American J. of Engineering and Applied Sciences 2 (2): 292-296, 2009
ISSN 1941-7020

Characterization and Evaluation of Algaof Kaolin Deposits of Yemen for Industrial Application

[1,2]Aref A. AL-Shameri and [1,2]Lei Xin Rong
[1]Faculty of Material Sciences and Chemical Engineering,
China University of Geosciences, Wuhan, 430074, China
[2]State Key Laboratory of Geological Processes and Mineral Resources,
China University of Geosciences, Wuhan 430074, China

Abstract: Problem statement: The Barat-Algaof kaolin deposits are characterized and evaluated for its potentials as an industrial raw material. **Approach:** This research studied the total mineralogical composition of the kaolin deposit, chemical and physical properties as well as intercalation of kaolinite by urea. Using X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM), Laser particle size, Centrifuge, data from UK (England) kaolin standard and Hinckley crystallinity index were also compared. Three samples of kaolin were treated by urea intercalation. **Results:** Results showed high content of kaolinite after the removal of non-kaolin minerals; the major elements percentages are almost similar to that of U.K kaolin and the low value of whiteness refers to the presence of iron containing minerals in the samples. Moreover, a well crystallinity index of kaolin was obtained. Intercalation of urea into kaolinite expands the basal space and the reduction of particle size of kaolinite after intercalation is evident in the Scanning Electron Microscopy. **Conclusion:** we concluded that kaolinite of the study area can be used as raw materials for industrial purposes.

Key words: Barat-algaof kaolin, kaolin character, kaolinite, urea-intercalation

INTRODUCTION

Kaolin consists of one tetrahedral silica sheet and one octahedral alumina sheet is an important industrial raw material having widespread applications in industries such as manufacture of papers, paints, rubbers, ceramic, cosmetics, plastic and medicines[8,12,13].The thickness of kaolin particles is significant whenever kaolin is being used as a coating, filler in paper, ceramic, rubber[6,14] in the industry, the kaolinite particles should be separated to thin platelets.

Industrials applications of kaolin is dependent on many factors including mineralogical composition of the kaolin deposits, geological of kaolin formed, as well as the chemical and physical properties and in almost every instance the kaolin has different properties and thus must be fully tested and evaluated to determine its utilization. In all applications, kaolinite has a function and is not just an inert component of the system.

Properties of kaolinite, particularly important for industrial applications are particle-size distribution, structural order-disorder or crystallinity, surface area and whiteness [13]. Some of these physical properties can be changed with several treatments such as grinding (either under wet or dry conditions), intercalation of salts and small molecules in the interlayer space and acid treatments[3-5,17,23]. Intercalation of kaolinte by molecules as, hydrazine, urea or potassium acetate[21,15] cause the weakening of interlayer hydrogen bonds and therefore kaolinite layer are easily displaced with respect to one another.

However, Wada[22] showed that salts such as urea and hydrazine can penetrate into the interlayer space of kaolinite and expand the basal spacing from 7.2-14.2 Å

The SEM study shows that kaolinite can occur as well formed, large crystals of clear hexagonal outline; often in stacks. It can also occur as much smaller crystals of less clearly defined outline. The SEM study of kaolinite and its related minerals has been the subject of numerous publications by[10,11]. Under an electron microscope, observed that after grinding of kaolinite with ammonium acetate, thin particles tend to fold such major morphological changes increasing the plasticity of the material. As no any systematic studies were carried out in the area under consideration concerning exploitation of kaolin deposits; the present study is mainly focused on characterization and evaluation of kaolinite of the study area for industrial uses, this is

Corresponding Author: Aref A. AL-Shameri, Faculty of Material Sciences and Chemical Engineering,
China University of Geosciences, Wuhan, 430074, China Tel: +862765199912

maintained through studying the physical and chemical properties of the kaolinite and treated both physically and chemically to meet the specifications for the said industrial uses.

MATERIALS AND METHODS

Description of the study area: Bart area in the Algaof province, of north Yemen, which extends between longitude 44°14´ and 44°27´E and latitudes 16°35´and 61°50´N (Fig. 1).

The study area is entirely underlain by crystalline Protrusion rocks of the Basement Complex, which comprises of high-grade gneissose rocks intruded by grainitiods and covered locally by tertiary and recent sediments. The rock units in the area constitute a series exposed from the older to the younger fallowing Migmatites, Amphibolites, Schists, Diorites and granites covered by quaternary superficial Aeolian and wadi deposits (Fig. 1).

Raw material: Three samples B_3, H_1 and J_3 of kaolinite from (Barat) Al-Jawf of Yemen are used in this study. The samples have been compared with the structural order degree of Hinckley[9], ideal kaolin and the UK. kaolin standards. The samples were purified and characterized according to their chemical constituents, mineralogy, particle size distribution, crystallinity and whiteness.

Instruments: The under listed are the major instrument used in this study:

- X-ray Diffraction X'Pert, MPD pro, for mineralogy and crystallinity
- Scanning Electron Microscopy (SEM) Quanta 200 for morphology
- Centrifuge×1000, r min^{-1} for remove non-kaolin

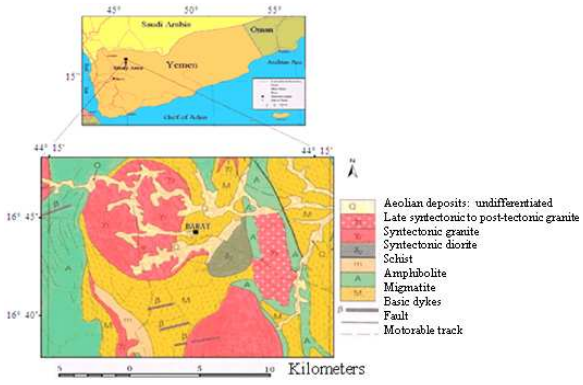

Fig. 1: Locational and geological map of study area

- Laser particle size JL-1155 for particle size distribution
- Device, WSD, I I I for determine whiteness

Intercalation of kaolinite with urea: The expansion of interlayer of samples was accomplished by mixing (1.0 g) of kaolinite with (0.3 g) of urea were grinded by using a mortar for 3 h and then heated at 120°C for 1 h. The product is referred to as the kaolinite-urea intercalate.

RESULTS

X-ray powder diffraction: The interpretation of the XRD patterns of three samples (Fig. 2), led to the identification of the following mineral: kaolinite and the Accessory minerals such as quartz found in the three samples, Illite found only in H_1, chlorite, found in sample B_3 and calcite, which was found in sample J_3 (Fig. 2) and (Table 1) and shows intercalation of urea into kaolinite expands the basal space from 7.2-10.5 Å (Fig. 3).

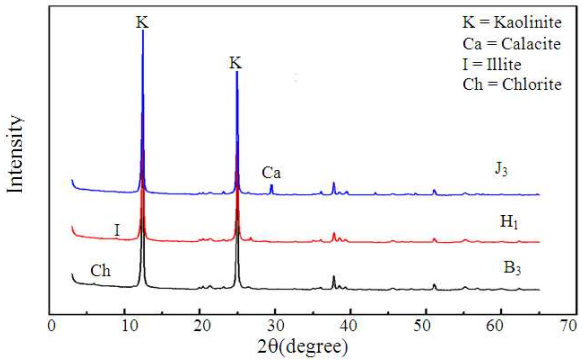

Fig. 2: X-ray diffraction of natural samples B_3, H_1 and J_3

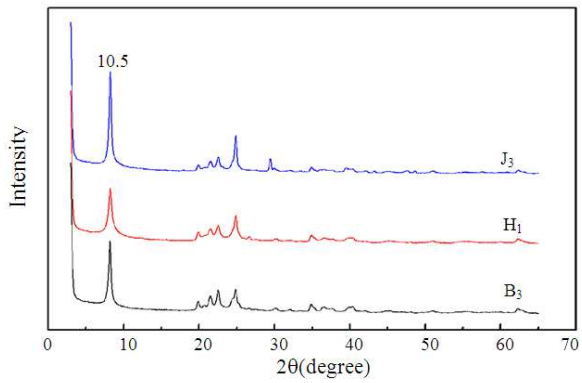

Fig. 3: X-ray diffraction of the samples B_3, $H_1$and J_3 of kaolinite-urea intercalates

Table 1: Semiquantitative mineralogical composition [wt %]

	Sample number		
Mineral	B_3	H_1	J_3
Kaolinite	95	95	90
Quartz	2	2	<2
Illite	-	<5	-
Chlorite	<5	-	-
Calcite	-	-	8

Table 2: Particle size distributions of the analyzed kaolin samples

	Particle size analysis %		
Samples	<2 μm	<5 μm	>5 μm
B_3	50.97	80.85	100.00
H_1	83.00	98.81	100.00
J_3	84.71	99.05	100.00

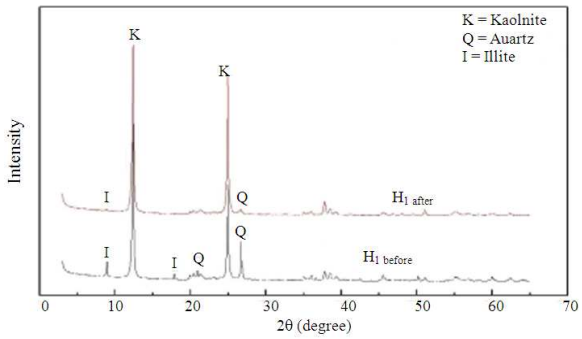

Fig. 4: X-ray diffraction of H_1 sample, before and after used centrifuge

The semi quantitative mineralogical composition was determined based on relative peak intensities (almost of low order Table 1).

The Hinckley crystallinity index was obtained by measuring the heights of the 110 and 111 kaolinite peaks in the region between 19 and 25° (2θ). The obtained values show that B_3, H_1, J_3 type kaolinite contains the high crystallized kaolinite crystals (Table 3) Purification of samples kaolin was made by centrifuge to remove non-kaolin where XRD show high content of kaolinite. For example, sample: H_1 had 65% kaolinite, 15% quartz and 20% illite before purifying by using the Centrifuge and after using the Centrifuge purification; the percentages becomes 95% kaolinite,<5% illite and 2% quartz (Fig. 4).

Scanning electron microscopy: Scanning electron micrographs showing the morphology of kaolinite raw material in stack and as observed book of kaolinite in the sample B_3 (Fig. 5). And morphology of kaolinite-urea intercalate shows texture of kaolinite disintegrate spontaneously to small stacks or flakes (Fig. 5).

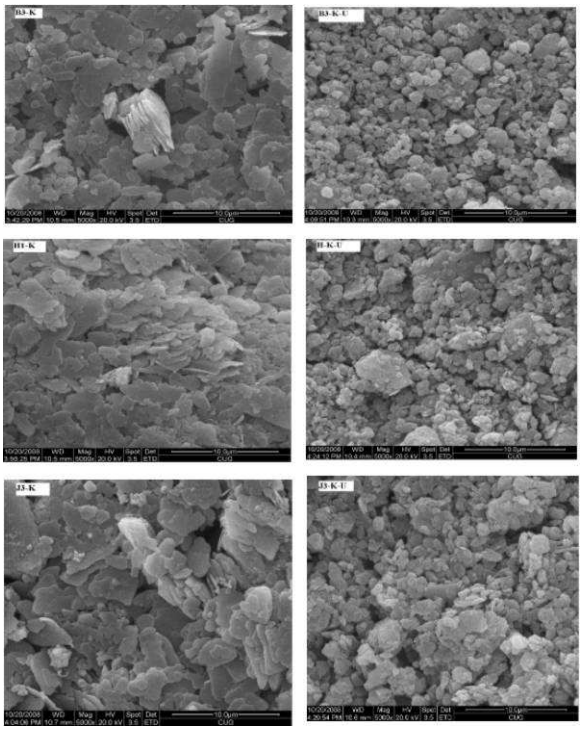

Fig. 5: Scanning electron micrographs showing the morphology of kaolinite: Samples B_3-K, H_1-K and J_3-K of natural kaolinite, B_3-K-U, H_1-K-U and J_3-K-U of kaolinite-urea intercalate

Table 3: Chemical composition of the analyzed samples

Oxide/sample	B_3	H_1	J_3	UK Kaolin	Ideal kaolin
SiO_2	44.870	45.510	39.430	46.770	46.55
Al_2O_3	37.270	36.990	33.790	37.790	39.49
Fe_2O_3	1.310	1.120	0.800	00.360	nd
MgO	0.100	0.120	0.160	00.240	nd
CaO	0.310	0.100	5.850	00.130	nd
Na_2O	0.031	0.034	0.055	00.050	nd
K_2O	0.069	0.180	0.170	01.490	nd
TiO_2	1.360	1.380	0.860	00.020	nd
P_2O_5	0.160	0.140	0.130	nd	nd
MnO	0.005	0.005	0.005	nd	nd
H_2O	0.200	0.220	0.320	nd	nd
L.O.I	14.100	13.920	18.480	nd	nd

Particle size analysis: The particles size distributions of analyzed kaolinite samples are presented in (Table 2), The sample J_3 is characterized by relatively large size of the particles-the fraction <2 and <5 μm represents 84.71, 99.05% and less size of the fraction <2 and <5 μm represents 50.97, 80.85% in B_3 sample.

Chemical composition: The Chemical composition of kaolin is important because of its influence on kaolinite properties. Table 3 shows the chemical composition of kaolin, SiO_2 of samples B_3, H_1 and J_3 is 44.87, 45.51and 39.43 and Al_2O_3 is 37.27, 36.99 and 33.79 respectively.

Table 4: Whiteness and Hinckley crystallinity index of samples

Sample/property	Whiteness (%)	Hinckley crystallinity index (HI)
B_3	59.90	1.70
H_1	71.77	1.36
J_3	62.89	1.60

Whiteness: The whiteness of the samples are shown in Table 4, observed low whiteness of three samples but The sampleH_1 is characterized by high whiteness represents 71.77% and low whiteness represents 59.90%, in B_3 sample.

DISCUSSION

Kaolin physical and physicochemical properties are dependent on features such as particle-size distribution, mineralogical composition and structural order; kaolin intercalation .These properties determine the potential applications as an industrial material. These properties characterized by high content of kaolinite after the removal of non-kaolin minerals by Centrifuge are: B_3 = 95%, H_1 = 95% and J_3 = 90% as shown in Table 1, high order structure of kaolinite (Table 4).

The particles size distributions are the key factors for the industrial uses of kaolinite, Coarse-particle clays differ from fine-particle clays in certain other physical and optical properties as well[15]. The particle size distribution also control whiteness, gloss, ceramic strength, shrinkage and the paper-filling and paper-coating properties such as the mechanical, optical and printing characteristics of paper sheets[18]. Particle sizes <2 μm of the samples H_1 and J_3 are moderate before Intercalation (Table 2). Intercalation of urea into kaolinite expands the basal space from 7.2-10.5 Å (Fig. 3) and the reduction of particle size of kaolinite after intercalation is evident in the scanning electron micrographs (Fig. 5) where intercalation into kaolinite can split larger particles into thinner lamellae. The extreme stability of Chinese eggshell porcelain results from intercalation of kaolinite particles by urea.

For comparison, as shown in (Table 3), SiO_2 and Al_2O_3 are almost similar to ideal kaolin and composition data of kaolin from UK[16] are included. The major element distribution reflects the mineralogy of kaolin samples. These kaolin samples are characterized by high content of Fe_2O_3 and TiO_2. However, SiO_2, Al_2O_3, Na_2O, K_2O and CaO percentages are almost similar to U.K sample standard and only sample J_3 has high content of CaO (Table 3).

Low whiteness of kaolin as shown in Table 4 is due to the presence of high iron containing minerals in the samples. The sample B_3 contains 1.31%, H_1 contain 1.12% and J_3 contain 0.8% of Fe_2O_3 (Table 3) but whiteness can be enhanced by adopting various physical and chemical processes like sieving, magnetic separation[20], leaching with various chemicals like oxalic and other organic acids[1], organic acids in presence of a fermented medium[2], lixiviant containing microbially produced oxalic and hydrochloric acid[7], sodium dithionate-H_2SO_4 mixtures' dissolves some iron-bearing phases to lower the iron content o f the kaolin.

Several treatments can be done to enhance physical properties, while whiteness of that kaolinite can be achieved by removing or reduction of iron. Kaolin of the study area can be used as raw materials for industrial purposes.

CONCLUSION

Characterization and evaluation of Barat- Algaof kaolin deposits was based on the kaolinite chemical composition and physical properties including mineralogical composition and particles size distributions, whiteness, crystallinity index as well as intercalation of kaolinite by urea. The percentages of kaolinite for three samples after the removal of non-kaolin minerals by Centrifuge are: B_3 = 95, H_1 = 95 and J_3 = 90% with a well-crystallized kaolinite obtained. The major elements percentages in chemical composition of kaolin are almost similar to that of U.K kaolin sample with the exception of Fe_2O_3 and TiO_2 which is higher in all samples and higher CaO presence only in sample J_3. Particle sizes <2 μm of the samples H_1 and J_3 are moderate before Intercalation. Intercalation of urea into kaolinite expands the basal space from 7.2-10.5 Å and reduced the particle size, thus becomes suitable for industrial applications as in SEM. The result equally shows low whiteness of three samples, low whiteness refers to the present of iron containing minerals in the samples, the sample B_3 contains 1.31%, H_1 contain 1.12% and J_3 contain 0.8% of Fe_2O_3. Low impurity level and easiness of processing to improve whiteness by removing or reduction of iron from kaolinite and also some physical properties can be enhanced with several treatments. These treatments depend on kaolinite properties and type of the industrial product required. Thus, we can conclude that the kaolinite of the study area can be used as raw materials for industrial purposes.

A detail study of Kaolin properties and its treatment is hereby recommended to meet the universal application of kaolin as an important industrial material.

ACKNOWLEDGEMENT

The researcher is indebted to geological survey and mineral resources board and Sana'a university of Yemen for their financial and moral supports. I also thank Dr. Ismail Al-Ganad for making this study possible.

REFERENCES

1. Ambikadevi, V.R. and M. Lalithambika, 2000. Effect of organic acids on ferric iron removal from iron-stained kaolinite. Applied Clay Sci., 16: 133-145. DOI: 10.1016/S0169-1317(99)00038-1
2. De Mesquita, L.M.S., T. Rodrigues and S.S. Gomes, 1996. Bleaching of Brazilian kaolins using organic acids and fermented medium. Miner. Eng., 9: 965- 971. DOI: 10.1016/0892-6875(96)00087-8
3. Frost, R., L. Horvath, E. Mako and J. Kristof, 2004. Modification of low-and high-defect kaoliinite surfaces: Implications for kaolinite mineral processing. J. Colloid Interface Sci., 270: 337-346. http://eprints.qut.edu.au/807/1/mineral-processing-QUT-JCIS2-revised4.pdf
4. Frost, R.L., J. Kristof, E. Mako and W.N. Martens, 2002. Modification of the hydroxyl surface of kaolinite through mechanochemical treatment followed by intercalation with potassium acetate. Langmuir, 18: 6491-6498. http://pubs.acs.org/doi/pdf/10.1021/la001453k?cookieSet=1
5. Frost, R.L., E. Mako, J. Kristof, E. Horvath and J.T. Kloprogge, 2001. Modification of kaolinite surfaces by mechanochemical treatment. Langmuir, 17: 4731-4738. http://pubs.acs.org/doi/pdf/10.1021/la001453k
6. Gradolinski, J.E.F.C. and G. lagaaly, 2005. Grafted organic derivates of kaolinite I. synthesis, chemical and rheological characterization. Clay Miner., 40: 537-546. http://claymin.geoscienceworld.org/cgi/reprint/40/4/537
7. Groudev, S.N., 1999. Bi obeneficiation of mineral raw materials. Miner. Metall. Process. 16: 19-28.
8. Harvey, C.C. and H.H. Murray, 1997. Industrial clays in the 21st century: A perspective of exploration, technology and utilization. Applied Clay Sci., 11: 285-310. DOI: 10.1016/S0169-1317(96)00028-2
9. Hinckley, K.D.N., 1963. Variabilityin crystallinity values among the kaolin deposits of the coastal plain of Georgia and South Carolina. Clays Clay Miner., 11: 229-235. http://www.clays.org/journal/archive/volume%2011/11-1-229.pdf
10. Keller, W.D., 1978. Classification of kaolins exemplified by their texture in scan electron micrographs. Clays Clay Miner., 26: 1-20. http://ccm.geoscienceworld.org/cgi/content/a26/1/1
11. Keller, W.D., 1982. Anauxite viewed by scanning electron microscopy. Clays Clay Miner., 30: 391-393. http://ccm.geoscienceworld.org/cgi/content/abstract/30/5/391
12. Murray, H.H., 1999. Applied clay mineralogy today and tomorrow. Clay Miner., 34: 39-49. http://claymin.geoscienceworld.org/cgi/content/abstract/34/1/39
13. Murray, H.H., 2000. Traditional and new applications for kaolins, smectite and palygorskite: A general overview. Applied Clay Sci., 17: 207-221. DOI: 10.1016/S0169-1317(00)00016-8
14. Murray, H.H. and J.E. Kogel, 2005.engineered clay products for the paper industry. Applied Clay Sci., 29: 199-206. DOI: 10.1016/J.CLAY.2004.12.005
15. Maxwell, C.B. and P.B. Malla, 1999. Chemical delamination of kaolin. Am. Ceram. Soc. Bull., 78: 57-59. http://cat.inist.fr/?aModele=afficheN&cpsidt=1637265
16. Murray, H.H. and W.D. Keller, 1993. Kaolins, Kaolins and Kaolins. In: Kaolin Genesis and Utilization, Murray, H.H., W. Bundy and C. Harvey (Eds.). Clay Min. Soc., Spec. Publ. 1, Boulder, Colorado, pp: 1-24.
17. Mako, E., R.L. Frost and J. Kristof, 2001.The effect of quartz content on the mechanochemical activation of kaolinite. J. Colloid Interface Sci., 244: 359-364. DOI: 10.1006/JCIS.2001.7953
18. Prasad, M.S., K.J. Reid and H.H. Murray, 1991. Kaolin: Processing, properties and applications. Applied Clay Sci., 6: 87-119. http://scholar.google.com/scholar?hl=en&lr=&newwindow=1&q=related:KWrw5QRukZ4J:scholar.google.com/
19. Chandrasekhar, S. and S. Ramaswamy, 2002. Influence of mineral impurities on the properties of kaolin and its thermally treated products. Applied Clay Sci., 21: 133-142. DOI: 10.1016/S0169-1317(01)00083-7
20. Veglio, F., B. Passariello, L. Toro and A.M. Marabini, 1996. Development of a bleaching process for kaolin of industrial interest by oxalic, ascorbic and sulphuric acids: preliminary study using statistical methods of experimental design. Ind. Eng. Chem. Res., 35: 1680-1687. http://pubs.acs.org/doi/abs/10.1021/ie950427s
21. Velho, J.A.G.L. and S.F. De Gomes, 1991. Characterization of Portuguese kaolins for the paper industry: Beneficiation through new delamination techniques. Applied Clay Sci., 6: 155-170. http://cat.inist.fr/?aModele=afficheN&cpsidt=4941164
22. Wada, K., 1961. Lattice expansion of kaolinte minerals by treatment with potassium acetate. Am. Miner., 46: 78-91. http://www.minsocam.org/ammin/AM46/AM46_78.pdf
23. Yariv, S. and I. Lapides, 2000. The effect of mechanochemical treatments on clay minerals and the mechanochemical adsorption of organic materials onto clay minerals. J. Mater. Synthesis Process., 8: 223-233. DOI: 10.1023/A:1011320328102