
1	87.20
2	76.50
3	62.00
4	60.70
MNJ 5	74.00
MNJ 6	70.00
MNJ 3	66.80
MNJ 2	75.00
UK standard	52.00

11.6.3. Adsorption of Water Vapour (Desiccants Properties)

The clay granules of the Q'a Al Azraq together with one reference clay sample (desiccant) provided by Süd Cheomi Ltd, were evaluated for their water vapour absorption properties to assess their use as desiccants. The maximum adsorption of water vapour was found to be about 17%. This value was recorded for palygorskite samples. The kinetics of adsorption of water vapour by samples is illustrated by Figure 7. The absorption of water vapour by bentonite was found to be lower than values displayed by palygorskite samples, the maximum being 11% after 12 hours exposure.

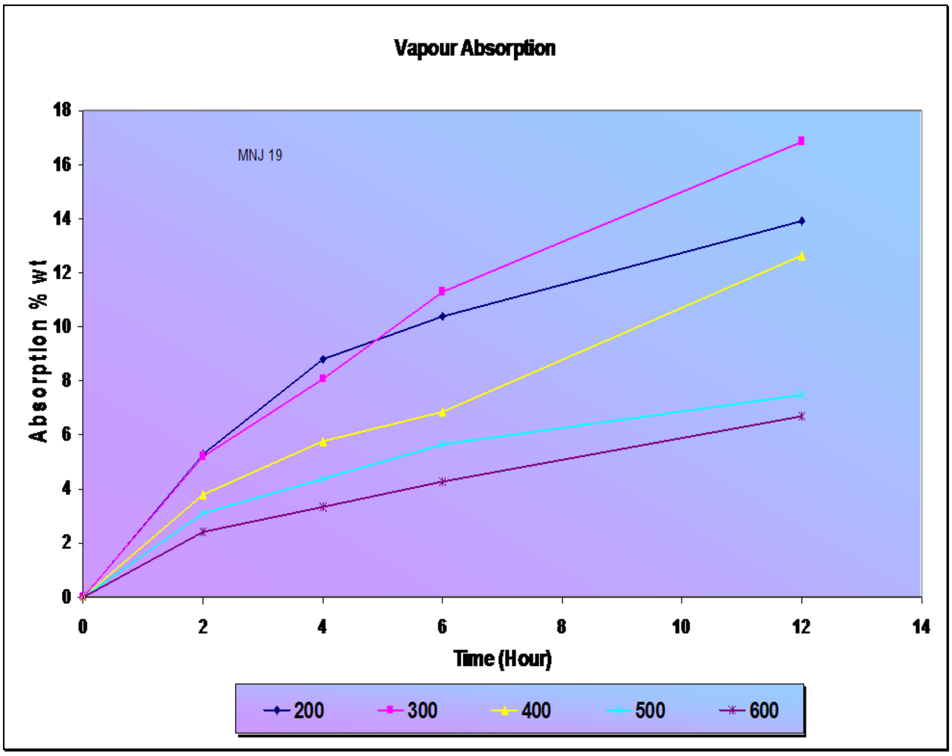


Figure (7): Water vapour absorption of clay samples.

11.6.4. Attrition Resistance of Clay Granules

Bentonite samples were subjected to attrition resistance tests by a procedure given by the U.S Federal Specification Standard for determination of resistance to attrition. The percentage amount of material passing through the 180 μm screen are calculated by the following equation and the total amount of the granules passing through the 180 μm screen must be not exceed more than 10 %.

Breakdown % = quantity pass through 180 μm screen/ 50∗100. Bentonite granules showed a high resistance to attrition with no variation in granules in resistance to breakdown and the most competent material was sample 2. Breakage of these materials during handling, especially when used as pet litter or floor absorbents, is not a desirable property.

11.7. Wastewater Treatment

11.7.1. Effluent Treatment of Irbid and Ramtha Sewage Treatment Plants by Bentonite

Raw, acid activated and basic activated bentonite from Q’a Al Azraq and Ein Al Bayda areas were used to remove macronutients particularly NH+4, K+ , PO4-3, biochemical oxegen demand (BOD) and chemical oxegen demand (COD) from Irbid and Ramtha Sewage Plant (Bakheet, 2002). The result of batch experiments is given in Table 26.

Table (26): Removal of NH+4, PO4+3 and K+ (Bakheet, 2002).

Sample	% Removal of NH+4			% removal of K+			% Removal of (PO4)-3			% Removal of BOD			% Removal of COD		
	0.9 g/l	2.4 g/l	4.8 g/l	0.9 g/l	2.4 g/l	4.8 g/l	0.9 g/l	2.4 g/l	4.8 g/l	0.9 g/l	2.4 g/l	4.8 g/l	0.9 g/l	2.4 g/l	4.8 g/l
Commercial	39	45	50	49	63	71	5	7	8	35	40	60	14	21	28
Q'a Azraq Raw	18	22	30	29	33	40	8	10	15	19	33	41	11	19	26
Acid acti.	24	28	34	39	36	47	7	8	10	19	26	34	7.4	19	26
Basic act.	20	25	31	33	36	43	7	9	12	22	41	62	7.4	18	26
Ein Al Bayda Raw	25	31	38	35	39	51	6.5	8	10	19	33	60	15	19	25
Acid act.	30	38	43	42	48	55	5	5	7	22	26	62	7.4	18	25
Basic act.	32	33	39	37	43	50	5	7	7.5	21	24	60	7.4	18	26

11.7.2. Low Cost Treatment of Olive Oil Mill Wastewater (OMW) by Bentonite

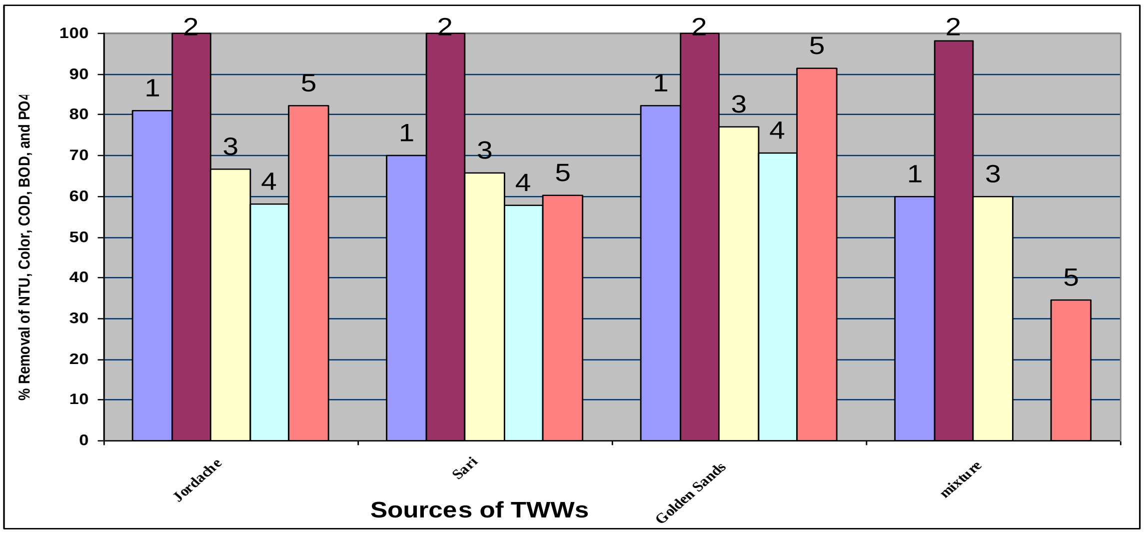
Bentonite samples from Q’a Al Azraq were used as coagulant and adsorbent to treat the wastewater that resulted from the olive oil mill. The results of treating olive oil mill wastewater with different reagents indicate that the using of Azraq bentonite as a single reagent treatment is very effective (Table 27), (Rababah, 2005).

Table (27): Treatment of Dajani OMW using different concentration of Azraq bentonite and commercial bentonite (Rababah, 2005).

Parameter	Turbidity NTU	% Removal of NTU	COD (g/l)	% Removal of COD	PH (SU)	TDS (g/l)
Control	3570	-	64	-	5.25	10.68
7% bentonite	1311	96	40	37.5	5.5	12.3
10% bentonite	1056	97	40	37.5	5.7	12.4
13% bentonite	2025	94	65	45.3	5.37	13.3
4% Terrana St.	3900	89	36	43.8	5.32	10.8
5% Tonsil St.	12500	65	41	35.9	5.34	13.62
5% Tonsil Opt.	ND	-	ND	-	-	-

11.7.3. Low Cost Treatment of Textile Wastewater (TWWs) by Bentonite

The TWWs generated by three textile companies (Jordache, Sari and Golden Sands) at Al Hassan Industrial Estate, Ramtha-Jordan contain significant concentrations of COD, BOD, TDS, PO43-, Turbidity and Colors (Al Sghireen, 2006). She considered the Azraq bentonite is the best available reagent for treating the wastewater. The results of treating a mixture of TWWs using optimum dose of Azraq bentonite is illustrated by Figure (8).



1) % turbidity removal 2) % color removal 3) % COD removal
4) % BOD removal 5) % PO43- removal.

Figure (8): Treatment of TWWs using optimum dose of Azraq bentonite after (Al Sghireen, 2006).

11.8. Locally Status

No mining activities for Bentonite were carried out in the past or in the present time. Bentonite deposits in Jordan should be oriented to oil refining industries as bleaching agent for mineral and edible oil. In addition, wastewater treatment and cat litter are other important sectors to orient Bentonite to these sectors.

12. References

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Appendices

Appendix (1): Absorption of β-Carotene by Acid Activated of Azraq Bentonite during the Bleaching Process of Crude Rape Seed Oil (Nawasreh, 2001).

Appendix (2): Absorption of β-Carotene by Acid Activated of Azraq Bentonite during the Bleaching Process of Crude Rape seed Oil (Sample 2) (Nawasreh, 2001).

Appendix (3): Absorption of β-Carotene by Standard Commercial Samples (TONSIL Bleaching Earth) provided by the Süd- Chemie Company (Acid Activated Bentonite and Thermal activated Palygorskite samples) During the Bleaching Process of Crude Rape seed Oil (Nawasreh, 2001).

Appendix (1): Absorption of β-Carotene by Acid Activated of Azraq Bentonite during the Bleaching Process of Crude Rape Seed Oil (Nawasreh, 2001).

S. No	Absorption At 450 nm (Absorbance unit)	Bleaching capacity %	Concentration of ß-carotene in solution (µg/ml)	Absorption At 430 nm (Absorbance unit)	Color change %	Concentration of ß-carotene in solution (µg/ml)	Concentration of absorbed carotene (10-4 moles/100gm)
1N&1h	0.239	92.90	1.488	0.223	92.34	1.39	7.255
1N&4h	0.049	98.54	0.305	0.094	95.07	0.59	7.696
1N&8h	0.015	99.55	0.093	0.101	96.52	0.63	7.795
1N&12h	0.036	98.93	0.224	0.069	97.63	0.43	7.726
1N&16h	0.057	98.31	0.355	0.092	96.83	0.57	7.678
8N&1h	0.175	94.80	1.090	0.236	91.88	1.47	7.404
8N&4h	0.041	98.78	0.255	0.039	98.66	0.24	7.715
8N&8h	0.125	96.29	0.778	0.105	96.39	0.65	7.520
8N&12h	0.617	81.68	3.842	0.482	83.41	3.00	6.379
8N&16h	0.234	93.05	1.457	0.209	92.81	1.30	7.267

Appendix (2): Absorption of β-Carotene by Acid Activated of Azraq Bentonite during the Bleaching Process of Crude Rape seed Oil (Sample 2) (Nawasreh, 2001).

S. No	Absorption At 450 nm (Absorbance unit)	Bleaching capacity %	Concentration of ß-carotene in solution (µg/ml)	Absorption At 430 nm (Absorbance unit)	Color change %	Concentration of ß-carotene in solution (µg/ml)	Concentration of absorbed carotene (10-4 moles/100gm)
2N&1h	0.086	97.45	0.54	0.130	95.53	0.81	7.608
2N&4h	0.067	98.01	0.42	0.105	96.39	0.65	7.653
2N&8h	0.044	98.69	0.27	0.093	96.81	0.58	7.709
2N&12h	0.047	98.60	0.29	0.066	97.77	0.41	7.702
2N&16h	1.060	68.52	6.60	1.128	61.24	7.02	5.351
5N&1h	0.048	98.57	0.30	0.065	97.77	0.40	7.698
5N&4h	0.016	99.53	0.10	0.083	97.15	0.52	7.773
5N&8h	0.039	98.84	0.24	0.035	98.80	0.22	7.720
5N&12h	0.030	99.11	0.19	0.074	97.46	0.46	7.739
5N&16h	0.044	98.69	0.27	0.059	97.97	0.37	7.709

Appendix (3): Absorption of β-Carotene by Standard Commercial Samples (TONSIL Bleaching Earth) provided by the Süd- Chemie Company (Acid Activated Bentonite and Thermal activated Palygorskite samples) During the Bleaching Process of Crude Rape seed Oil (Nawasreh, 2001).

S. No	Absorption At 450 nm (Absorbance unit)	Bleaching capacity %	Concentration of ß-carotene in solution (µg/ml)	Absorption At 430 nm (Absorbance unit)	Color change %	Concentration of ß-carotene in solution (µg/ml)	Concentration of absorbed carotene (10-4 moles/100gm)
215FF	0.139	95.87	0.866	0.093	96.80	0.58	7.487
110FF	0.033	99.02	0.205	0.082	97.18	0.51	7.733
T350	0.207	93.85	1.289	0.164	94.35	1.02	7.330
T550	0.443	86.84	2.758	0.177	93.91	1.10	6.782
T3151	0.269	92.01	1.670	0.297	89.79	1.85	7.187
Bleaching earth	0.044	98.69	0.274	0.068	97.66	0.42	7.708
Refined oil	0.035	98.96	0.218	0.108	96.28	0.67	7.729