An Appraisal on the Potential uses of Bentonite and its Availability and Exploitation in Kenya

Peter K. Mutisya, S. M. Maranga and B. W. Ikua

***Abstract*—** Bentonite is a smectite clay formed from the alteration of siliceous, glass-rich volcanic rocks such as tuffs and ash deposits. The major mineral in bentonite is montmorillonite, which is a hydrated sodium, calcium, magnesium or aluminum silicate, or a combination of these. The industrial bentonites are generally either the sodium or calcium variety.

Bentonites are important and essential in a wide range of applications including well drilling, foundry sand binding, iron ore pelletizing, pet waste absorbents, and civil engineering uses such as waterproofing and sealing.

In many developing countries, local bentonite producers provide the livelihood for many marginalized workers.

This paper presents the many economic uses to which bentonite can be put. In addition, the paper gives a highlight on the numerous opportunities for investment in which bentonite is key.

Special focus is given on the use of bentonite in deep drilling and foundry which together use the largest quantity of bentonite in the world.

***Keywords*—**Bentonite, Foundry, Industrial minerals, Well drilling

I. INTRODUCTION

INDUSTRIAL minerals are geological materials mined for their commercial value. These exclude fuels (fuel minerals or mineral fuels) and metals (metallic minerals). They are used in their natural state or after beneficiation as raw materials or as additives in various industrial applications such as construction, ceramics, paints, paper and detergents, among others [1]. Bentonite is one such mineral.

Bentonite is a smectite clay formed from the alteration of silicious glass-rich volcanic rocks. The main mineral is montmorillonite which is a hydrated sodium, calcium ,magnesium or aluminium silicate. Industral bentonites are generally either the sodium or calcium variety [2]

II. HISTORICAL BACKGROUND

THE name bentonite is derived from the cretaceous Benton shale, a Wyoming geological formation near Rock River USA where Wilber C. Knight found deposits of the clay in 1898. Early uses of bentonite included applying it to the skin or consuming it for medicinal purposes [3]. The Americans found bentonite vital to their lives. Pioneers found moistened bentonite to be an ideal lubricant for squeaky wagon wheels. The mixture was also used as a sealant for log cabin roofing. Indians also found that bentonite could serve as soap [4].

Some river deltas naturally deposit such a blend of clay, silt and sand, thus creating a natural source of excellent molding sand that was critical to ancient metal working technology.

Peter K. Mutisya, Department of Mechanical Engineering, JKUAT (corresponding author: +2540727988088; e-mail: petkiokoh@gmail.com)
S.M. Maranga, Department of Mechanical Engineering, JKUAT (e-mail: smmaranga@yahoo.com).
B. W. Ikua, Department of Mechatronic Engineering, JKUAT(email: ikua_bw@eng.jkuat.ac.ke).

As new uses for bentonite increased, its mining increased to meet commercial, industrial and medicinal demands. Currently, bentonite is mined and produced in many countries [3].

III. OCCURRENCE AND PRODUCTION

THE largest sodium bentonite deposits are located in the Western United States in Wyoming, Montana, and South Dakota. These sodium bentonites are also called Western or Wyoming bentonite. They highly swell in the presence of water.Other smaller sodium bentonite deposits occur in Argentina, Canada, China, Greece, Georgia Republic, India, Morocco, South Africa, and Spain [4].

Calcium bentonite deposits are much more common than those for sodium bentonite. In the United States, calcium bentonites occur in Georgia, Alabama, Mississippi, Texas, Illinois, and Missouri. Elsewhere calcium bentonites occur in England, Germany, Spain, Italy, Greece, Turkey, Georgia Republic, Czech Republic, Ukraine, Japan, Algeria, Morrocco, South Africa, China, India, Japan, Argentina and Brazil.

The world production of all types of bentonite was estimated by the United States Geological Survey (USGS) to be 10,226,119 tons, in 2001. The major production by country is given in Table 1.

Table 1: World production of bentonite by countries [source: USGS]

COUNTRY	PRODUCTION (Metric Tons)
USA	4,080,000
Japan	415,115
Greece	1,150,000
Ukraine	300,000
Brazil	275,000
Turkey	636,273
CIS	700,000
Mexico	269,731
Italy	600,000
Germany	500,000
Others	1,300,000
Total	**10,226,119**

Two value added products namely, organo clays and acid activated clays are processed, from sodium bentonite and calcium bentonite, respectively. In this process, organic compounds are reacted with the high exchange capacity sodium bentonite where the organic component is exchanged for sodium. Organoclays are used in oil base paints, high temperature grease, oil base drilling muds, and several other niche markets [4]. Calcium bentonite is acid activated to produce bleaching clays which are used to clarify edible oils and beverages. Acid activation increases the surface area and pore volume thus improving the clay's performance in removing colour and impurities from liquids. The total world volume of the bleaching clay market is estimated at about 850,000 tons.

A potential new value added growth market for montmorillonites is nanoclays. A nanoclay is clay having nanometer-thick platelets that can be chemically modified to make the clay complexes compatible with organic monomers and polymers. The properties of a polymer that limit its use are stiffness and/or strength. Heat distortion temperature is also a limiting factor for polymers in many products. All the above properties can be significantly improved through the use of nanoclays and therefore, the market potential for nanoclays is very large [4].

IV. IDENTIFICATION

Bentonites range in colour from black through to white , but most frequently are bluish-green when fresh, weathering to a yellowish brown colour at or near outcrops due to the oxidation of ferrous iron. However despite their often characteristic appearance at outcrops, where they tend to exhibit a frothy or popcorn texture due to successive wetting and drying, deposits may easily be overlooked during mapping particularly in the tropics where this feature may be obscured [5].

For precise identification, techniques such as X-Ray analysis, Differential thermal analysis, and Chemical analysis are used. Tests for material characterization, product testing and process research include those that directly determine the properties employed in the usage of the bentonite [6].

Locally, reports by the Kenya's Department of Mines and Geology indicate the presence of bentonitic clays in different parts of the country, including Athi river basin, Timau, Meru and Namanga among other [7]-[9]. However, the characterization of these local bentonites is yet to be fully done, leading to a situation where the bentonite used in the local industry is majorly sourced from outside the country.

V. MINING AND PROCESSING OF BENTONITE

A) Mining

Before mining can begin, delineation of the deposit is performed by drilling/trenching and sampling. .Mining, which is usually done by the open pit method, begins by removing the overburden from above the deposit with the use of large earth movers. The overburden is then stockpiled nearby for reclamation after the deposit has been removed from the bed.

The mines are easily reclaimed so that the land is put back into its original form. A good example is in Germany where the overburden is stacked so that it goes back into the pit in the reverse order of its removal so that the top soil is put in place and crops can immediately be grown[10].

Variations in the properties of bentonite from within the same bed as well as different beds means that selective mining is often necessary to match different qualities with specific applications [10].

b) Processing

Raw bentonite is rarely used, but undergoes processing to essentially modify its properties for specific applications. A typical processing flow chart for Ca-bentonite is shown in Figure 1.

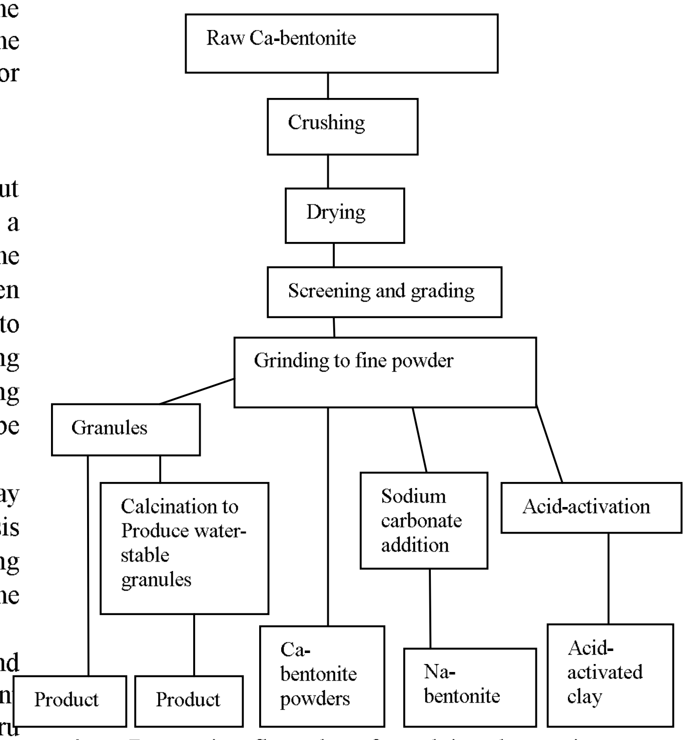

Fig.1. Processing flow chart for calcium bentonite

The major product groups include;

- Ca-bentonite (fine powder or Granules)
- Na-bentonite or Na-exchanged bentonite
- Acid activated clays
- Specialty clays (white bentonite and organo clays).

Most bentonites are processed by dry methods in a factory set up as shown in Figure 2. During processing, the bentonite is crushed, dried, pulverized or screened for granular products, classified, bagged and loaded.

However, for organo clays, acid-activated clays and nanoclays, a wet process is used. This includes blunging at low solids, screening or centrifuging to remove coarse particles, acid leaching or reaction with organic compounds, filtering, and drying.

For nanoclays an intense grinding or shearing is required to delaminate the montmorillonite into very thin flakes before reaction with an organic compound [4].

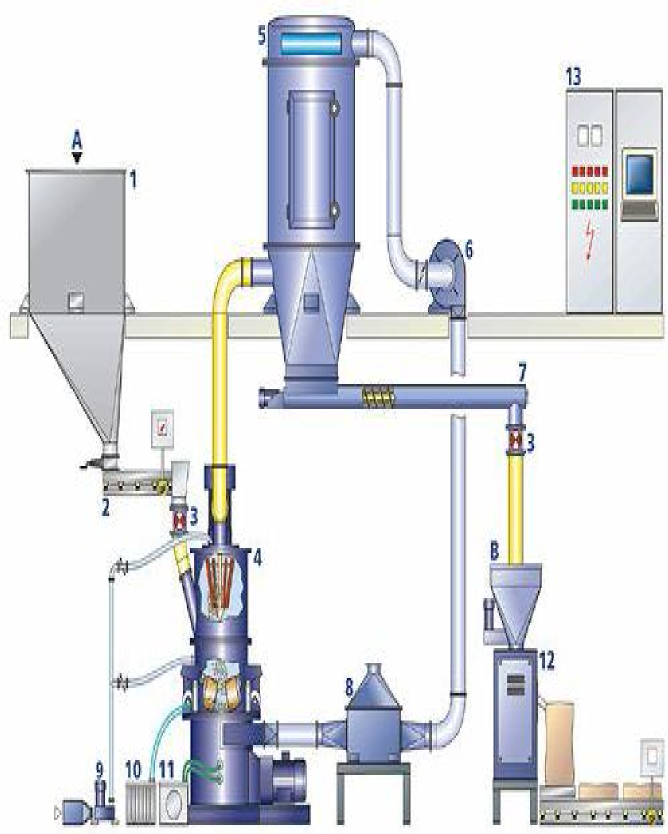

Fig.2. Factory setup for dry processing of bentonite

Legend

1 = Feed bin
2 = Feed metering unit
3 = Rotary valve
4 = Table roller mill AWM with MS classifier
5 = Automatic reverse jet filter
6 = Fan
7 = Feed screw
8 = Heat exchanger
9 = Rinsing air fan
10 = Hydraulic unit
11 = Lube oil supply
12 = Packing machine[11]
13 = Control cabinet

VI. GENERAL PROPERTIES AND USES

Bentonites have several important physical and chemical properties which make them important in a wide range of applications. In addition to its rheological and absorbent properties, bentonite has excellent
Plasticity and lubricity, high dry bonding strength, high shear and compressive strength, good impermeability and low compressibility.

Bentonites are important and essential in a wide range of uses including but not limited to the following;

- drilling mud,
- foundry sand binding,
- iron ore pelletizing,
- pet waste absorbents,
- and civil engineering uses such as waterproofing and sealing.
- Clarifying oils and fats
- Carrier for insecticides
- Coating for seeds
- Paints, cosmetics and pharmaceuticals[4]

VII). PARTICULAR USES OF BENTONITE

a) Use of bentonite in foundry

Castings can be produced in either permanent metal or expendable refractory molds. The use of metal molds or dies for shaping components is subject to certain major limitations.

The exacting conditions imposed by repeated contact with molten metal restricts useful mold life to a level which has so far largely confined the technique to metals of low melting points [12].

In addition, the cost of die manufacture can only be sustained by a large production requirement. Thus the greater part of the foundry industry consists of castings made in refractory moulds, chiefly sand castings. Since the properties of casting materials are crucial to the production of sound, dimensionally accurate castings, its selection and testing constitutes one of the vital steps in foundry [12].

The soundness or otherwise of a casting depends on the nature and properties of the initial materials used. These materials include various types of foundry sand and binders used to provide the necessary strength, both in the green and dry state to the molding sand. These binders include bentonite clay and other inorganic binders such as sodium silicate [13].

Sand molds are designed to have a good collapsibility and accommodate shrinkage of cast metals during solidification to avoid defects in the cast metals. Casting sand should have good flowability so as to pack well during molding to produce good surface finish as well as exhibit lower permeability to give a better as-cast finish [14].

Bentonite helps in retaining the mechanical shape of the mould by making the particles of sand adhere and also making the surface impermeable.

Generally, the swelling type of bentonite (Na bentonite) is used, though other types of bentonite have also been used. The ionic surface of Bentonite has a useful property in making a sticky coating on sand grains. When a small proportion of Bentonite clay is added to hard sand and wetted, the clay binds the sand particles into a moldable aggregate called green sand used for making molds in sand casting.

Foundries also employ sodium bentonite to clear impurities from melted metals before pouring them. A typical casting sand mould which is being inspected by a metal caster is shown in Figure 3.

Fig. 3: A metal caster inspecting a sand mould

The value of Bentonite as foundry sand binder was recognized in the 1920s and the iron and steel foundries have since then been major consumers of bentonite*[14]*.

The use of high active bentonite content is important for the following reasons:

- Obtaining high green compression strength in order to produce stronger moulds that are easier to convey and in order to avoid mold deformation in the parting line.
- Maintaining high green tensile strength in order to avoid tear off at stripping and weakened sand cores in the mold cavities.
- Obtaining a higher wet tensile strength in order to avoid mold scabbing in the water condensation zones and sand expansion defects.
- Ensuring good molding sand plasticity to avoid sand spring back and that the sand starts flowing through the injection slot and down in to the molding chamber between shot operations.
- Stabilizing the mold cavity to avoid casting defects such as shrinkage, porosities, casting expansions, sand erosion and sand inclusions [15].

The use of clay of optimum quality is one of the most important requirements in molding. The following qualities are inherent in good quality bentonite:

- It should be able to resist reasonable heat influence, such that its body strength and plasticity properties are maintained.
- It should give the molding sand the correct consistency (moldability), which renders it possible for the sand to be conveyed, stored and handled in the correct way during processing.
- It should enable the molding sand to compensate for the thermal expansion of the silicon grains, which counteracts casting expansion defects.
- It should give the molding sand the correct stability and plasticity so that perfect lifting of pattern plates can be accomplished.
- It should make it possible for the sand to resist the influence from heat shock, so that it is still economical to reuse the molding sand.
- In molding sand mixtures, it should maintain sufficient sand bonding properties in dry and hot conditions, so that the metal can be poured without any risk of casting defects and such that the poured melts may be correctly conveyed, and still it should be economical to re-use the return sand.
- The molding sand mixture should collapse readily after casting and be reused.
- It should be economical in terms of price, transport, delivery and storage [15].

Sands produced from natural sodium bentonites have medium to low green strengths, but high dry strengths, which increase the resistance to erosion by the molten metal. Wet tensile strengths are high. Sodium bentonites usually show good high-temperature durability, and their bonding properties are not destroyed by moderate heat. These bentonites are used in casting steel and high-duty iron [16].

Sands from Ca-bentonites have medium green strengths and low dry strengths. They have low resistance to erosion by molten metal and are likely to cause scabbing and expansion defects in the moulded metal.

Sands made from sodium exchanged calcium bentonite have high green strengths, low dry strengths and improved resistance to scabbing and expansion defects. They are used in casting iron, non-ferrous metals and light-section steel [16].

Often, a natural Na-bentonite is blended with a Ca-bentonite or an activated bentonite to give a specific set of properties in the sand.

The analysis of casting sand moulds in foundry work is based on standards. A commonly used standard is that by the American Foundrymen's Society. From this standard, the satisfactory property ranges for the sand casts of different metals are given as shown in Table 2.

TABLE 2:
SATISFACTORY PROPERTY RANGES FOR DIFFERENT SAND CAST METALS. SOURCE: (ADEMOH, 2009)

Metal	**Green Compressive Strength, kN /m^2**	**Dry Compressive Strength, kN/m^2**	**Permeability Number**
Heavy Steel	70-85	1000-2000	130-300
Light Steel	70-85	400-1000	125-200
Heavy Grey Iron	70-105	350-800	70-120
Aluminium	50-70	200-550	10-30
Brass and Bronze	55-85	200-860	15-40
Light Grey Iron	50-85	200-550	20-50
Malleable Iron	45-55	210-550	20-60
Medium Grey Iron	70-105	350-800	40-80

The foundry industry is diverse and complex. Although there are differences in some specific operations, the basic foundry processes differ only slightly from one foundry to the other. The main foundry processes produce metal or alloy castings by pouring molten metal into moulds. After hardening, the castings are removed from the moulds, processed and finished.
Green sands are composed of three major ingredients: silica sand, clay, and water. Silica sand comprises the major component of the materials in a mould. Bentonite clay acts as a binder for the green sand. Clays form approximately 4 to 10 percent of the green sand mixture [17].

b) Use of bentonite in deep drilling.

Bentonite with montmorillonite as the principal component when mixed with water forms non Newtonian suspensions. The bentonite suspensions have the unique property to gel when left undisturbed. In addition, since the mineral swells considerably in water, it is used heavily in the drilling industry as drilling mud. Research indicates that demand for continuing use of bentonite by the drilling industry is strong [18].
Majority of deep wells are drilled using rotary drilling rigs. The rigs can use high pressure circulation (air flush), water or drilling fluid such as bentonite mud (fluid flush)
In deep holes, use of a mud which can be adjusted to meet extreme needs as they arise is important. In these extreme conditions, temperatures as low as 1-5^{o}C on sea bed, high temperatures in excess of 200^{o}C and high pressures of over 1000 bars in the bottom of the well are often encountered.
In these harsh environments, synthetic oils and oil-based drilling fluids are used, but the former are expensive while strict environmental requirements have limited the use of the latter. Thus the drilling industry has turned back to water based drilling fluids which use bentonite as the primary viscosifier and as a fluid loss control additive.
Bentonite fluids can be given a wide range of properties and for this reason must be preferred in deep hole drilling [18].
The use of bentonite as drilling mud serves the following important functions[19],[20].

a) Removal of cuttings
The ability to lift solids of various sizes from the tip of the drilling bit to the surface is an essential function of any drilling fluid and is usually dependent on velocity, density and viscosity.
The annular velocity of the mud must be sufficient to overcome the slip velocity of the cuttings being removed. The annular velocity of the drilling fluid is directly affected by the pump output. Sufficient pump output produces adequate annular velocity and the drilled cuttings are effectively carried to the surface. The annular velocity is calculated as follows:

$$V = Q / A$$

Where V= annular velocity of the fluid
Q=pump output
A= area of the annulus

Increase in density of the drilling mud increases the buoyancy effects on the drilled cuttings and this helps suspend the drilled cuttings better.
Increasing the viscosity increases the lifting capacity of the fluid. If fresh water is being used, bentonite will increase the viscosity rapidly with only small increases in mud weight.

b) Control subsurface pressure.
The density of the drilling fluid must be such that the hydrostatic pressure exceeds the formation pressure. This is the major requirement of any drilling fluid and receives priority over other mud properties and functions.
The hydrostatic pressure is directly proportional to the density of the fluid and the height of the drilling fluid column.
It is calculated from the formula:

$$P = \rho g h$$

Where P=Hydrostatic pressure
ρ = mud density
g =gravitational pull
h = depth of well

c) Suspend drilled cuttings.
A good drilling fluid must suspend both cuttings and weight material during circulation as well as during periods of quiescence. This is based on the ability of the drilling fluid to develop a gel strength and also by controlling the thixotropic properties of the mud.

d) Cool and lubricate the bit.
The considerable heat generated by the friction of the revolving bit and drill string will be conducted away to the surface by the drilling fluid when sufficient annular velocity is maintained. The mud itself will lubricate the bit to a certain extent, thus decreasing the required torque, increasing bit life and reducing pump pressures.

e) Wall building.
A good drilling fluid should deposit a thin filter cake on the permeable formations of the well bore. The deposition of the filter cake which reduces the invasion of the mud fluid to the formation can reduce shale instability in some troublesome areas.

f) Drill string and casing support.
Both drill string and casing weight decrease as mud density increases due to the additional buoyancy which the fluid exhibits. The reduction on string force allows for less support from the surface equipment.

g) Formation evaluation.
Optimum control of all drilling mud properties must be maintained so that all the necessary information for evaluation of the well can be gathered. The mud must not invade the formation but provide protection and allow maximum production.

h) control corrosion.
Drilling mud guards against invasion of corrosive fluids such as hydrogen sulfide gas and subsequent corrosion of drill pipes and other fittings when the mud is treated with corrosion control chemicals.

VIII. CONCLUSION

This review has revealed that bentonite has many applications and can be exploited to uplift the livelihood of many Kenyans. This can be first and foremost through direct and indirect employment opportunities for the local communities. Other benefits include reduced cost of bentonite and bentonite related products/ services, improvement in the local infrastructure and provision of social amenities, government revenue through taxes and foreign exchange.

REFERENCES

[1] Industrial Mineral, Available: en.wikipedia.org/wiki/industrial_mineral
[2] R. B. Williams, Bentonites, Kaolin and selected clay minerals, 2005
[3] Hosterman I.W, Patterson SH,. "Bentonite and Fullers Earth Resources of the United States". *US Geological Survey; Professional Paper 1522*, P45, 1992
[4] Abram Teplitskiy, Dallas, Texas, USA Richard Gee, P.E., GEE Consultants, Dallas, Texas, USA Roustem Kourmaev, *KRUS Company, UFA, Russian Federation* tepl@sbcglobal.net
[5] British Geological Survey, *Industrial Minerals Laboratory Manual Technical Report*
[6] Consultants Report, Market study of bentonite products,. *British Columbia Geological Survey Report,* March 1994
[7] M. Rask,. Geological memoir 11."Assessment of Perminter's Bentonitic clay in Meru district, Kenya". Ministry of Environment and Natural Resources, Mines and Geological, Department, 1991.
[8] P. Joubert, "Geology of the Namanga-Bissel Area" Ministry of Environment and Natural Resources, Mines and Geological Department, Kenya. *Report No.39*, 2007
[9] E. P. Saggerson, "Geology of the Nairobi Area". Ministry of Environment and Natural Resources, Mines and Geological Department, Kenya. Report No. 98
[10] F.G Bell. *Engineering Treatment of Soils* 1st EditionSt. Edmundsbury Press, Great Britain, 1993.
[11] Available: www.alpinehosokawa.com/engl/powder/bentonite.
[12] Peter R. Beeley, *Foundry Technology*. Butterworth Heinemann, Great Britain, 2001.
[13] O. A. Olasupo, J. A. Omotoyinbo, "Molding Properties of a Nigerian silics clay mixture for foundry use", *Journal of Applied Clay Science*, Vol. 45, No. 10 of 2009, P244-247. 2009.
[14] Nuhu A. Ademoh, *Evaluation of the foundry properties of River Niger Sands, Ajaokuta, Nigeria*. American-Eurasian Journal of Scientific Research, Vol. 3(1) of 2008 P75-83, 2008
[15] Nuhu Ali Ademoh, Ahmed Tijani Abdullahi, 2010. *Determination of the Optimal Binding Properties of Grade 1 Nigeria Acacia species for Foundry Molding Sand.* Middle East Journal of Scientific Research. Vo.5 No.5 P 402-406, 2010.
[16] John R.Brown,. *Foseco Non-Ferrous Foundryman's Hand book,* 11th Edition. Pergamon Press PLC, Oxford, UK. 1994
[17] George Alther, 2004. *Some Practical Observations on the Use of Bentonite*. The Geological Society of America. Journal of Environmental and Engineering Geoscience, Volume X, No. 4, p. 347-359, Nov. 2004.
[18] V. C. Kelessidis. "Indicators in the Minerals Industry" *3rd International Conference on Sustainable Development,* ,Milos Island, Greece.
[19] Byron Daven Port 1984. *HandBook of Drilling Practice.* Gulf Publishing Company, Houston, London, Paris, Tokyo, 2007.
[20] Fair Head, Larry Keith, MC Fadyon, Cal King, Dal Gorriel. *Drilling Fluids HandBook.* 1990