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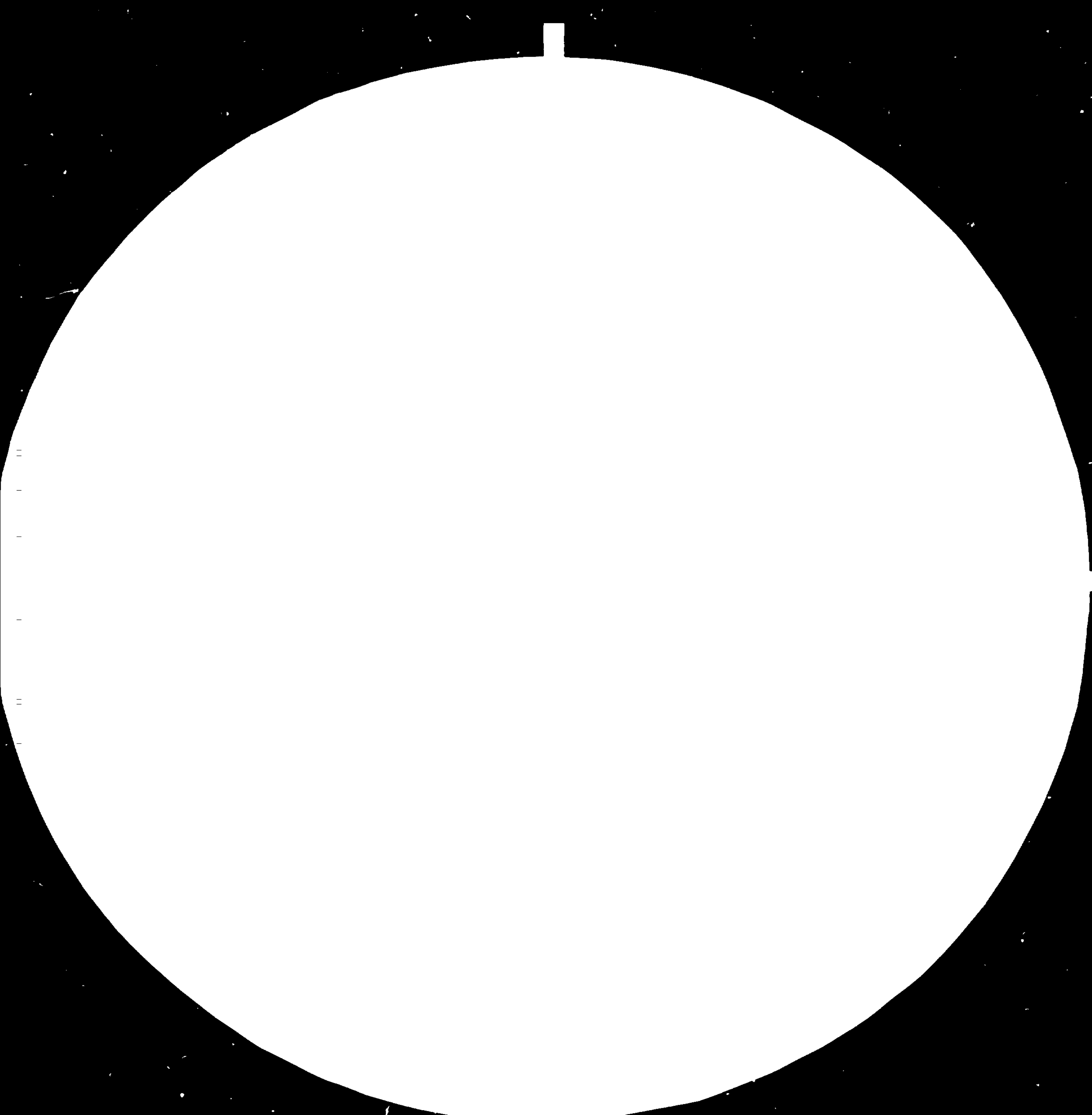
UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org



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DP/ID/SER.A/326
28 August 1981
English

IMPROVEMENT OF BUILDING MATERIALS MANUFACTURE

DP/CPR/80/010

PEOPLE'S REPUBLIC OF CHINA

China

Technical report: The production of kaolin in Soochow.

Prepared for the Government of the People's Republic of China
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of Henry E. Cohen,
adviser on kaolin processing

United Nations Industrial Development Organization
Vienna

V.81-29206

Explanatory notes

The following abbreviations have been used in this document:

HDPE	high density polyethylene
ZPC	zero point of charge

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ABSTRACT

As part of the United Nations Development Programme (UNDP) project entitled "Improvement of building materials manufacture" (DP/CPR/80/010), an expert was sent by the United Nations Industrial Development Organization (UNIDO), the executing agency, for one month to Soochow, China, to investigate the conditions and problems of kaolin production at the Soochow Clay Company (SCC), and to report on possible methods of improving the quality of products as well as raising the level of extraction of kaolin from the deposits.

The greatest problem at the SCC is the heavily flocculated nature of the clay slurry. Preliminary tests showed that excellent dispersion could be obtained which resulted in good separation of the fine impurities from the clay. Tests by the expert's Chinese counterparts were still necessary for further improving the product quality.

Additional processes were also recommended such as clay dispersion by chemical additives in the mixing tanks, and the introduction of a third stage of cyclone classification in a centrifuge for separating very fine impurities.

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INTRODUCTION

The purpose of the one month mission to Beijing, China, entitled "Improvement of building materials manufacture" (DP/CPR/80/010), a United Nations Development Programme project with United Nations Industrial Development Organization as executing agency, was for the expert in collaboration with his Chinese counterparts, to familiarize himself with conditions and problems of kaolin production at the Soochow Clay Company. He was also requested to report on possible methods of improving the quality of the product as well as methods of raising the level of extraction of kaolin from the deposits. The mission was carried out from 12 July to 12 August 1981.

The expert was attached to the Ministry of Building Materials Industry, the counterpart agency, which has overall responsibility for non-metallic mineral resources and for associated activities. The Government of China has identified kaolin refining as a priority area for short- and medium-term development.

The expert acknowledges the help and willing collaboration given by SCC personnel with special thanks to the General Manager of SCC, Mr. Chan Shi Hua. The expert also wishes to thank the interpreter, Mrs. Ding Yun Di.

FINDINGS AND CONCLUSIONS

The Soochow clay deposits are of volcanic origin; their total clay content is about 60% kaolin, accompanied by 40% halloysite.

The impurities include varying quantities of hydrous ferric oxide, alunite, pyrite and quartz. These are heavily flocculated with the clays.

In the water, impurities such as iron salts and organic material especially contribute to the heavy flocculation of the processing slurries. Sooty carbon from smoke emission aggravates the problems of flocculation.

The present simple process of dispersion and classification fails to liberate the clays from the finer impurities. Only the coarser-grained waste is removed. Clays are therefore selectively mined and treated in batches of different grades.

The most important requirement is achieving good dispersion. A programme of tests has been arranged for this purpose. It is possible that selective dispersion or flocculation will provide an adequate method of producing improved clays. The present flow sheet may need the addition of a further stage of classification, or of centrifuging.

After dispersion has been achieved, tests can be carried out with other methods of processing, including various types of flot ation and possibly magnetic separation. None of these methods can be applied effectively until the problems of dispersion have been mastered.

Housekeeping in the processing plants should be improved. Unprotected iron needs to be removed in order to avoid contamination of the clays by rust.

I. APPRAISAL AND OPERATIONS

The operations of the Soochow Clay Company are located about 20 km west of the town of Soochow. SCC mines about 150,000 tonnes of crude clay per year which yield approximately 130,000 tonnes of finished clay products. Four grades of clay are marketed on the basis of chemical composition, as follows:

	Percentage	
	Al_2O_3	SiO_2
Supergrade	37	41
No. 1 grade	36	48
No. 2 grade	35	49
No. 3 grade	34	50

No other specification terms are normally used in marketing the products. Main uses are for electrical insulators, sanitary ware and refractories. The clays are also used for fillers, especially for rubber.

Open-cast mining was originally carried out and several old workings are visible on the hills which contain the deposits. Mining is now underground, at a depth of 33 m below the surface. Development for a downward extension to a depth of 58 m is under way. Mining is carried out with pneumatic picks and the clay is dropped through loading chutes to the haulage level which is in the footwall. Electric haulage is in 1 t tub cars, 12 cars to the train. Mining and loading produce 3.5 t per shift. There are two main mining areas, two mechanical processing plants and one manual plant which produces several grades of finished clay by hand, breaking and sorting. The manual plant has an output of 300-500 kg per worker per shift. If it were estimated that the manual plant produces some 9,000 to 10,000 tpy, it can be seen that the two mechanical plants account for more than 90% of total production.

The ore body appears to strike east-west, dipping north at about 45 degrees. The ore overlies limestones of Permian age, but is covered by older Devonian quartzite which has been thrust over the deposit. The ore body appears to be volcanic in origin, and consists of flow-banded rhyolites, breccias and coarse to fine-grained tuffs. The more highly altered portions form the "industrial" ore. They have lost most of the original rock structure and consist of irregular masses of clay, quartz, iron oxides and other secondary minerals, including alunite and pyrite. The distribution of these minerals seems irregular and this may be due partly to the heterogeneous volcanic origin and partly to the disturbance associated with the thrust movement that pushed the older rocks over the top of the ore. Some of the iron oxides may have been derived from the overlying quartzite, but the alunite and pyrite are presumably of volcanic origin. Small quantities of organic material are also present and contribute to the mineral complexities which make treatment and purification of the clay difficult.

A. Mineral appraisal

The main valuable mineral constituents of the ore are kaolinite and halloysite. Of the total clay content, kaolinite represents about 60% and halloysite 40%. Montmorrillonite is said to be present only in trace quantities. Iron oxide is present mainly as limonite, which either coats all other minerals, or forms larger masses which may be hard or soft. Irregular lenses of clay can be quite free from limonite and these form the highest grade material. Alunite can form large aggregates, or can be irregularly disseminated. Pyrite seems to be mostly present as fine grains disseminated through the tuff bands and hence through their alteration products. The ore cut-off grade is said to be about 24% Al_2O_3, equivalent approximately to 50% clay. However, selective mining is said to produce an average grade of 80% clay or better.

There was insufficient time during the mission to examine the variability of the ore in greater detail, but this would be desirable for future work. The mining plan should contribute to greater constancy in the quality of the concentrator feed. The current principle of operation is to rely on selective mining and to treat different grades of raw clay in batches according to customers' requirements. This is necessitated by the variability of the deposit and by the inability of the present processing methods to improve the different feed grades to any constant standards.

Processing of the deposit is made more difficult than usual by the high proportion of halloysite. Most commercially worked deposits of good quality material contain kaolinite as 90% or more of the total clay content. The less well-ordered structure of halloysite, as compared with kaolinite, causes stronger surface interactions with hydrous ferric oxide and with organic matter. As a result, this mixture is difficult to disperse and shows high viscosity.

In the present production practice it is usually not possible to raise the solids content of process slurries higher than about 13-15%. This reduces the throughput capacity and raises the costs of water handling and removal per tonne of product.

These mineralogical difficulties are aggravated by the amount of iron salts and organic material in the process water. There is, in addition, contamination by sooty ash from the discharge of the low chimney of the thermal drying plant. The result is a heavily flocculated process slurry. Dispersion is not achieved by present methods and the cyclone classifiers remove only the coarser impurities. The finer impurity particles remain locked within the clay by flocculation and this necessitates separate batch treatment of different qualities of feeds.

B. Processing flow sheet

The ore selected for a processing batch passes through a jaw crusher and is fed into one of five stirred mixing tanks which are intended to disperse the clay and thus to liberate it from the coarser waste fractions. The residence time is about 20 minutes, but as this is judged by experience and according to the quality of the feed, the residence time may be longer or shorter.

The coarse reject is raked out of the mixer tank with a frequency, judged by the operator, varying from every loading to once in two days. The coarse waste is discarded. On visual inspection it is found to contain significant quantities of harder clay which has not been dispersed in the available residence time. The clay slurry formed in the mixing process has to pass through an 0.5 mm screen. It is flushed out of the mixer by adding return process water after completion of the chosen mixing period. The slurry passes to a tank which acts as the feed sump for the centrifugal pump that feeds the first hydrocyclone classifier (250 mm diameter). The slurry has a solids concentration of 13-15%. The coarse reject from this cyclone (at 65% solids) is discarded to tailings. The fine product (at 12% solids) passes into another tank which acts as the feed sump for the second hydrocyclone (150 mm diameter). This cyclone produces another reject (at 35% solids) and a final fine product (at 7-8% solids) which passes to the clay settling tanks for dewatering.

Of a total feed of about 65-70 t per shift (about 10 t per hour), the mixer tanks discard about 6.5-8 t per shift (1-1.2 t per hour) of coarse waste. The hydrocyclones discard about 9-11 t per shift (1.5-2 t per hour) and the total tailings amount to 2.5-3.2 t per hour, or between one quarter and one third of the feed. The two cyclone tailings pass jointly through a further cyclone (250 mm diameter) for dewatering and disposal. The water is returned to the mixing tank.

The final clay product in the settling tanks has a residence time of 48 hours and reaches a solids concentration of only about 12-15%. This clay is then passed through filter presses and tunnel kilns. The bagged end-product has a guaranteed moisture content of 14%. The best brightness normally achievable is only about 65% and the proportion of minus 2 micrometer particles is not more than 60%, compared with a desired figure of over 80%. Thus, current production is characterized by low quality clay products which remain contaminated by impurities. There are losses of 20% or more of the total clay to tailings. The water content of the system is too high, owing to excessive viscosity and dewatering is both slow and inefficient.

C. Plant operation

Much of the plant operation is discontinuous in principle because it is tied either to mixing times or to the periods of filling and emptying tanks. The hydrocyclones are operated discontinuously and receive rather variable feeds in respect of pulp density and solids size distribution. This does not permit attainment of steady, optimal classifying performances. Misplacement of both coarse and fine products is further aggravated, beyond the problems due to the flocculated and viscous character of the pulp.

Matters are not improved by the usual practices of breakdown maintenance. Poorly functioning equipment and unscheduled stoppages add to the inconsistency of plant operation and performance. The quality of the clay products is further affected by rust derived from unprotected iron which is used freely, and from scrap equipment lying around the plant. For example, the final clay settling tanks contain rusty iron pipes.

It would be desirable, ultimately, to redesign the entire process plant so as to facilitate good housekeeping and to maintain meticulous cleanliness. Operators should be provided with special shoes or boots for wear inside the plant, and should not be allowed to introduce food or any other extraneous matter into the plant. All iron ware should be replaced by plastic or other non-corroding materials, or should be given heavy protective coatings i_ removal is impractical for the time being.

D. Assessment

After consideration of all the circumstances, the following conclusions were reached:

(a) The largest single problem which forms the root of almost all operational difficulties is the heavily flocculated nature of the slurried clay. Suitable methods of dispersion and all measures which might aid dispersion should have first priority;

(b) Until reasonable dispersion can be achieved, little useful purpose would be served by introducing additional methods of separation. They would fail to function properly, just as classification in the hydrocyclones is not functioning properly. No method of separation can make a useful contribution until the ore is adequately liberated. If centrifuges, flotation, or magnetic separation were introduced now, they would be judged failures or partly successful at best;

(c) After good dispersion has been achieved, the present flow sheet can provide a baseline performance to which improvements may be added. First among additional processes for consideration should be a third stage of cyclone classification, or a centrifuge for separating fine impurities. In addition, bleaching will yield a significant improvement in brightness. This cannot be attempted as long as iron oxide impurities remain flocculated in the clay. The bleaching process is intended only to reduce iron oxide coatings on the clay particle surfaces;

(d) More difficult and sophisticated processes such as flotation should not be introduced until the effects of simpler improvements have been assessed, and until the whole operation of the plant has been brought under consistent control;

(e) As a simple temporary measure which can be introduced immediately, use of a general dispersant such as a polyphosphate or polyacrylate will produce some interim relief and improvement for the period which will be needed to develop better dispersion methods. Prolonged systematic tests are needed, due to the difficult condition of the ore and the contributing factors of contamination;

(f) Recommendations have been made for immediate modifications and tests. After conclusion of this work, when good dispersion conditions have been established in the plant, it is suggested that the products and the processes should be re-examined so that the most cost-effective modifications and additions may be selected;

(g) During the present mission, preliminary tests have shown that excellent dispersion can be attained, and that this results in good separation of fine impurities from the clay. The chemical composition, the particle size and the brightness of the clay were all much improved. Both iron oxides and sulphur were greatly reduced. However, these results were attained fortuitously and the precise conditions for reliable treatment need to be established by detailed tests, as outlined below;

(h) During the preliminary tests in the laboratories of the SCC Research Institute and during associated detailed discussions, the counterpart personnel of SCC have become conversant with the details of the problems presented by this project. With their longstanding knowledge of the practical difficulties, the counterpart personnel are in an excellent position to carry out the necessary test work, as discussed with the expert. Various papers and references have been supplied by the expert to supplement available information.

II. PROPOSALS FOR MODIFICATIONS AND TESTS

The aim of all the proposals is to improve the quality of the products and to increase recovery of clay from the ore. An overall increase in the rate of throughput is not envisaged at this stage. However, it should be noted that approximately double the present rate of production (an increase from about 130,000 t to about 250,000 t per year) would make all processes far more cost-effective and would greatly reduce the costs per tonne of product. Such an increase may have to be considered if expensive additional processes such as flotation or magnetic separation were to be introduced.

A. Modifications to the present processing plants

Unprotected iron should be removed from the entire plant area. This includes ladders and hand rails; support structures for stirrers, tanks etc.; and pipes and other parts of the treatment circuit. Pipes should be constructed of high density polyethylene (HDPE). The discharge screens on the mixing tanks should be replaced by nylon screens or should be made of some other non-rusting material. The absence of iron needs to be enforced more and more stringently as the process proceeds towards the final product. The greatest degree of cleanliness is necessary around the settling tanks for the clay products. It should be noted that hydrous ferric oxide is strongly adsorbed by clay minerals. Minute traces of iron oxides produce quite disproportionate staining.

Dispersion of clay by chemical additives in the mixing tanks should be introduced immediately. It will improve the quality of the products and also reduce the losses of clay with the coarse waste. Pending the results of detailed tests on dispersion and selective flocculation, it is recommended that Calgon or a similar sodium hexametaphosphate should be used at a rate of 2-3 kg per tonne of clay. The exact proportions of additives for different grades of feed will have to be judged by experience. Sodium silicate should be used to raise the pH to about 8. For economy, the sodium silicate may be mixed with sodium carbonate if the quantity of additive becomes too large. It is essential that no part of the clay feed should be exposed to a pH greater than 11.5. It is recommended that the sodium reagents should be added to the water in a separate mixing tank ahead of the existing mixing tanks. Since a large proportion of water is recirculating, it is expected that pH conditions in the plant will progressively stabilize and the necessary additions of pH reagents will be related to the quantity of new water entering the system.

The hydrocyclones should be operated as continuously as possible and under the most constant conditions of pulp density and flow rate. The state of wear of the cyclone liners should be inspected regularly and any worn liners should be replaced before they break down. A worn liner (more than 20% loss of thickness) adversely changes the performance of the cyclone and a torn liner causes severe misplacement of products. The liners of the apex orifices which discharge the coarse reject are especially vulnerable. Samples of worn liners that were seen at the plant were worn too much for acceptable performance.

The problem of sticky ore in the jaw crusher could be solved by replacing the crusher with a twin, knobbly roll crusher. Alternatively, it could be replaced by a ball mill. The dispersant would have to be added to the charge in the mill and less work would be needed in the stirred tank. This aspect requires more study.

B. Tests

To assist in the initial addition of sodium hexametaphosphate as a dispersant, systematic tests should be carried out so as to optimize the pH, the method of addition and the conditioning time for best dispersion of the clay. It should be noted that one of the purposes of good dispersion is the attainment of higher pulp densities so as to reduce the quantity of water needed per tonne of clay. Other clay producers commonly operate with solids concentrations between 20% and 36%.

For the purpose of this test it is recommended that a measurement of low shear viscosity (Brookfield) related to pulp density should be used to assess the quality of dispersion. In order to relate the laboratory tests to the plant dispersion conditions, ore feed samples should always be prepared dry. The ore should be crushed to less than 2 mm so as to minimize sampling errors, and each test should use not less than 1 kg of dry solids. A suitably large and robust stirrer should be used. The stirrer and the tank should be coated in inert material (plastic, enamel or glass).

The method of testing should be to dissolve the reagents in the total volume of water and, keeping the stirrer in motion, to add the dry solids to the water. Although the term "dry solids" is used, it is recognized that the "dry ore" may contain a considerable proportion of water. This is not serious, but the samples should be of a known moisture content and should be partly dried if necessary. It is undesirable to dry the samples completely, because this may alter the structure of the clay and it also makes dispersion more difficult. At the end of each run, the proportions of solids in the suspension should be determined and the viscosity should be measured. The residual coarse solids should not be included in the density determination, but their mass should be recorded. Since the more viscous suspensions will contain proportions of 325 mesh material, it would be convenient to define the "coarse residue" as plus 10 mesh particles. The scrubbing efficiency is shown by the decrease in plus 10 mesh material.

One aim of dispersion tests is to find the shortest conditioning time and the lowest-cost reagent for acceptable dispersion. The tests for sodium hexametaphosphate should be repeated therefore for other dispersants, including polyacrylates (e.g. Dispex), sodium silicate with and without sodium carbonate, or ammonia etc. It would be desirable to contact various manufacturers for test samples. These are usually supplied free, together with recommended dosages and conditions. Obvious suppliers are Cyanamid, Hoechst and Allied Colloids, but there are many other firms.

Another aim of the dispersion tests is the attainment of higher solids concentrations than those used so far. If any of the tests yield good dispersion and relatively low viscosity, additional tests should be carried out to determine how far the solids concentration can be increased without affecting the performance of the hydrocyclone classifiers. For this purpose, hydrocyclone tests may be needed, as described below

Selective dispersion or flocculation has occurred during four of the preliminary tests and this may form a most interesting method of improved treatment. The conditions needed for this purpose are not known and will necessitate systematic testing. During the successful runs of selective dispersion or flocculation, samples of clay product slurry were treated with sodium silicate to raise the pH to 8.5 and then with sulphuric acid to lower the pH to 4.0. At that stage, settlement of waste material occurred; this included iron oxides, silica, pyrite, alunite and organics. A stable and clean clay suspension remained and the addition of sodium dithionite produced significant improvements in brightness by leaching some ferric oxides from the surfaces of the clay particles. The sediment showed clear size classification, coarse particles settling fast and finer particles more slowly. The sediment was flocculated but the clay suspension was highly dispersed and of low viscosity. The two products were easily separated by decantation after settlement.

If this condition could be reproduced reliably, it would permit treatment at higher solids concentrations, it would yield better classification in the hydrocyclones, and it would offer a final method of cleaning by sedimentation in the product settling tanks, without the need for centrifuge finishing. Alternatively, centrifuges could produce a fine-grained product at greater speed. Sodium dithionite bleaching after such separation should reach very high brightness.

In the preliminary tests it was not possible to reproduce the separation at will, and it must be assumed that the experimental procedure was inadequate. A possible defect was the method of dropping fairly concentrated reagents into the stirred clay slurry. It is proposed, therefore, that tests should be carried out using the procedure described above for dispersion. A "dry" sample of finished clay should be used, crushed to less than 2 mm. The sample should be gradually stirred into water which was previously raised to a high pH. Various values of pH should be tested with various sodium salts, e.g. silicate, carbonate and hydroxide, singly and in various combinations with each other and with ammonia.

Varying periods of dispersion stirring should also be tested. Each time, the viscosity of the slurry should be measured. For the next step, dilute sulphuric acid should be added. Acid concentrations in the range 1-5% should be tested.

It is possible that one of the impurities of the clay needs to be present in a certain concentration to cause flocculation. This could be iron oxide or silica; there is less likelihood of pyrite or alunite. In the preliminary tests, the slurry samples were heavily flocculated and may have contained dissimilar proportions of impurity minerals. For the new tests, the "dry" clay samples should be chemically analysed so that variations may be noted; samples should also be carefully mixed from one feed batch so that several runs can be made on similar material. In addition, samples of the slurry suspension should be chemically analysed after conditioning at high pH. All details of procedures and all observations, qualitative as well as quantitative, should be recorded at the time, down to the smallest detail. It is difficult to judge what is significant and what is unimportant until the process can be repeated.

Separately from the above tests with "dry" clays, it is recommended that tests should be carried out daily with new clay slurry taken directly from the production line. These slurry samples should be conditioned with dilute reagents and the large stirrer and tank mentioned above should be employed. It may be found that clays from different sources show a different behaviour, and this could help in identifying the factors needed for selective flocculation.

It seems necessary to establish whether or not the organic content of the clay slurry contributes to the flocculation in any way. This could be tested by boiling the clay with concentrated hydrogen peroxide and then boiling it again several times with triple distilled water. This should remove all organics without interfering with the clay minerals. It might also remove the ferric oxide which normally coagulates with clay minerals at a pH of 7. The dispersion characteristics of the clay after the boiling treatment could be of interest in understanding the problem, but it is not of practical value itself.

It should be noted from previous work that organic carbon in concentrations as low as 0.005 parts per million is sufficient to cause flocculation in the clay-ferric oxide system. Further, it is possible that the sodium silicate (and other reagents used) are not completely free of fatty impurities and it is advisable to use a fresh supply which was not previously opened. All glassware (beakers, rods etc.) should be cleaned in chromic acid as it is not known whether carbon is helpful or hostile for the process.

Two further factors may be relevant to dispersion or flocculation behaviour; ferric hydroxide has its zero point of charge (ZPC) in the pH range 7-8. The ZPC of silica is at pH 2. It may therefore be desirable to raise the pH first to about 8, and then to drop it either to 3 or to 1, i.e. on either side of the ZPC of silica. For full stability of the kaolin dispersion the pH could be raised to 9.

Flotation tests for the removal of impurities should be deferred until the dispersion characteristics of the clay products are better known. There is little point in trying to float the present heavily flocculated clays. The removal of impurities would not be adequate and clay losses would be high. This comment applies to all forms of flotation, including two-liquid flotation.

For the latter process it is necessary to have special equipment, as described in the papers given to SCC staff. These papers should be studied carefully if two-liquid flotation is to be attempted. The need for excluding air after the oleate collector has been added is especially important. The technique is regarded as a more long-term project for the staff of the SCC Research Institute.

Bleaching with sodium dithionite ($Na_2S_2O_4$) at a neutral or acid pH is entirely feasible with additions in the range of 2-8 kg per tonne of clay. However, it should be applied after the iron impurities have been removed and it is thus dependent on previous dispersion. It should be noted that the use of sodium dithionite is for the purpose of removing the iron oxides which coat the surfaces of the clay minerals. Removal of soluble iron salts by washing and prevention of re-oxidation are essential subsidiary steps to make the bleaching effective.

High intensity, high gradient magnetic separation, either with conventional or with superconducting magnets, could be used for removing iron impurities which occur as separate mineral grains. The process could neither remove alunite, nor pyrite. It would essentially depend on good dispersion. Magnetic separation is therefore, regarded as a longer term project of limited interest. Laboratory tests would require a unit capable of field strengths of the order of 2 tesla or higher if limonite is to be removed. Pyrite would require field strengths above 2.5 tesla and this would necessitate a super-conducting magnet.

Classification in hydrocyclones could benefit from test work in a closed circuit rig. The rig should comprise a sump which feeds a centrifugal pump which then delivers the slurry flow to a cyclone while the cyclone products return to the sump. From the delivery side of the pump, a by-pass valve back to the sump allows regulation of the flow delivery to the cyclone. A pressure gauge should be provided near the feed inlet to the cyclone to measure delivery pressure. Alternative cyclones of 250 mm, 150 mm and 100 mm diameter could be used for classification tests, to select flow rates and pulp densities, and to study the possibility of adding a third cyclone stage (100 mm diameter) for improved product grades. This cyclone rig could also serve to assess the effect of dispersion on grade and recovery.

In a modified form, the cyclone rig could be used to test possible changes of the flow sheet. For example, it could be attractive to run a two-stage classification with two close-coupled cyclones. The overflow product (fines) from the first cyclone (250 mm) could pass directly as feed into the second cyclone (150 mm). The overflow from the second cyclone would be the final product. The underflow (coarser) of the second cyclone could return to the feed for the first cyclone. The underflow from the first cyclone would be the final reject. This arrangement has an advantage in that it can be run with a dense underflow from the first cyclone, thus making a clean reject. Any coarse material passing into the overflow of the first cyclone will be recovered in the underflow of the second cyclone, because the solids concentration there is much lower. Both water and pumping costs could be less than for the present system of running two cyclone stages separately, each with its own pump.

Delamination of kaolin to increase the proportion of minus 2 micrometre particles has been practised for a long time by English China Clays. Tests should be carried out with various products and with both overflows and underflows from the cyclones, in order to establish whether the SCC material can benefit from the process. Delamination can be tried with various mixtures of sand and clay in the laboratory's porcelain batch mill. A dispersed feed with fairly high solids concentration would be desirable. The laboratory products would be too small in volume for separation in the cyclone rig, but they could be separated simply by sedimentation. Variously classified sand sizes below about 2 mm could be compared for efficiency. The fine grinding of impurities would have to be assessed as an adverse factor.

Preliminary tests have indicated that grinding of the coarse reject from the mixing tanks may provide additional clay extraction. Tests should be carried out initially in the laboratory's porcelain mill with porcelain balls. A pulp dispersed with sodium hexametaphosphate should be used to determine the optimum pulp densities and grinding times. The aim should be to obtain additional feed material which is similar in composition to the normal feeds for the 250 mm cyclones. If the results continue to be as promising as those of the preliminary tests, consideration should be given to the acquisition of a small cylindrical mill which could be used with balls, rods or pebbles.

For the determination of the mill size, it would be necessary to carry out some Bond grindability tests with the feeds. Since the desired throughput is only of the order of 1.0-1.2 tph, it is unlikely that the mill would need to be larger than about 1.5 m in diameter. In order to avoid iron contamination it would be ideal to use a rubber-lined mill with a pebble charge. Good pulp dispersion would be essential.

The grinding of coarse reject from the stirred tanks could be solved by introducing a ball mill in place of the jaw crusher. The ball mill could be operated in closed circuit with a spiral classifier or in closed circuit with the stirred tanks. In either case, the result would be higher energy consumption, because all coarse waste would be ground to, say, less than 1 or 2 mm. A permanent magnet separator may have to be included at the mill discharge to remove the scrap iron which would inevitably arise from the mill liners and ball charge. Better extraction of clay would be achieved and the problem of sticky ore would be removed, provided that adequate dispersion occurs in the mill. This would require long-term testing and the above-mentioned small mill could be employed for this purpose. Such tests would be essential for assessing the size of the primary mill needed in relation to the residence time dictated by the rate of disaggregation of clay balls which usually form under such treatment.