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MINERALOGY AND TECHNICAL APPRAISAL OF KAOLINITE-BEARING ROCKS FROM ZAMBIA

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Mineralogy and technical appraisal of kaolinite-bearing rocks from Zambia

C J Mitchell, D A Briggs and A J Bloodworth

1. INTRODUCTION

Four samples of kaolinite from Central Zambia were collected in April 1990 by D.A. Briggs (Mineralogy and Petrology Report WG/90/15R) in order to characterise them mineralogically and assess their suitability as industrial raw materials, possibly in the manufacture of paper. Other applications such as use in ceramics, as fillers in paint, plastic and rubber, or in agriculture were also to be considered.

The mineralogy of the head samples was determined by X-ray diffraction (XRD) and the kaolinite content by thermogravimetric analysis (TG). The samples were processed by hydrocycloning to produce kaolinite-rich concentrates; these were analysed by XRD, TG, X-ray sedigraph (for particle-size distribution) and reflectance spectrophotometer (to assess their brightness).

This investigation was carried out as part of the ODA/BGS research and development project "Minerals for Development".

2. SAMPLE CHARACTERISATION

2.1. Description and locality

CJM 14 and CJM 29 - Kapiri Mposhi kaolinite

These samples were collected from old kaolinite pits close to Kapiri Mposhi, Central Province. Each sample contains coarse quartz, muscovite mica and a small amount of feldspar, with fine-grained kaolinite. Iron staining gives the sample a brownish colouration.

CJM 15 - Musofu kaolinite

This sample was collected near Musofu, Central Province. It is an off-white, fine grained sample with few coarse grains of quartz, fine-grained kaolinite and soft aggregates of mica. It was originally thought to consist of talc or pyrophyllite because of its soapy texture, but this was later shown to be due to the presence of mica flakes in the soft clay.

CJM 17 - Serenje clay

This sample was collected from the Chiluwe pegmatite, near Serenje, Central Province. The sample is composed mainly of very white, coarse feldspar, with a small amount of mica flakes and fine kaolinite. It was submitted by Minex with a request that it be assessed for quality and possible uses.

2.2. Mineralogy

Each of the head samples was analysed by XRD and TG. The XRD analyses were carried out using a Phillips PW 1700 X-ray diffractometer, using Co-*K* alpha radiation at 45 kV and 40 mA and scanning over a range of 3 - 50°2θ. The TG analyses were performed on 10 milligrams of sample heated to 1100° C at 50°C / min^{-1} in a CO_2 atmosphere, losses being recorded continuously as a function of temperature increase.

Table 1 contains a summary of the mineralogy of each sample, with kaolinite content determined by TG. The weight percentages of quartz, feldspar, mica and ferromagnesian minerals were derived from modal analyses (by binocular microscope examination) and are therefore approximate. The mineralogy was confirmed by XRD.

CJM 14 is composed mainly of kaolinite, quartz and muscovite mica, with a smaller amount of K-feldspar (microcline ?) and iron oxides. CJM 15 contains mostly quartz and muscovite mica, with smaller amounts of kaolinite, microcline feldspar and iron oxides. CJM 17 contains mainly microcline feldspar, with smaller amounts of kaolinite and (phlogopite ?) mica. CJM 29 is composed mainly of kaolinite, quartz and muscovite mica, with smaller amounts of K-feldspar (sanidine ?) and iron oxides.

3. BENEFICIATION TRIALS

3.1. Beneficiation overview

The aim of the beneficiation testing was to upgrade the kaolinite content, and also to improve the use-related properties such as particle-size distribution and brightness. The processing scheme used is outlined in Fig.1. Essentially, the head samples were thoroughly dispersed in water, and then wet screened on a series of sieves down to 63 µm. The < 63 µm fractions were then hydrocycloned to separate the < 10 µm material into the cyclone overflows, which would be expected to have higher kaolinite contents, higher brightness values, and of course contain higher proportions of fine particles.

3.2. Wet screening

The head samples were thoroughly dispersed prior to screening by attrition scrubbing to remove clay coatings from coarse material and to disaggregate clay lumps. The samples were wet screened through 1 mm, 500 µm, 250 µm, 125 µm and 63 µm sieves, using an automatic sieve shaker. Table 2 summarises the particle-size distribution of each sample, which incorporates the particle-size distribution of the sub-sieve material as determined by X-ray sedigraph.

The > 63 µm sieve residues were examined by binocular microscope. CJM 14 is largely composed of quartz, K feldspar and mica, with a small amount of iron oxides. CJM 15 is mainly quartz and muscovite mica, with a small amount of ferromagnesian minerals and iron oxides. CJM 17 is mainly composed of a very white K-feldspar, with a small amount of mica in the finer fractions. CJM 29 is mainly composed of quartz, K-feldspar and muscovite mica, with a small amount of ferromagnesian minerals and iron oxides.

3.3. Hydrocyclone treatment

The < 63 µm fraction suspensions derived from wet screening were settled out to produce suitable concentrations, about 5 - 8 % w/w, for hydrocycloning. The samples were separated using a glass hydrocyclone 30 mm in diameter, with a 1.5 mm i.d. spigot, attached to a small pump. The suspensions were circulated through the pump alone prior to separation to thoroughly disperse the material. The separation produced an underflow, containing the > 10 µm material and an overflow, containing the < 10 µm material. The overflow was repassed in order to improve the separation efficiency and the kaolinite grade.

4. ASSESSMENT OF PRODUCTS

4.1. Overview

The hydrocyclone feed material and products, underflow and overflow, were analysed to assess the changes in mineralogy, particle-size distribution and brightness. The results from these analyses were compared to the known properties of commercially available kaolinite products. Table 3 summarises the properties of commercial kaolinite products including paper, ceramic, filler and agricultural grades.

4.2. Mineralogy of products

The hydrocyclone feed material was analysed by XRD and the products by XRD and TG. Table 1 summarises the mineralogy of the hydrocyclone products, as well as that of the feed materials (< 63 µm) and the original head samples already referred to above in section 2.2.

The feed material for CJM 14 has a high kaolinite grade, 83%, well over twice the head grade. The separation resulted in an underflow with a slightly reduced kaolinite grade, 76%, and an overflow containing 91% kaolinite. The amount of quartz is most notably depressed in the overflow. CJM 15 feed has a low kaolinite grade, only 12%, and the separation produces low-grade underflow, 9% kaolinite, and overflow, 22% kaolinite. The amount of quartz and feldspar is lowered in the overflow. CJM 17 feed has a reasonably high kaolinite grade, 68%, well over three times the head grade. The separation results in an underflow with 62% kaolinite and an overflow with 87% kaolinite. The amount of feldspar is lower in the overflow. CJM 29 has the highest kaolinite grade of all the feed materials at 79%, twice that of the head grade. The separation results in high-grade products, the underflow grading at 74% kaolinite and the overflow at 92% kaolinite, which is the highest grade of all the products. Amounts of quartz and mica are lower in the overflow.

4.3. Particle-size analysis

The hydrocyclone feed material and separation products were analysed by a Micromeritics X-ray sedigraph particle-size analyser to determine the changes in particle-size distribution. The particle-size distribution is determined from the changes in X-ray absorption in a settling sample suspension, assuming a density of 2.65 g/cm^3 for all the material. Table 4 summarises the particle-size distributions. Figures 2, 3, 4 and 5 display the grain-size distribution plots for the hydrocyclone products of CJM 14, 15, 17 and 29 respectively.

In CJM 14, the feed to the hydrocyclone contains 64.5 % of material < 10 μm. This is upgraded to 94.5% in the overflow, although a significant proportion remains in the underflow, 42%. The amount of < 2 μm material is increased to 50% in the overflow. CJM 15 feed has a low proportion of < 10 μm material, 41%, but this is significantly increased to 86% in the overflow and only 24.5% remains in the underflow. The amount of < 2 μm material was very low in the feed, 2.0%, and this is increased to only 5% in the overflow. CJM 17 has a moderate amount of < 10 μm material in the hydrocyclone feed, 54%. This is upgraded to 97% in the overflow and reduced to 19% in the underflow, the most efficient of all the hydrocyclone separations. The amount of < 2 μm material is increased to 55% in the overflow from 22% in the feed material. CJM 29 hydrocyclone feed has a moderately high proportion of < 10 μm material, 60%, which is upgraded to 93% in the overflow and reduced to 28.5% in the underflow. The amount of < 2 μm material is increased from 29% in the feed to 42% in the overflow.

4.4. Grade and recovery of kaolin

To assess the efficiency of the hydrocycloning in terms of the total amount of kaolinite concentrated into the overflow products, recovery figures were calculated. These were determined from the kaolinite grades and weight percentages of the products relative to their respective head materials. The grade and recovery figures are outlined in Table 5.

The hydrocyclone feed (i.e. the < 63 μm fraction) for CJM 14 represents 37.1% of the head material, with a kaolinite grade of 83% and a recovery of 90%. The overflow has a grade of 91% kaolinite and a recovery of 48%, which compares to a grade of 76% kaolinite and 42% recovery in the underflow. CJM 15 hydrocyclone feed is 48.1% of the head, with a kaolinite grade of only 12% and recovery of 96%. The overflow has a grade of 22% kaolinite and 36% recovery. The underflow has a grade of 9% kaolinite and recovery of 60%. CJM 17 hydrocyclone feed represents only 25.3% of the head, with a kaolinite grade of 68% and 96% recovery. The overflow is upgraded to 87% kaolinite, with a recovery of 30% and the underflow grades 62% kaolinite with 66% recovery. CJM 29 has a hydrocyclone feed that is 45.8% of the head, with a kaolinite grade of 79% and 86% recovery. The overflow grades 92% kaolinite at 26% recovery and the underflow grades 74% kaolinite at 60% recovery.

4.5. Brightness

The brightness values of the hydrocyclone overflow products were measured to assess their suitability for use in paper manufacture, aiming for those values outlined in Table 3. The brightness values of the -125 +63 μm fraction of the K-feldspar by-product of CJM 17 were also measured. The brightness of the samples was determined using an EEL reflectance spectrophotometer which measured light of four different wavelengths reflected from pressed powder discs. The reflectance was compared to that of a barium sulphate standard taken as 100 and the brightness is expressed as a percentage of this. Table 6 summarises the brightness values and Figure 6 is a plot of the spectral reflectance (brightness) curves.

CJM 29 has a range of brightness values between 41.5 and 63.1% and CJM 14 ranges from 50.2 - 69.7%, both giving curves that rise toward the higher wavelengths. CJM 15 has a range of brightness values between 74.4 - 78.0%, giving a relatively horizontal plot across the wavelengths. CJM 17 has a brightness range of 70.1 - 72.7%, and the K-feldspar has a range of 85.6 - 86.4%; both plot horizontally.

5. DISCUSSION OF RESULTS

CJM 14 has a relatively high head kaolinite content (34%), most of which is contained in the hydrocyclone feed material. Hydrocycloning results in an almost equal split of the feed, with the overflow having a higher kaolinite grade than the underflow. The particle-size distribution is relatively fine, but the brightness values are very low. This is probably due to the iron-staining as iron absorbs the lower wavelengths of light and this accounts for the characteristic spectral reflectance curve. A hydrocyclone separation with a coarser cut point, for example 20 μm instead of 10 μm, would improve the recovery of kaolinite in the overflow, but this would also reduce the grade, coarsen the particle-size distribution and not have an appreciable effect on brightness.

CJM 29 has the highest head kaolinite content (39%), most of which occurs in the higher-grade hydrocyclone feed. The overflow product has the highest kaolinite grade (92%) and a fine particle-size distribution but unfortunately the recovery and brightness are very low.

The low brightness values alone rule out the possible use of CJM 14 and CJM 29 in paper manufacture. Both samples could be used as low-grade fillers in paint, plastic and rubber products where high brightness is not crucial and may be suitable for use as anti-caking agents for fertilisers and feedstuffs, or as carriers for insecticides, pesticides and weedkillers.

CJM 15 has a low head kaolinite grade (6%), which is not increased significantly either in the hydrocyclone feed or the overflow. Muscovite mica forms a higher proportion of the overflow than kaolinite. Despite the high brightness values, the overflow has a coarse particle-size distribution and a low kaolinite recovery. A lower particle-size cut point, for example 2 μm, would improve the kaolinite grade, but the recovery would decrease drastically. CJM 15 is not suitable for paper manufacture mainly due to the low kaolinite grade, but also to the coarse particle size. It could be useful as an anti-caking agent for fertilisers and feedstuffs, and also as a carrier for insecticides, pesticides and weedkillers where high kaolinite content is not critical.

CJM 17 has a low head kaolinite content (18%) that is increased considerably to 68% in the < 63 μm hydrocyclone feed and to a moderately high grade of 87% in the overflow. The overflow recovery is poor, but increasing the hydrocyclone cut point would improve this at the expense of the grade. The overflow has a very fine particle-size distribution and reasonably high brightness values. CJM 17 is suitable for use as a filler in paper manufacture and also as a general filler in paint, plastic and rubber. It could also be suitable for use as an anti-caking agent for fertilisers and feedstuffs, or as a carrier for insecticides, pesticides and weedkillers. The K-feldspar that forms 90% plus of the +63 μm material has high brightness values and could be a useful by-product, possibly as a ceramic raw material.

In normal commercial operations material is passed through several hydrocyclones, the first pass having a relatively large cut point to maximize recovery and subsequent passes have finer cut points to produce higher grade kaolinites. In this investigation the material was passed through the same hydrocyclone twice; further hydrocycloning would result in higher grade products but also lower recoveries.

6. CONCLUSIONS

1. Kapiri Mposhi clays

   CJM 14 and CJM 29 are both unsuitable for use in paper manufacture, due to their poor brightness values. They could possibly be suitable as general fillers or agricultural minerals.

2. Musofu clay

   CJM 15 is unsuitable for use in paper manufacture, due to its low kaolinite grade and coarse particle-size distribution. It could be suitable for use in agriculture.

3. Serenje clay

   CJM 17 is suitable for use as filler-grade kaolinite in paper manufacture, with a reasonably high kaolinite grade, fine particle-size distribution and high brightness values; low recovery poses the only drawback. It would also be suitable for use as a general filler or as an agricultural mineral. The K-feldspar by-product has a high brightness and could be useful, possibly in ceramic manufacture. However, no details of the occurrence of this sample were communicated by Minex, and it is to be hoped that it is representative of an extensive deposit as it is clearly the best of the samples examined.

ACKNOWLEDGEMENTS

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Table 1. Mineralogy of the Zambian kaolinites

Sample	Kaolinite Wt %	Quartz Wt %	Feldspar Wt %	Mica Wt %	Ferromags Wt %
CJM 14					
Head	34	33	6	26	< 1
< 63 μm	(83)	**	*	*	-
Underflow	76	**	*	*	-
Overflow	91	*	*	*	-
CJM 15					
Head	6	48	5	40	1
< 63 μm	(12)	**	*	**	-
Underflow	9	**	*	**	-
Overflow	22	*	-	**	-
CJM 17					
Head	18	-	80	2	-
< 63 μm	(68)	-	***	*	-
Underflow	62	-	***	*	-
Overflow	87	-	**	*	-
CJM 29					
Head	39	32	4	25	< 1
< 63 μm	(79)	*	*	**	-
Underflow	74	*	*	**	-
Overflow	92	-	*	*	-

The kaolinite contents were determined by TG, except for the < 63 μm (hydrocyclone feed) figures, in brackets, which were back-calculated from the underflow and overflow kaolinite contents. The other head figures, ie the quartz, feldspar, mica and ferromagnesian mineral contents, were determined by modal analysis on a binocular microscope of the > 63 μm fractions. The mineralogy of the products was determined by XRD, the asterisks representing the proportion of mineral present as follows:

Key: * = 0 - 25 % ** = 26 - 50 *** = 51 - 75 **** = 76 - 100
(Percentages are relative to the maximum intensity for each sample)

Table 2. Cumulative particle-size distribution of Zambian kaolinites

Grain size	CJM 14 Wt %	CJM 15 Wt %	CJM 17 Wt %	CJM 29 Wt %
< 2 mm	100.0	100.0	100.0	100.0
< 1 mm	72.6	99.2	63.6	80.1
< 500 µm	64.8	98.9	50.7	68.4
< 250 µm	55.4	97.1	36.6	58.9
< 125 µm	47.2	90.7	28.7	49.3
< 63 µm	37.1	48.1	25.4	45.9
< 10 µm	23.9	19.8	13.7	27.5
< 2 µm	11.3	1.0	5.6	13.3

The percentages represent the 'cumulative percentage less than' the corresponding grain size. The particle-size distributions are derived from a combination of the wet sieving and X-ray sedigraph figures for each sample.

Table 3. Commercial-grade kaolinite properties

Application	Kaolinite Wt %	< 2 µm Wt %	> 10 µm Wt %	Brightness (4570 Å)
Paper				
Coating grade	93 - 100	78 - 97	0.2 - 1.5	78 - 93
Filler grade	89 - 97	30 - 78	3 - 41	70 - 90
Ceramic grade	87 - 97	39 - 70	2 - 18	86 - 91 (Fired 1180°C)
Filler				
Paint	High grade	25 - 80	0.5 - 25	76 - 91
Plastic	High grade	17 - 90	0 - 22	70 - 92
Rubber	High grade	20 - 80	As above ?	As above ?
Agricultural	Low - medium	As fillers ?	As fillers ?	Not applicable

Paper-grade and ceramic-grade figures from Bristow CM (1987) World kaolins - genesis, exploitation and application, *Industrial Minerals*, **July**, pp.45 - 59. Paint figures from Toon S (1985) Minerals for paint, *Industrial Minerals*, **December**, pp. 49 - 75. Plastic figures from Katz HS & Milewski JV (Editors) (1987) Chapter 7. Kaolin, in *Handbook of Fillers for Plastic*, pp.143 -155. Rubber and agricultural figures from Highley DE (1984) *China Clay*, Mineral Dossier No. **26**, Mineral Resources Consultative Committee, HMSO.

Table 4. Cumulative size distribution of hydrocyclone products

Sample	Grain size	Hydrocyclone feed (< 63 μm) Wt %	Underflow Wt %	Overflow Wt %
CJM 14				
	< 10 μm	64.5	42.0	94.5
	< 2 μm	30.5	12.0	50.0
CJM 15				
	< 10 μm	41.0	24.5	86.0
	< 2 μm	2.0	0.5	5.0
CJM 17				
	< 10 μm	54.0	19.0	97.0
	< 2 μm	22.0	3.0	55.5
CJM 29				
	< 10 μm	60.0	28.5	93.0
	< 2 μm	29.0	7.0	42.0

The percentages represent the 'cumulative percentage less than' the corresponding grain size.

Table 5. Kaolinite grade and recovery

Sample		CJM 14 Wt %	CJM 15 Wt %	CJM 17 Wt %	CJM 29 Wt %
Head					
	- Wt %	100	100	100	100
	- Grade	34	6	18	39
	- Recovery	100	100	100	100
Hydrocyclone feed (< 63 µm)					
	- Wt %	37.1	48.1	25.3	45.8
	- Grade	(83)	(12)	(68)	(79)
	- Recovery	90	96	96	86
Underflow					
	- Wt %	18.8	38.8	19.1	34.0
	- Grade	76	9	62	74
	- Recovery	42	60	66	60
Overflow					
	- Wt %	18.1	9.3	6.2	11.8
	- Grade	91	22	87	92
	- Recovery	48	36	30	26

The kaolinite grades were determined by TG, the < 63 µm grades were back calculated from the hydrocyclone products. All weight percentages and recovery figures relate to the head.

Table 6. Brightness values

Sample	Wavelengths 4700 Å %	4900 Å %	5500 Å %	5800 Å %
CJM 14	50.2	50.5	62.6	69.7
CJM 15	75.0	74.4	76.3	78.0
CJM 17	70.1	70.4	71.9	72.7
CJM 29	41.9	41.5	53.8	63.1
K-feldspar	86.0	85.6	86.0	86.0

The brightness values are percentage reflectance against a barium sulphate standard representing 100 % brightness.

Figure 1. Scheme for assessment of processing characteristics of Zambian kaolinites

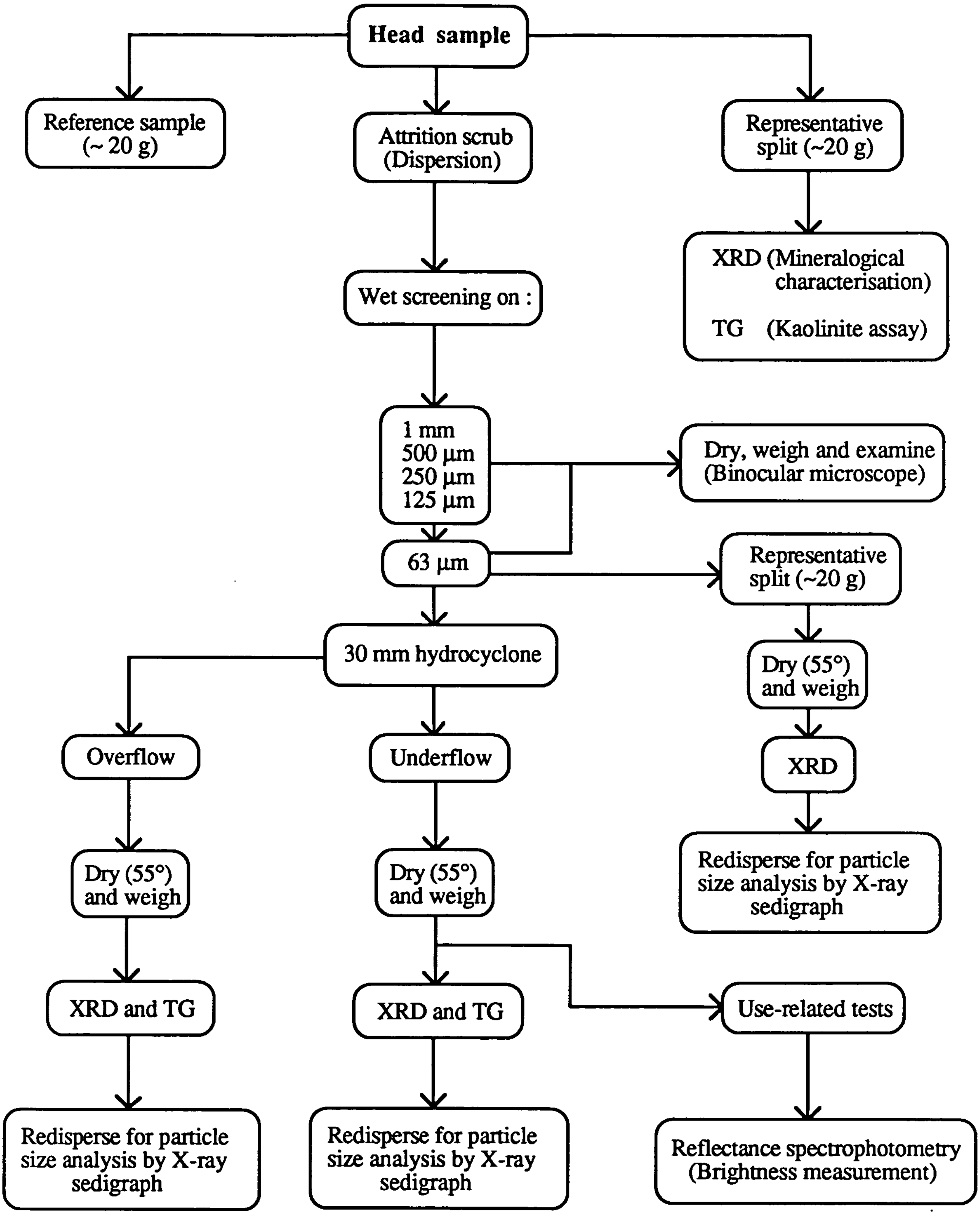

Figure 2. CJM 14 hydrocyclone product cumulative size curves

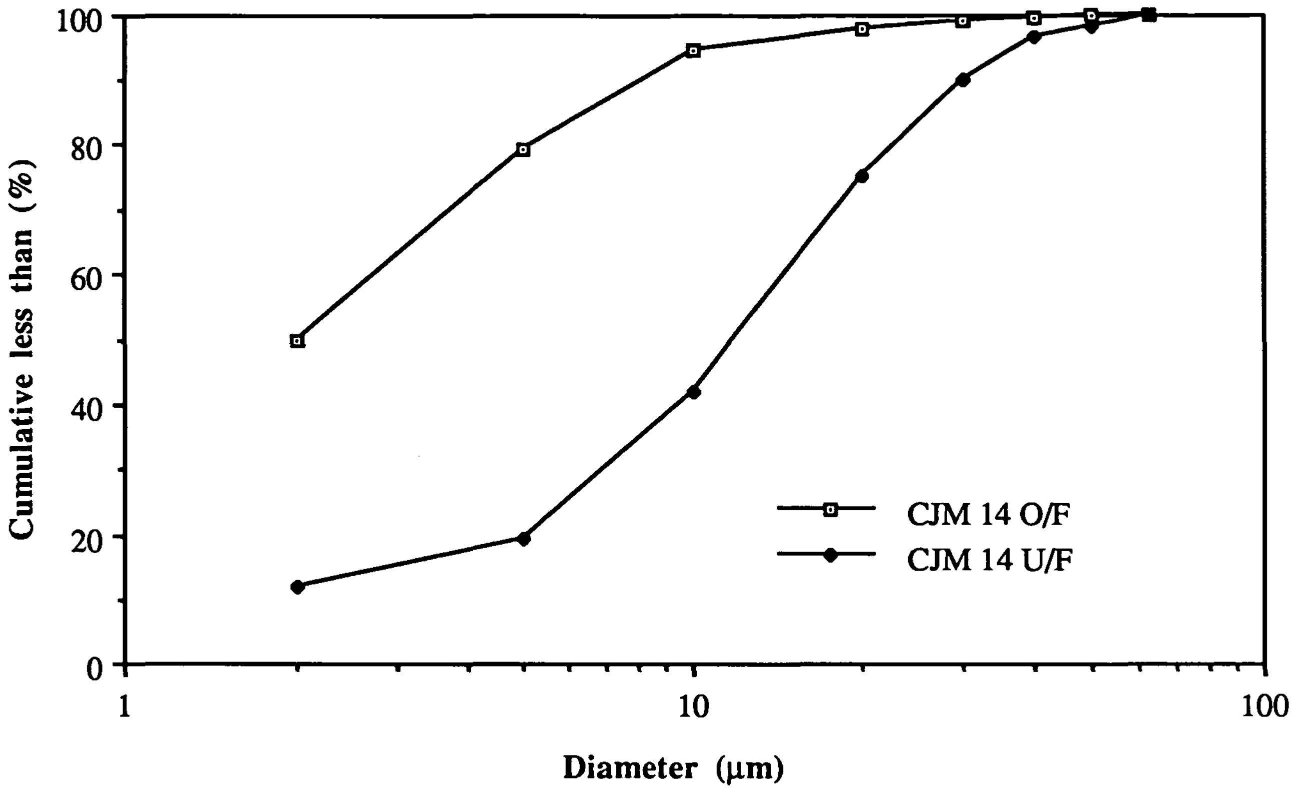

Figure 3. CJM 15 hydrocyclone product cumulative size curves

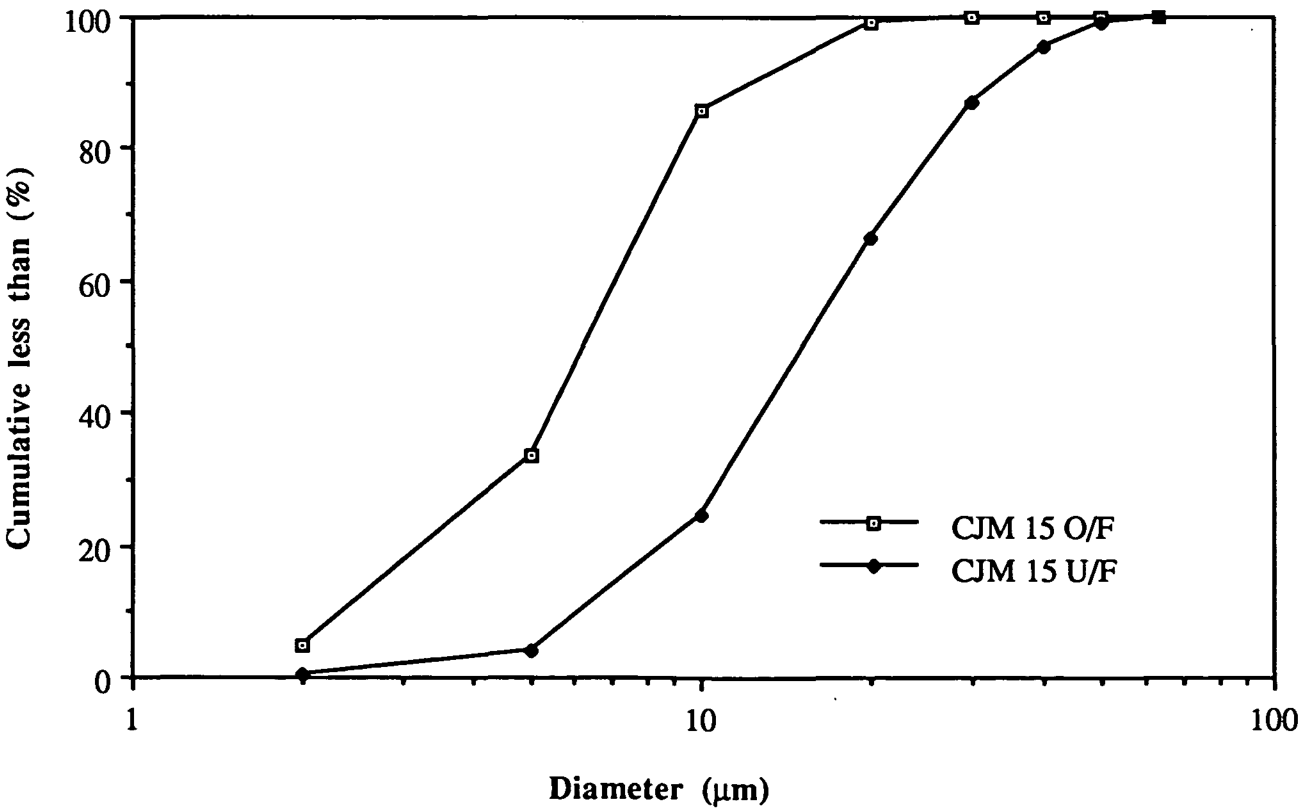

Figure 4. CJM 17 hydrocyclone product cumulative size curves

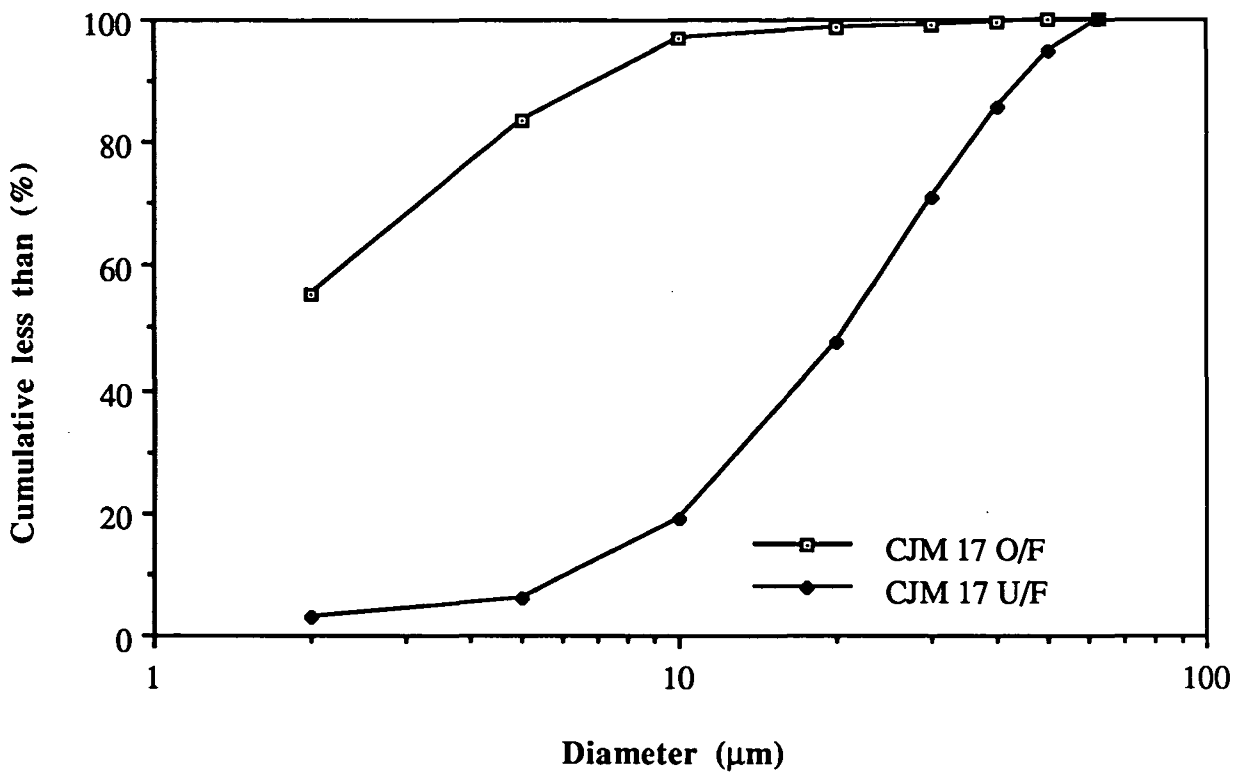

Figure 5. CJM 29 hydrocyclone product cumulative size curves

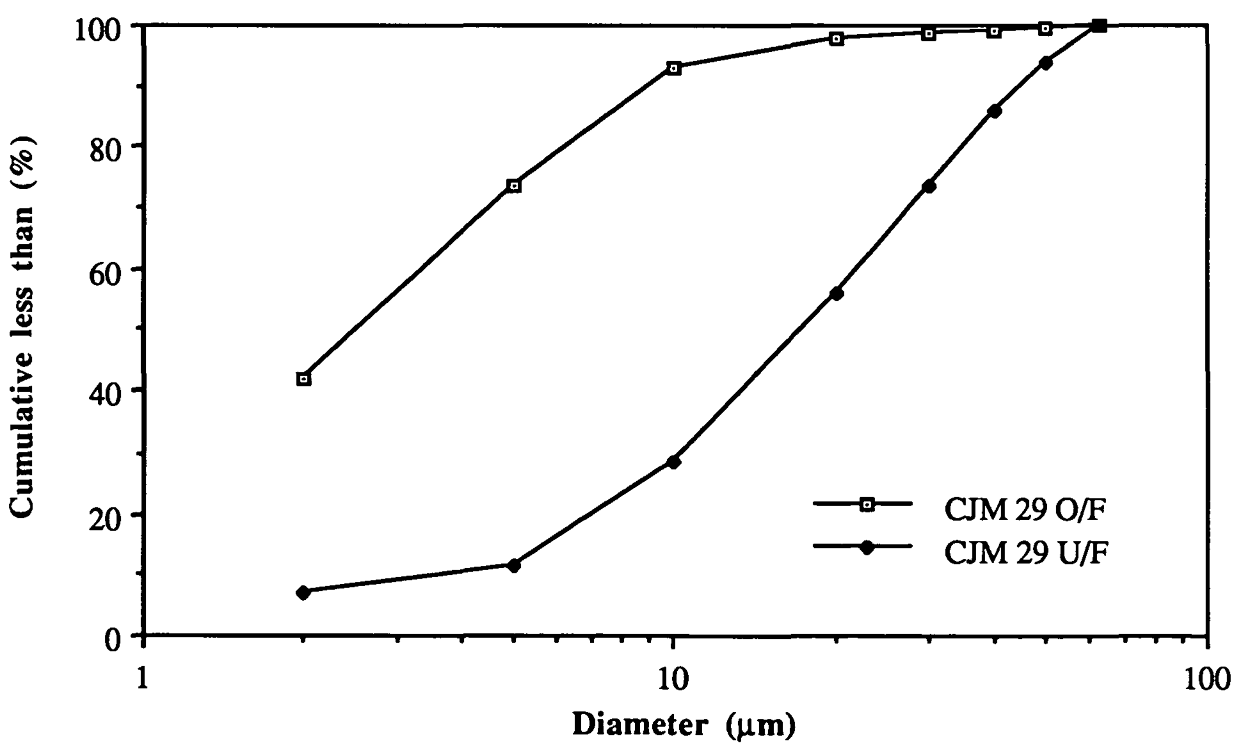

Figure 6. Spectral reflectance (brightness) curves for overflow products