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UTILISATION OF KAOLIN CLAYS IN DEVELOPING COUNTRIES*

by

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Henry E. Cohen

Introduction

Industrial minerals represent substantial natural resources which attain growing technological and commercial importance as raw materials for many branches of modern industry. Both bulk minerals and speciality mineral products have considerable growth potentials, in their own spheres, as well as in many new applications such as high strength ceramics, composites and metal replacements.

Workable deposits of many industrial minerals are widely distributed, but their industrial utilisation is concentrated mainly in the more developed countries. The reasons for this are complex. For low-price bulk materials like silica sand, clay, or cement, transport constitutes a high proportion of the total costs, often more than 50%. Hence, sources within developed countries, especially if they are located close to industrial users, enjoy obvious cost advantages. Additionally, mineral users are very conservative in respect of quality characeristics of their raw materials. Their wish to avoid hazards to their own manufacturing processes would mitigate against experimenting with new suppliers, even if there were inducements of product quality or price.

When more valuable speciality mineral products are developed, e.g. for use in pharmaceuticals or modern ceramics, industrial countries equally have signifiant advantages. Such products usually require relatively high front end investments, good research and engineering back-up facilities, with a reservoir of skilled labour. Due to this combination of factors, developing countries, which hold some 90% of the earth's remaining untapped mineral resources, have seen only around 10% of new mineral investment in recent years.

In terms of utilising the value of mineral resources, developing countries have fared equally badly. They tend to export mineral raw materials although this is not very profitable and import mineral-based consumer goods. This is purely historically based and there is no fundamental technical reason why developing countries should not make better use of their mineral resources. The development of mineral-based industries is no more difficult (nor is it any easier) than any other form of industrialisation. It requires know-how, enterprise and capital, as well as adequate supplies of energy and labour. Prior to assembling these basic ingredients it is of course essential to establish proven mineral reserves and to confirm the existence and magnitude of market potentials.

For the production of industrial minerals, great attention needs to be devoted to labour training, because the quality of mineral products is highly dependent on operator performance. Reliable quality is a key factor for successful entry into mineral markets. This is somewhat easier to achieve locally rather than internationally and benefits of increased added value are a further consideration. Therefore, it would seem reasonable to advocate schemes for the combined development of mineral production and indigenous manufacture of mineral-based goods.

As a typical example for industrial minerals, this paper outlines the background and the technological requirements for increasing the participation of developing countries in the production and utilisation of kaolin clays.

The Scenario for Kaolin Clays

Kaolin clays were developed originally for producing porcelain, first in China and then in Europe. They are now used mainly for paper (about 70% of total production), both as fillers and for surface coating. High quality art paper may contain more than 35% (by weight) of kaolin. Modern coating clays have to be extremely pure and very fine-grained (85-90% minus 0.002mm particle size) in order to achieve the desired high surface finish and whiteness.

Other major present-day uses are in the manufacture of sanitary ware, refractories, electrical and electronic ceramics, porcelain, cosmetics and pharmaceuticals. However, together with important consumptions for fillers or exenders in plastics, paints and rubber, all uses, other than for paper, account for only 30% of total kaolin clay consumption.

The raw material value of most kaolin clays is low relative to the added values of resultant manufactured products. A filler clay for paper may have a price tag in the region of US$ 40-60/tonne, compared with the prices for finished art paper up to US$ 140-180/tonne.

High quality speciality clays can attain very much higher prices than fillers. For example, kaolin for cosmetics (85% minus 0.002mm) can fetch up to US$ 500/tonne, more than ten times the price of some filler clays. However, for any major clay producer this can only rate as a by-product interest, because the market volume is usually small. Tonnage outputs of filler/coating clays must provide the main finacial basis for substantial operations. Scope for smaller quantity by-products with high added-values arises only when the nature of a deposit permits separate extraction of a proportion of top quality clays. An ability to secure contracts in limited and conservative markets is also important.

Kaolin Clay Producers

Although kaolin clays occur widely in all five continents, their market is dominated by only three major producing countries, the USA, UK and USSR, accounting for about 70% of world production. Smaller producers, including China, Brazil, Germany, France, India, Czechoslovakia and Spain, add another 15%. Amongst these countries, Brazil, as a relative newcomer, is exploiting large deposits in Amazonia since 1976 . The others benefit from long-established industrial bases in local industry. The remaining 15% of world output of kaolin clays appears widely scattered, with production rates in excess of 100,000 tonnes per year from Japan, Korea, Indonesia, Bulgaria, Belgium, Austria, Italy and Colombia. Some 35 other countries are smaller contributors and many others are either very small producers, or potential producers.

Developing countries often have to import processed kaolin clays for some local manufacture. They als import many clay-based consumer products such as paper, sanitary ware, electrical insulators, high quality table ware, or cosmetics. Their GNP and balance of payments could benefit considerably from more domestic outputs of refined clays and clay-based products. In addition to substitution for imports of clays and consumer goods, some might aim at exporting to regional neighbours or internationally, perhaps within bilateral trade arrangements. However, unless they were able to offer paper grade clays at attractive prices, they would find it hard to compete with established major producers on open markets.

Thus, developing countries face three challenges: To produce clay qualities which maximise the utility and value of their natural resources; to expand clay-based industries to benefit from the added-value increase between raw materials and consumer goods; and to break into export markets.

Geological Background

Most of the world's larger kaolin clay deposits occur at or near surface and are worked in open pits, either wet by hydraulic mining or dry on benches with scrapers or mechanical excavators and front end loaders. Relatively few deposits are worked in underground mines with pneumatic spades or boom-type cutter loaders. Commercially exploitable formations of kaolin clays occur in three quite distinctive and dissimilar geological environments, differing genetically, as well as in their mineralogical characteristics, mineral assemblages and impurities.

Kaolin clays are formed as in situ alteration products of granites (e.g. in Cornwall, UK); as in situ products of volcanic activity (e.g. in Milos, Greece); or as bedded sediments, transported and laid down in water. These are sometimes referred to as "ball clays" (e.g. in Georgia, USA). Variants of this last type are clays formed from airborne volcanic ashes that were deposited in water.

The family of kaolin clays comprises four members, kaolinite, halloysite, dickite and nacrite which are similar, but not quite identical, in chemical composition and crystal structure. Deposits may contain all members of the group in varying proportions, but kaolinite and halloysite are by far the most common and dominant. Dickite and nacrite are rare and occur usually in negligibly small amounts. Broadly, there is a tendency for kaolinite to be the dominant clay mineral in granitic deposits, whereas halloysite can form 60% or more of the clay in volcanic kaolin formations. By contrast, sedimentary kaolin clay deposits can range from almost pure kaolinite to almost pure halloysite.

Quartz and micas are common associated gangue minerals and are almost ubiquitously present with kaolin in most types of deposits. Other impurity minerals may variously include chalcedony and other forms of silica, hydromicas, feldspars, complex siliates, metal oxides, hydroxides, sulphides, sulphates and chlorides, carbonates and many others.

The granitic sources tend to yield the lowest clay contents, usually not more than 20%, with clays of relatively coarse particle size and of high quality. Deposits of volcanic origin can contain up to about 50% clay, usually of variable quality and contaminated through intimate admixture with a variety of other volanic products.

Sedimentary deposits vary from very low clay contents to more than 80% clay, mixed with other sedimentary material from divergent sources, including carbonaceous matter from organic debris. They often contain kaolin clays mixed with other types of clay, especially with swelling clays such as montmorillonite, but the different clay minerals cannot be separated from each other. This generally limits the attainable quality of a clay product and hence its potential applications. For example, a small proportion of some swelling clay in kaolin might be very desirable in making it suitable for use in cosmetics, but would almost certainly make it unsuitable for paper coating due to poor brightness. Sedimentary clays are usually of finer particle size and exhibit higher plasticity than clays mined directly from granitic or volcanic formations .

The differences in clay mineral characteristics arising from the varied geological provenances can impose widely different requirements on clay production. These affect technical and financial considerations in respect of process and plant design for optimal resource utilisation. Hence there are good practical reasons for drawing attention to the somewhat complicated mineralogical background for kaolin clay processing.

Mineralogical Background

In general, the kaolin group of clay minerals is characterised by more or less well-formed tabular crystals with a highly developed basal cleavage. The crystals can be sheared out along this cleavage into very thin platelets with a high aspect ratio. Platelets can be as thin as 0.00005mm. This useful characteristic arises from a sheet-like crystal structure. Each sheet consists of a double layer, comprising one layer of silica tetrahedra (SiO_4) linked to a layer of alumina octahedra. The octahedra are formed by four hydroxyl and two oxygen anions, with a central aluminium cation. The crystal made up of stacks of these two-layer sheets can be separated into thin platelets due to weak bonds between the sheets.

The structural formula for kaolinite is $(OH)_8Si_4Al_4O_{10}$, which may be written as $Al_2O_3.2SiO_2,2H_2O$. The molecular ratio of silica to alumina is usually 1. Higher proportions of silica have been reported, but these were probably due to contamination with colloidal silica. The theoretical composition is SiO_2 46.54%; Al_2O_3 39.50%; and H_2O 13.96%. Analyses of many samples of the kaolin minerals show that there is relatively little substitution within the lattice of highly crystalline material. Poorly crystalline examples can show some substitution of iron and/or titanium for aluminium.

Three members of the group, kaolinite, dickite and nacrite have similar equidimensional lattice structures with somewhat different unit cell dimensions and they share the chemical composition $Al_2O_3.2SiO_2.2H_2O$. The fourth member, halloysite, contains $4H_2O$, is slightly less well ordered and has an elongated structure. Dehydration of all kaolin clays occurs when they are heated above 400C and mullite begins to form above 1000C.

In their purest forms all members of the kaolin family are colourless and therefore appear brilliant white (in white light) due to multiple reflections from the many platelet surfaces. Thin platelets of halloysite show a tendency to roll up into tubes and this results in a lower apparent whiteness compared with flat platelets of kaolin of similar particle size. Dry grinding can quickly distort and ultimately destroy the crystal structure of kaolins, reducing the particle size and increasing their cation exchange capacity. Wet grinding does not appear to cause appreciable structural disturbance, but achieves a splitting (delamination) into thin platelets. Wet grinding can also reduce viscosity and increase plasticity, but these effects are influenced by the presence of contaminants.

All members of the kaolin family can be discoloured by small traces of impurity cations such as iron, either due to substitution in the crystal lattice, or due to adsorbtion on the edges or surfaces of the double-layer sheets. Thus, not only do different members of the kaolin family usually occur mixed together in varying proportions, they also may have different contaminants.

These mineralogical notes are greatly condensed, but it is hoped that they indicate the essential need for detailed mineralogical studies as part of any process design work for a new deposit, or for the improvement of product qualities.

Operational Strategy

Even high grade deposits are inconsistent in quality, potentially yielding varieties of clay products and necessitating an optimising process approach so as to maximise utilisation of the resource. Selective mining and careful quality control, separate stockpiling of different grades of clay and blending to meet quality specifications, are as important in this context as the correct choice of separation and refining processes. By-product minerals such as mica, quartz, topaz, etc., are sometimes recoverable with profit, but it is unlikely that they can ever redeem operations based on an unprofitabe yield of clay products.

The main purpose of any clay mining operation remains the extraction and recovery of the highest possible proportion of clay from the deposit, in the cleanest possible products and at the lowest possible operating costs. Since these three conditions are rarely compatible with each other, each operation needs to find a compromise which yields the highest possible profit and hence the best conversion of a natural resource. An important element in this compromise is the planned scale of production in relation to the reserves of the deposit.

All mineral deposits are wasting assets, because they have finite economic life spans and must be worked out eventually. It is therefore in the national interest of every developing country to generate more permanent benefits during their exploitation. This can be achieved through establishing an infrastructure and secondary industries, with the creation of wider reservoirs of manufacturing and service skills. Derived industrial resources can be re-deployed in other enterprises when the mine reserves are exhausted and should be recognised as an important secondary target of the kaolin clay project.

Process Strategy

The purpose of processing kaolin clay products is to enhance their desirable characteristics, mainly fine particle size and freedom from impurities. This needs to be achieved with high recovery and low cost to maximise the profitability of the operation. The realistic measure of acceptable costs is that prices of domestic products should not exceed those of comparable imports. This may be marginally influenced by the value of hard currency savings.

Almost every clay deposit has a mineral assemblage which is somewhat different from all others, in mineral types, proportions and particle size distribution. Each clay source thus poses its own peculiar processing problems which necessitate detailed mineral appraisal and process design studies for the selection of optimal treatment routes. The complete mineralogical composition and the processing behaviour of each constituent need to be clearly identified in advance. However, all clay processing routes follow certain universal and well-established principles.

If deposits are unusually clean (e.g. Evans Clay at McIntyre, Georgia, USA) they may naturally approach user specifications. For these it can suffice to mine, stockpile for blending and then treat the clay dry by comminution (usually in two stages) with heated air supply and classification, with over-size rejection to waste. The product passes directly to a bagging plant and/or to bulk transport.

Such simple operations carry great financial attractions and merit serious consideration when a new project is planned. They provide opportunities for familiarisation with the clay, for possible subsequent diversification to more complex processing. The initially low production costs offer a strong competitive position for fillers and ceramic grades.

The more normal condition of kaolin clay deposits is considerable impurity and this calls for a wet processing route. The basic sequence of operations then includes the following stages:

mining - stockpiling for blending - (comminution if necessary) - dispersion in water - grit separation (coarse waste) - size classification - removal of fine impurities (by gravity separation, flotation, and/or bleaching) - dewatering and filtration (usually requiring flocculation) - dispersion - drying - bagging and/or bulk transport.

Although the process route is simple in principle, the necessarily separate treatment and storage of different products and size fractions can become very complex. Specific additions of reagents and adjustments of pH are necessary, depending on mineral peculiarities as well as on the slurry characteristics at various stages.

Attainment of good initial dispersion of the plant feed is as important as attaining liberation when treating a hard rock ore. Without good dispersion the subsequent processes of separation remain inefficient, resulting in poor product grades and low clay recovery. Good dispersion necessitates careful attention to the mineralogy, the water quality and the correct practice of reagents addition. These aspects need detailed study during process design so that dispersion may be attained at lowest costs.

Considerable advances have been made in design and construction of appropriate separator units. Separation of clay from waste is achieved mainly by size classification, the clay particles being of finer sizes than the majority of other minerals present. Size classification is carried out in very dilute suspensions in which the clay is well dispersed. Most modern flowsheets employ sequential combinations of hydroseparators (gravitational settlement of coarse waste), hydrocyclones (vortex flow separators for fine waste) and centrifuges for separating finest waste. Centrifuges are also used for separation of coarser from finer clay products. Throughout the sequence of unit processes the clay is kept in dilute suspension and only the final products are flocculated for dewatering.

Discolouration of the clay by iron oxides is a common problem which is usually ameliorated by bleaching during the final stages of treatment . The iron oxides are rendered water soluble by an addition of sodium dithionite at a temperature around 60°C and are then removed by washing.

A process refinement included in some operations for improving the brightness of coating clays is the use of froth flotation for removal of finegrained anatase (titanium dioxide). The process termed "ultraflotation" employs addition of another phase (pulverised calcite) which is easily floated, to act as a collector/carrier for the anatase which is difficult to float by itself.

Processing details need to be determined by sequential procedures of process design, including mineral appraisal, amenability testing and evaluation of alternative process routes. The choice depends not only on the mineral caracteristics of the deposit, but also on the rate of throughput, the types of products and any special local conditions including water quality and climate.

Designers can call on fairly standardised process equipment obtainable from various manufacturers. Good equipment is important when high purity of clay products is sought, but rivalling claims of superiority by competing brands must be treated with severe skepticism. Preference should favour those with good records for service and spares. Without first hand experience of a machine, it is desirable to see a unit working under similar industrial conditions elsewhere and to seek comments from operators.

The operation of kaolin clay processing plants is no more difficult than other forms of mineral processing and new operators should be trainable without unusual difficulties. However, they will require substantial hands-on experience to appreciate properly the meticulous attention to details which is essential for achieving the constancy of product qualities expected by customers.

Constancy of quality is perhaps one of the most important attributes for commercial success, because of the sensitivity of most kaolin clay users to quality variations. Constant quality is achieved by consistency in production and this is more dependent on operator performance and machine reliability than on almost any other process factor. Consistent operating conditions (feed rate, pulp density, reagents addition, water quality, etc.) are the ingredients of performance which depend on the skill and vigilance of the operator. Of equal importance is meticulous cleanliness and regular maintenance of all equipment, including pumps, pipes and storage vessels. Most operators can learn the specific tricks needed for running a plant, but is is their competent vigilance in attending to small details, during long hours of shift work, which yields a constant product quality.

The achievement of credibility is especially important for new operations in developing countries which lack a tradition of skills in clay production. They need to gain the confidence of customers by establishing a reliable track record. This is attained more easily if initial operations have relatively simple flow sheets and by concentrating efforts on small ranges of products. Close contacts with domestic customers are invaluable during the important early stages when operators are gaining experience and when performance standards are more liable to fluctuate.

Development Strategy

A National Mineral Resources Inventory, covering all potentially workable deposits, should be available as an important record of national assets. If it is not already in existence, its compilation and ongoing updating should be commissioned as soon as possible. This must be regarded as an essential pre-requisite for starting or expanding the utilisation of any mineral resource. Relevant geological information should be available from survey records, but this may require updating and amplification to facilitate the necessary technical, industrial and commercial assessments.

A National Mining Development Corporation should be formed and should be given responsibility for initiating mineral resource enterprises. It should also be responsible for the collation and upkeep of the inventory as a basis for subsequent selection of deposits for development.

The Mining Development Corporation needs to collaborate closely with an Industrial Development Corporation which should contribute commercial assessments of domestic and export market opportunities. The Industrial Development Corporation would also be expected to initiate manufacturing enterprises based on domestic mineral resources.

A Research/Development Institute would be needed to colaborate at an early stage, contributing preliminary amenability tests for initial technical evaluation of the range of possible products. The Research/Development Institute should also have full capability and responsibility for carrying out subsequent process design work, up to and including batch tests on a pilot plant scale.

The work of these three organisations should build up ultimately to a full feasibility study for any deposit, as the necessary basis of evaluation for financing and for development by an operating company.

Planning a Kaolin Clay Operation

A kaolin clay deposit must depend on its quality and reserves for financial acceptability for development. The necessary business plan would be favoured by the identification and/or creation of an immediate domestic market. This might include domestic needs for filler clays, or scope for manufacture of industrial/consumer goods such as electric insulators, sanitary ware, table ware and/or tiles. An assured domestic base would also provide a platform of financial continuity and technical experience for subsequent diversification or expansion of production into exports.

However, it would seem neither obligatory, nor even appropriate, that all new clay producers should have to grow through a prolonged evolutionary development to become able to compete with foreign suppliers. It may be true that hundreds of years of experience lie behind some of the major clay producers. However, the controls, process technology, equipment, materials, and know-how available now, at the end of the 20th Century, did not exist when they started. New producers starting today should be expected to take full advantage of modern facilities, not to repeat the historic development curve of older operators. They will nevertheless face formidable challenges in having to learn the skills and disciplines, of operation and of management, which are now essential for competing in the production of kaolin clays.

New operations that have good enough reserves and quality potential for export markets should be designed ab initio for an all-embracing scale of production. However, to allow for inevitable initial difficulties and mistakes, kaolin clay production should be conceived for growth in stages, by means of modular add-on expansion of throughput capacity. Efficient process and plant designs can be provided in modular units, starting with a modest rate of production that would not over-extend initial financial and technical means. Such production should cover supplies for the initial market commitment, facilitate staff development and provide samples for additional market penetration. Modular expansion by means of add-on process units could be phased in after securement of further contracts. However, initial planning needs to make proper provisions for subsequent growth stages. This must cover the whole range of unit operations, from mining layout, plant sites and water supply, to product storage, transport, waste disposal and effluent control.

The scale of production and appropriate sizes of mining and processing units need to be pre-determined for the initial operation and for every stage of modular growth. Feasibility studies should provide pertinent data for sequential scenarios of production. This would facilitate development of the necessary advance marketing for directing the products of the next phase of expansion towards suitable customers. Such anticipatory planning would also be needed to provide a business plan for substantive support when finance for further growth is sought from public or private sources. This applies equally to the production of kaolin raw materials and to operations that are intended to be fully integrated with manufactures of consumer goods.

Conclusions

1. Developing countries can and should seek larger shares of the world market for kaolin clays. They need to prove the size and quality of their domestic kaolin clay resources and they need to develop appropriate skills.

2. The technical and managerial requirements for kaolin clay production pose no unusual problems, but the necessary product qualities demand great operational discipline. The utilisation of industrial minerals as raw materials for indigenous manufactures could offer significant benefits for the economies of developing countries.

3. Development projects should assess the potential ranges of kaolin clay products for domestic consumption and for export. Also included in the assessment should be the scope for manufacture of clay-based industrial and consumer goods.

4. The necessary initiatives and responsibilities should be assigned to the three national organisations:

4.1. A Mining Development Corporation, with responsibilities for a national inventory of mineral resources, for feasibility studies and for initiating mineral projects.

4.2. An Industrial Development Corporation, with responsibilities for collaboration in market research and for initiation of industrial projects based on kaolin clay raw materials.

4.3. A Research and Development Institute, providing processing support services, from preliminary mineral appraisals, process design, pilot plant studies, feasibility studies and plant design, to production trouble shooting and product evaluation.

5. The national mineral resources inventory should be maintained and updated as a permanent source of reference and information for future dvelopment projects.

6. It would be advantageous if kaolin clay projects could be identified with, and linked to domestic manufactures of industrial or consumer goods in order to replace imports.

7. Any project based on kaolin clay deposits of sufficient size and quality for export markets should be designed, ab initio, for an appropriate capacity, but in modular units. Built and operated with a modest initial throughput, suitable for domestic uses, it should be capable of modular expansion to a tonnage commensurate with targeted exports.