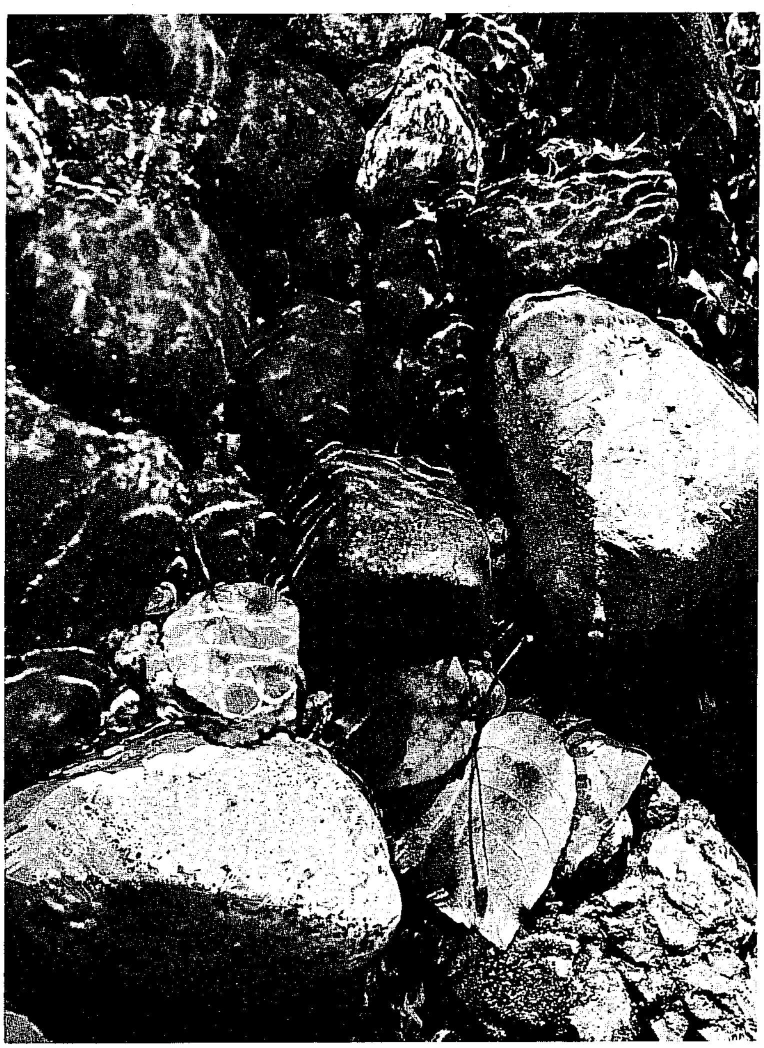
EFFECT OF ULTRAFINE GRINDING ON METALLURGY

VANGORDA PLATEAU ORES

YUKON TERRITORY

006649



CONTENTS

SUMMARY

At rated capacity, treating ore of average resistance to grinding, the modified Anvil concentrator will produce a grind of about 80% passing 50 microns. In treating the softest ore type (Type 4G) known in the Vangorda Plateau area the concentrator, at rated capacity, could probably produce a grind of 80% passing 30-35 microns.

The test data generated by the program demonstrated that, of the major ore types which could be treated, no deleterious effects in metallurgy may be expected until the fineness of grind surpasses 80% passing 15-20 microns.

T. H. Lafreniere, C.E.T.
Kamloops Research & Assay
Laboratory Ltd.
Kamloops, B.C.

Peter Brown, P. Eng.
Met Engineers Ltd.
Edmonton, Alberta

KM022

INTRODUCTION

For many years conventional lead-zinc processing was governed by the concept that lead minerals, in particular galena, would be lost if ground too fine. On the basis of this concept many plants incorporated a coarse lead flotation and severely limited degree of primary grinding in order to preclude "slime lead" losses.

With the development of some of the more complex massive sulphide lead-zinc deposits, especially those in Canada and Europe, it became apparent that in many cases satisfactory metallurgy could only be achieved with very fine grind levels. Typically in operations of this type primary grind levels of 50-70 microns are now regarded as normal.

When the design calculations for the Cyprus Anvil concentrator modifications were completed they indicated an average primary grind P_{80} of 45-50 microns on average hardness ore. At this grind level no excessive losses of lead were observed in testwork. However since ore hardness was known to vary over a wide range, it was concluded that the primary grind P_{80} could fluctuate between 30-50 microns on a short term basis. No test data were available to determine if excessive losses of lead and zinc would occur at this level of primary grind.

In May 1980 we were contacted by Mr. L. P. Taggart, Manager, Feasability and Development for Cyprus Anvil Mines and asked to perform a series of laboratory tests to determine the effects of ultrafine grinding (20-50 microns P_{80} range) on lead and zinc metallurgy.

Work commenced in late May and the first stage completed in July at which time a preliminary report was issued. Further work was carried out in July on different samples and the data reported here.

Additional work on samples of ore from Zone III of the Cyprus Anvil deposits forms the basis of another report KM028 which will be published in mid-October.

THE TEST PROGRAM

1. Test Program Objectives

The objectives of the test program as outlined by Mr. Taggart were as follows:

(a) To perform standard laboratory open circuit cleaner tests to determine the effect on overall metallurgy of primary grinding in the range 20-50 microns P_{80}.

(b) To carry out the test in a uniform manner on representative samples of ores from each of the deposits on the Vangorda Plateau.

(c) To perform tests on the ground samples to permit the P_{80} values to be accurately determined.

2. Ore Samples Used In The Program

For the purposes of the initial stages of the test program we were instructed to use samples available from storage at the laboratory. During the final phase of the testwork samples of ore from Zone III would be forwarded to the laboratory for similar testing.

The samples used in this phase of the program were as follows:

TABLE 1

Ore Samples Used In Program

Ore Source	Type	Description	Assays	
			Pb	Zn
Vangorda	1A4G	Barite rich-high grade	3.7	7.7
	2B4E	Medium grade-Pyritic	4.4	4.3
	3C4A	Low grade- Quartzitic	2.5	4.6
Grum	Composite	Pilot Plant Composite from Lakefield Research	4.7	8.9

These samples with the exception of the Grum pilot plant composite had been stored under nitrogen at Kamloops. The Grum samples, prepared by Lakefield, were stored in plastic bags with most of the air excluded.

3. Test Procedures

Open Circuit Cleaner Flotation Tests

These tests followed the usual standard test format with lead flotation being performed in a soda ash-cyanide environment. Lead cleaning, following a regrinding stage, was carried out in a soda ash modulated circuit.

It was observed that the appearance of the lead flotation improved perceptibly in almost all cases, as fineness of grind was increased. Of special note were the very clean froths observed in the latter stages of cleaning with ultra-fine grinds.

Zinc activation and subsequent flotation at high pH followed standard procedures. Zinc flotation appearance improved more dramatically than the lead as fineness of grind increased. Typically the color ot the froth became ligher and the rate of mineral flotation appeared enhanced.

Samples from the test program were filtered, dried at 105^{o}C, weighed and prepared for assay. Assays were performed using standard techniques on the Techtron Model 475 atomic absorption unit. Assay data was then processed to generate metallurgical balances for each test. Details of equipment used in the flotation work are to be found in Appendix I.

Ultrafine Sizing Procedure

The Andreasen Pipet method was used to determine the sizing of the ground ore from each test. The method which is essentially one of sedimentation in the stokesian region is precise, reproducible and accurate to $\pm$ 5% within the range of Stokes Law.

Sizing was carried out at three different levels for each sample 10, 20, and 30 microns. From the data generated by the sizing procedures, size distribution graphs were plotted and P_{80} values calculated.

Details of the procedure plus calculation sheets and size distribution graphs are recorded in Appendix II.

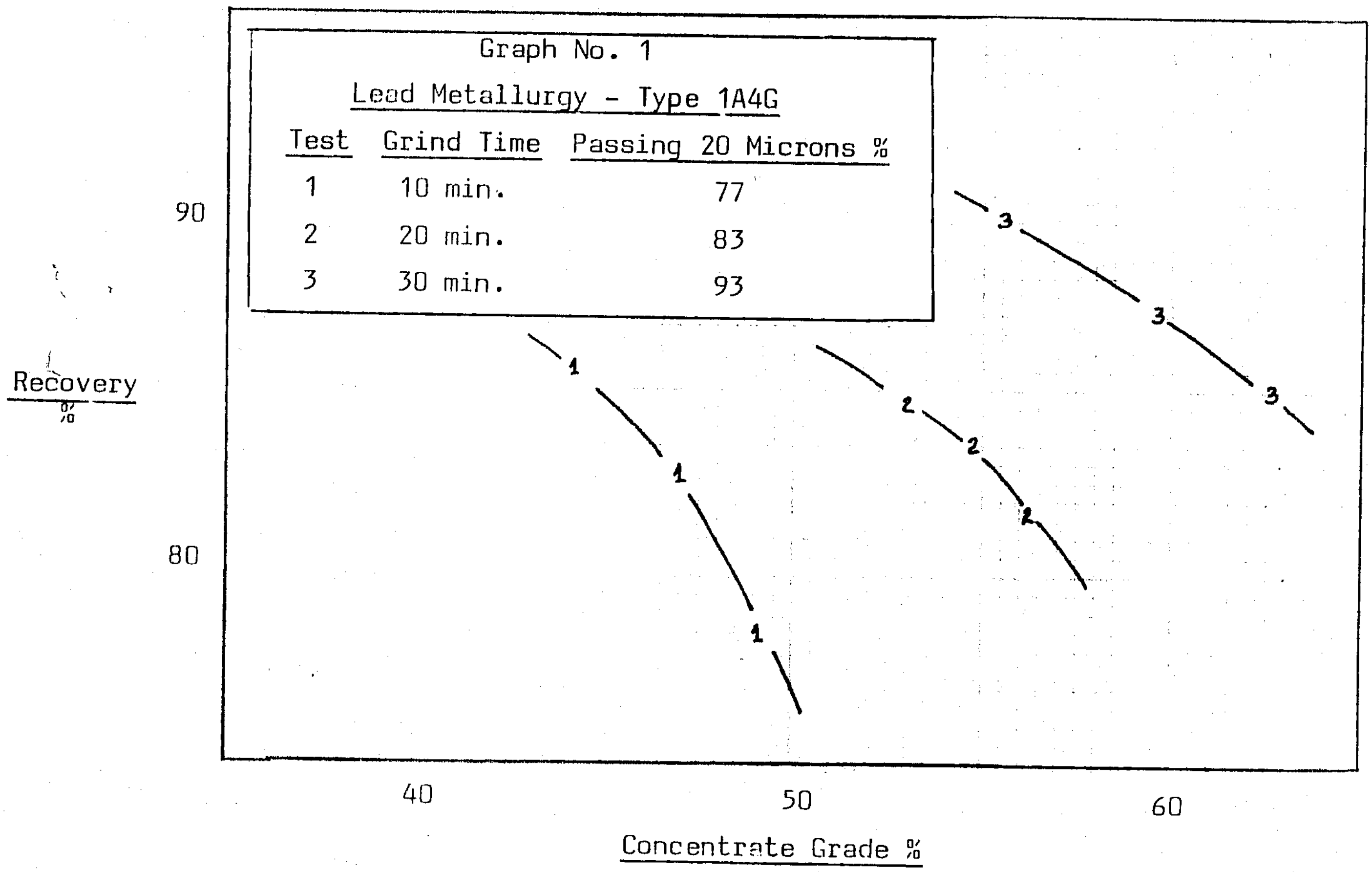
ANALYSIS AND DISCUSSION OF RESULTS

The analysis of the data generated by this program was facilitated by plotting graphs of grade and recovery for each grind level. Also because of the extreme fineness of grind involved it became impractical to use the P_{80} concept for judging grind. Instead it was decided to qualify grind on the basis of percent passing 20 microns.

Each group of data, refering to a specific sample and to a particular metal, is shown below plotted on a separate sheet. The results are interpreted and discussed in the test adjacent to the appropriate graph.

1. Type 1A4G - Baritic High Grade

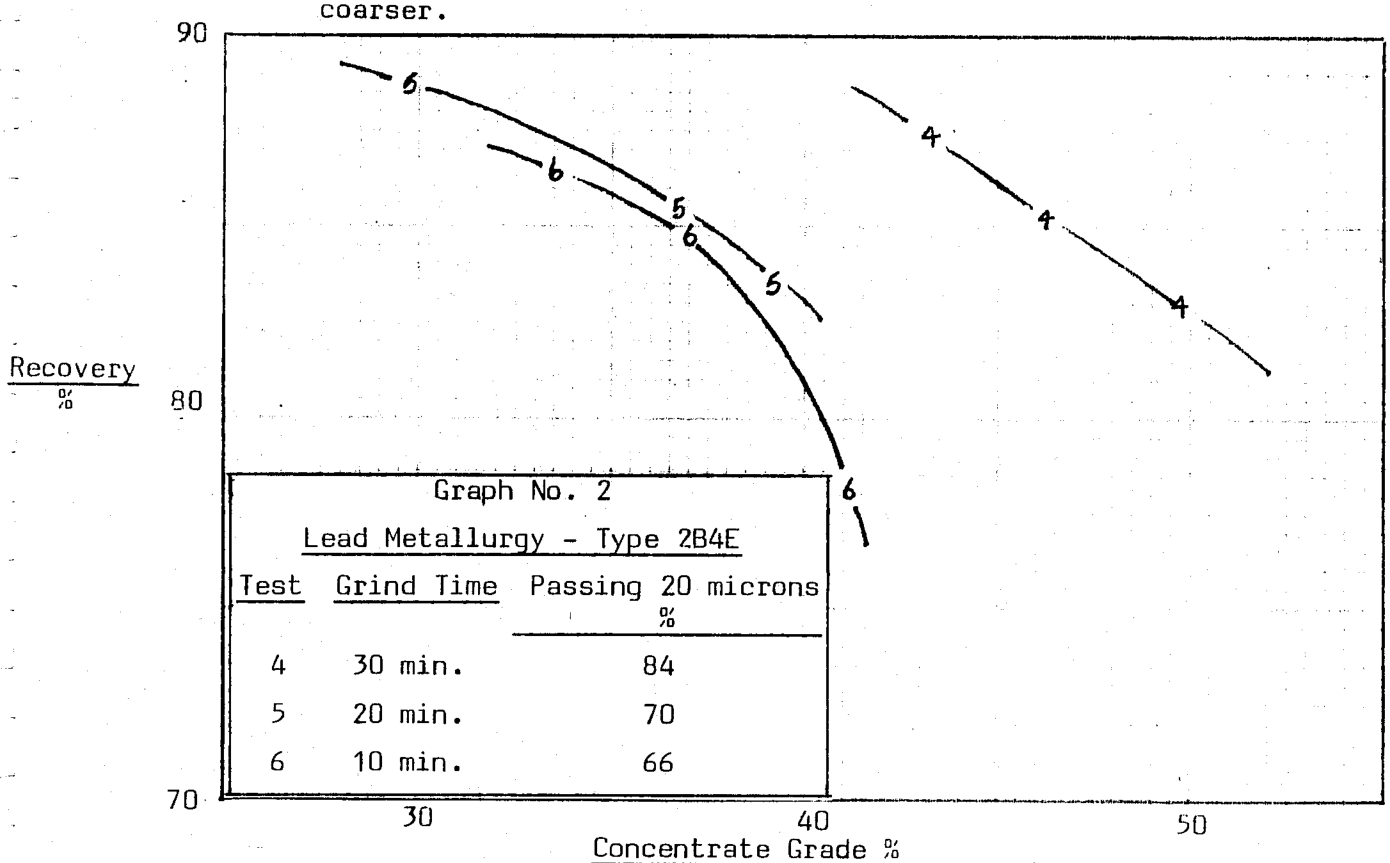
This ore type composed principally of sulphides in a baritic matrix was judged to be the softest available material. Therefore if lead "slime losses" were likely to be a problem. then the problem should manifest itself with this sample.



The data in Graph No. 1 shows quite clearly that, in the range 77-93% passing 20 micrins, lead metallurgy continues to exhibit substantial improvements with finer grinding. The grade recovery curves are essentially parallel and equally spaced, suggesting that even at 96% passing 20 microns this sample is still far removed from the point at which slimes production would interfere with flotation selectivity.

2. Type 2B4E - Pyritic Ore

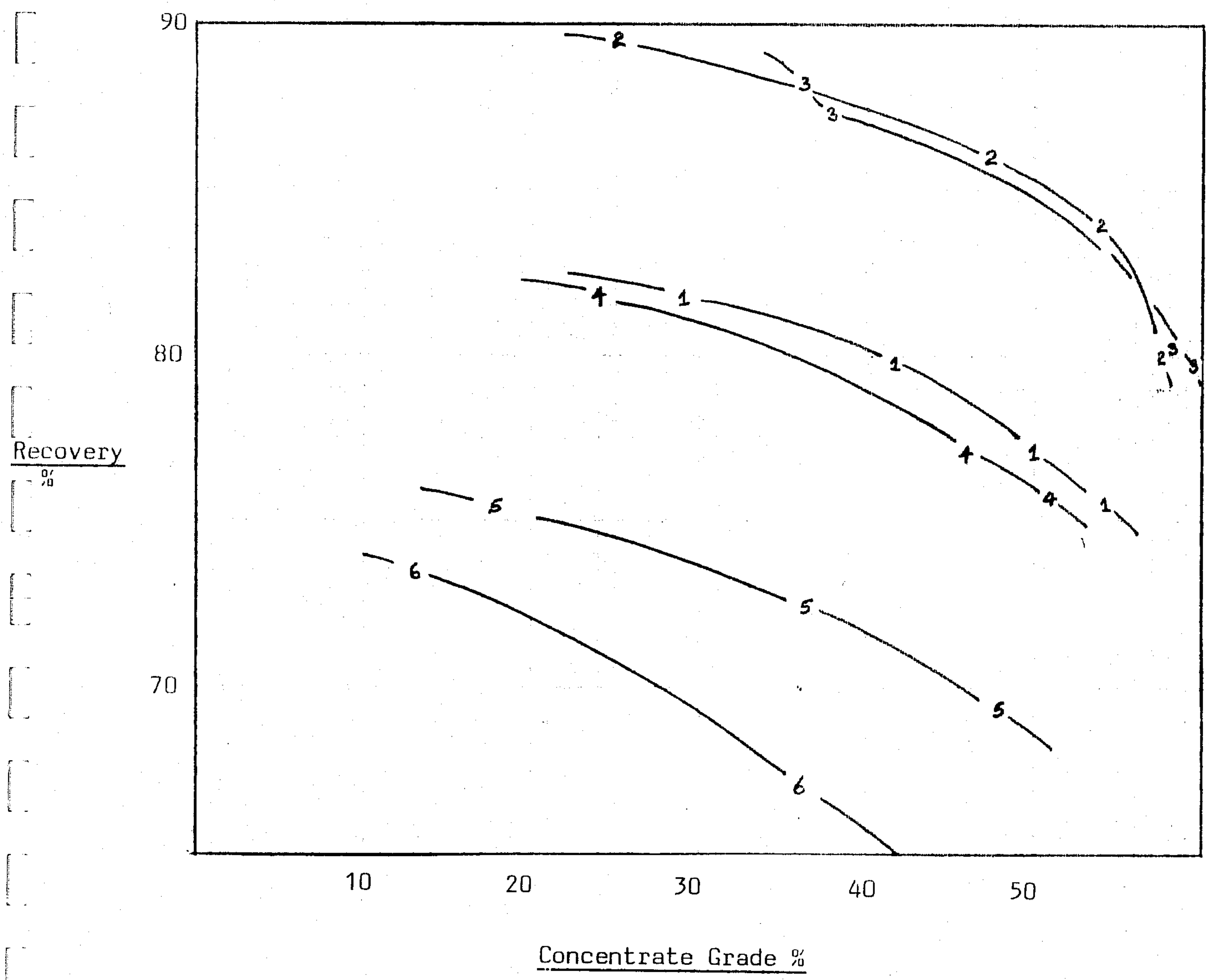
It was anticipated that this ore type, which is composed of lead and zinc sulphides interspersed with moderately large crystals of pyrite, would be quite difficult to reduce to ultrafine sizes. As the data shown below in Graph No. 2 demonstrates this proved to be the case. With equal grind time increments the equivilent grind levels were substantially coarser.



Although this data set lacked the symmetry displayed by Type 1A4G there is still no sign that metallurgy is inhibited by finer grinding in the range 66-84% passing 20 microns.

3. Zinc Metallurgy - Type 1A4G and 2B4E

It is generally accepted that zinc metallurgy continues to improve with finer grinding. As shown in Graph No. 3 both 1A4G and 2B4E exhibit remarkably large increments in metallurgy as fineness of grind increases. Possibly with sample 1A4G the near congruency of data for tests 2 and 3 might suggest that some sort of metallurgical limit has been achieved. In this case that limit may be the maximum grade of the zinc mineral itself.



Graph No. 3

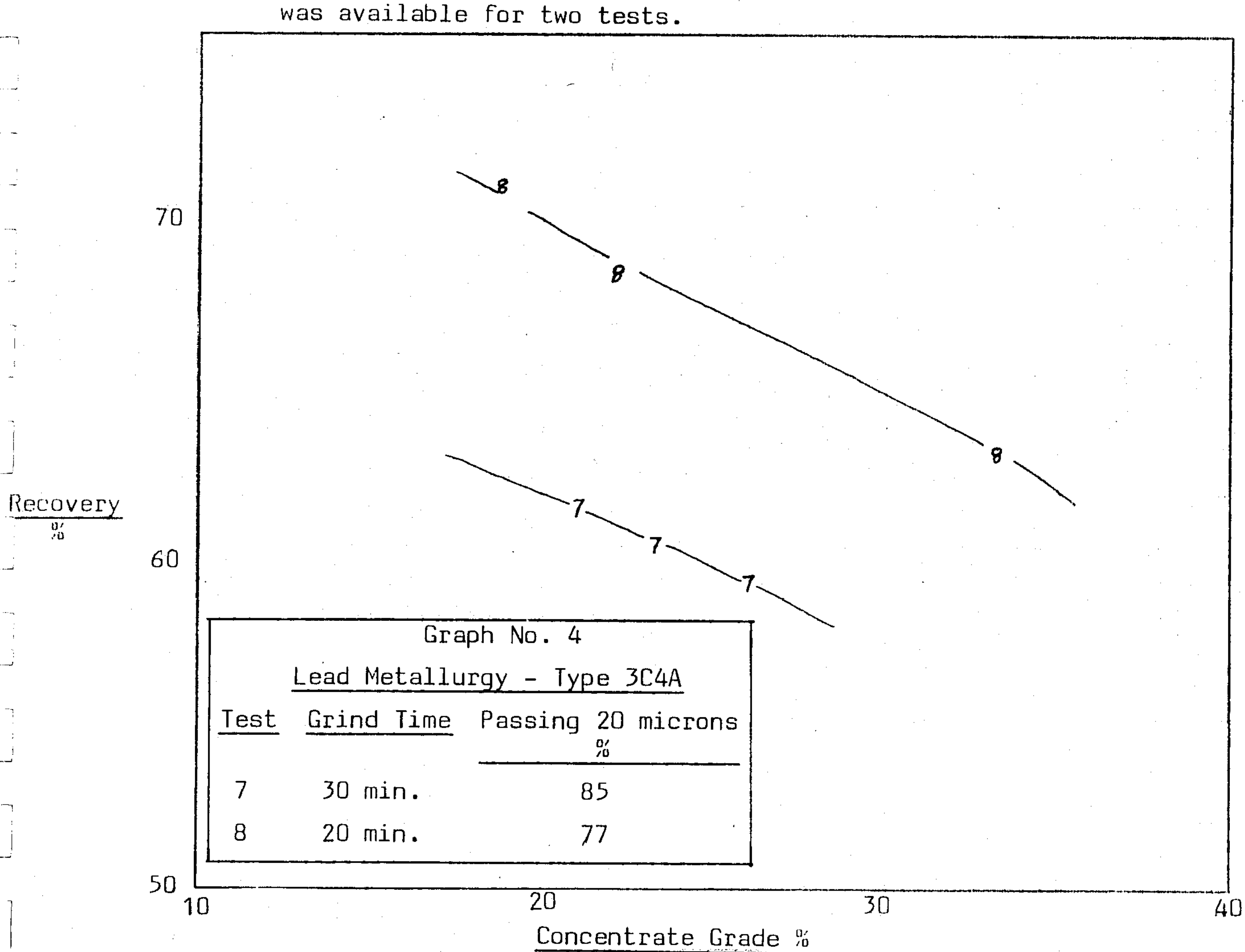
Zinc Metallurgy - Ultrafine Grind

Test	Ore	Grind Time	Passing 20 microns %
1	1A4G	10 min.	77
2	1A4G	20 min.	83
3	1A4G	30 min.	93
4	2B4E	30 min.	84
5	2B4E	20 min.	76
6	2B4E	10 min.	66

4. Type 3C4A - Graphitic Quartzitic

This particular ore type was basically a low grade material rich in graphite and quartzite and low in iron. The presence of the graphite masked the lead float and caused a considerable reagent imbalance compared with a normal test.

As the results show the ore of this type is of approximately the same resistance to grinding as ore type 2B4E. It was unfortunate that only sufficient sample of this ore was available for two tests.

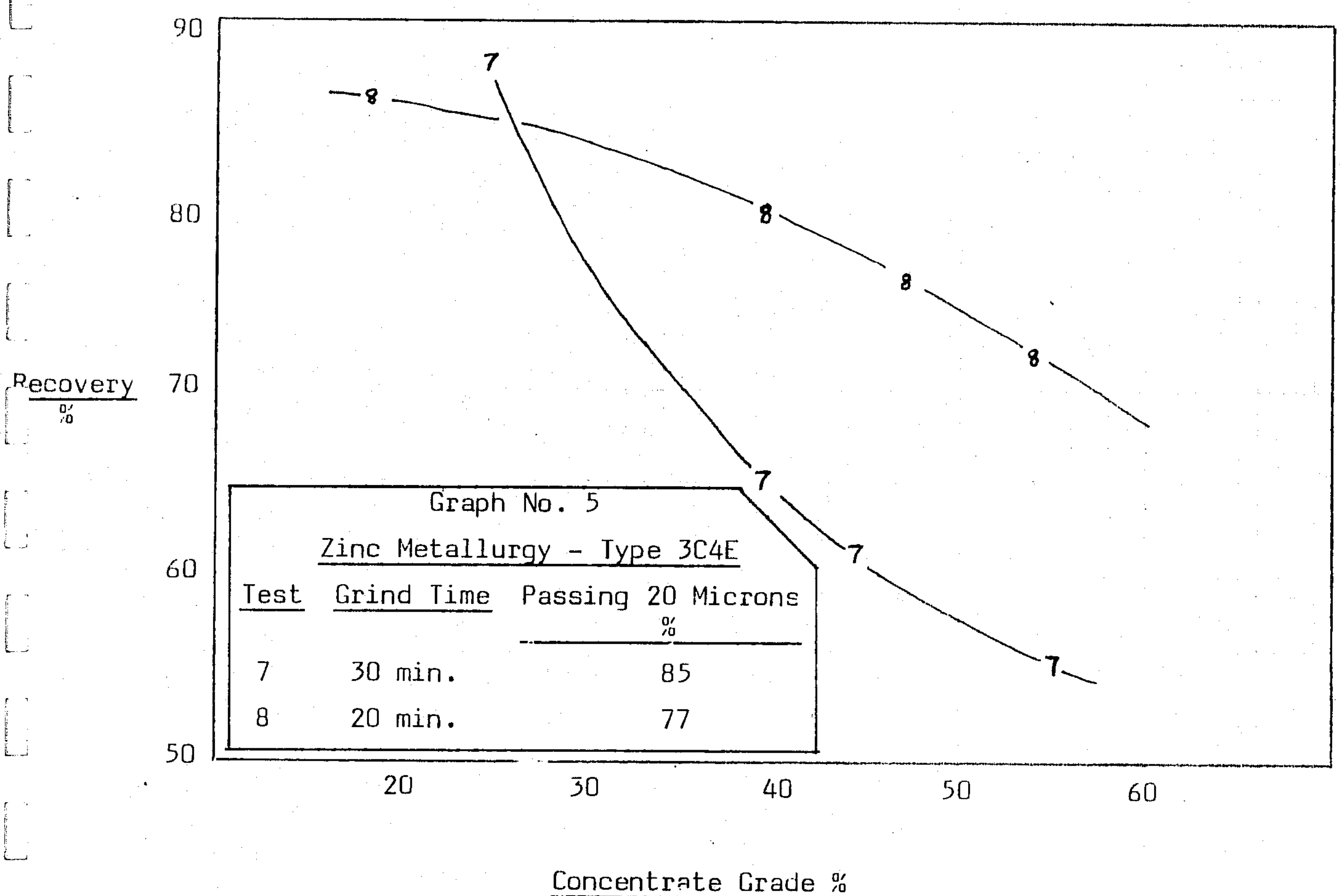


Graph No. 4

Lead Metallurgy - Type 3C4A

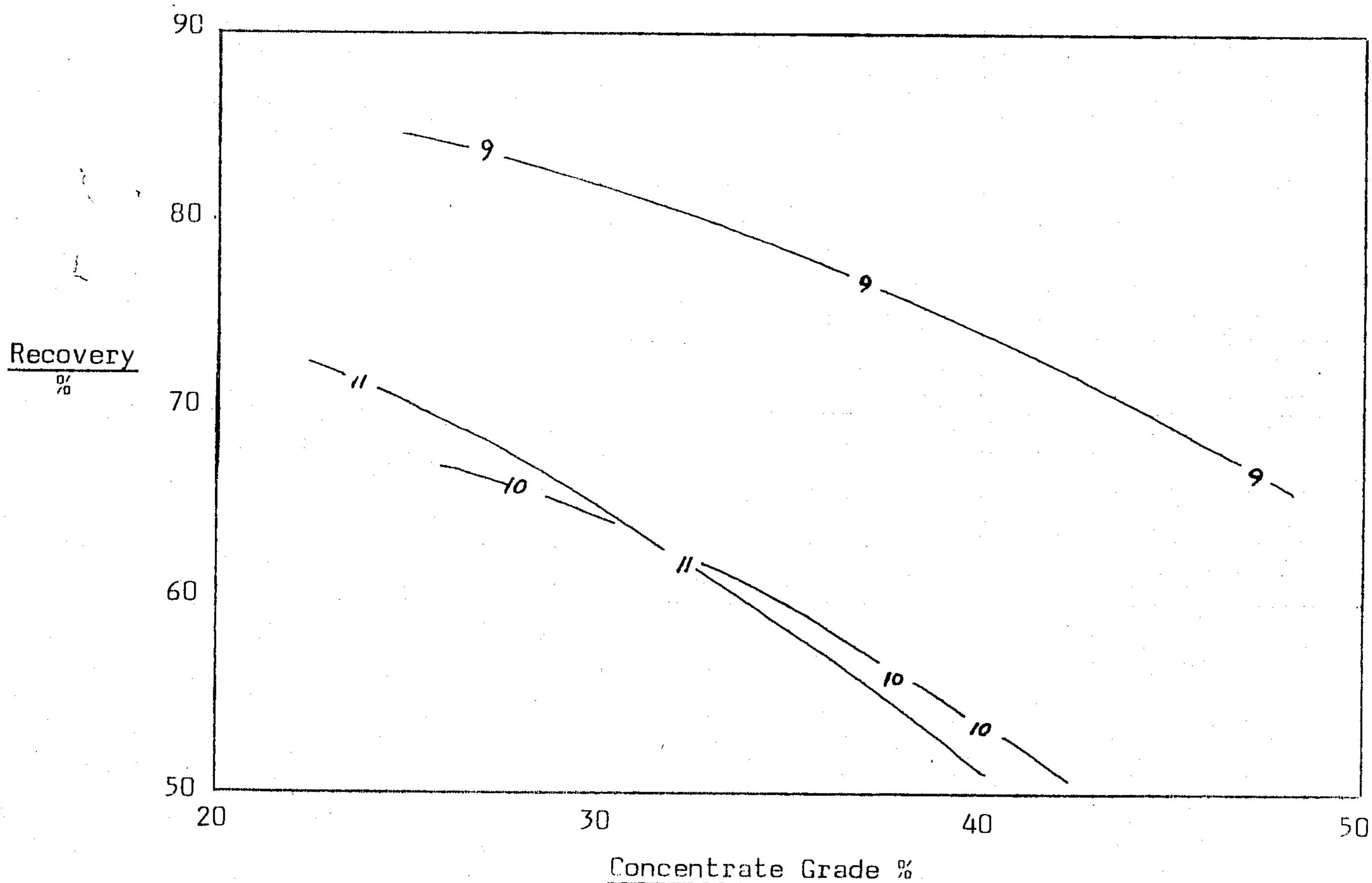
Test	Grind Time	Passing 20 microns %
7	30 min.	85
8	20 min.	77

Both lead and zinc grade recovery curves for this sample show a reversal of the previously noted trends with the coarser grinding providing better metallurgy. However the peculiar sample composition and the skewing of the zinc curves indicate these tests were probably influenced by generally poor flotation conditions which prevailed throughout these tests.



5. Grum Ore Composite

Samples of this ore, provided by Lakefield Research, were somewhat oxidized. The ore was relatively difficult to treat and produce satisfactory concentrate grades. The ore was composed of a blend of ore types with the major components being massive sulphide with quite finely disseminated lead and zinc sulphide.

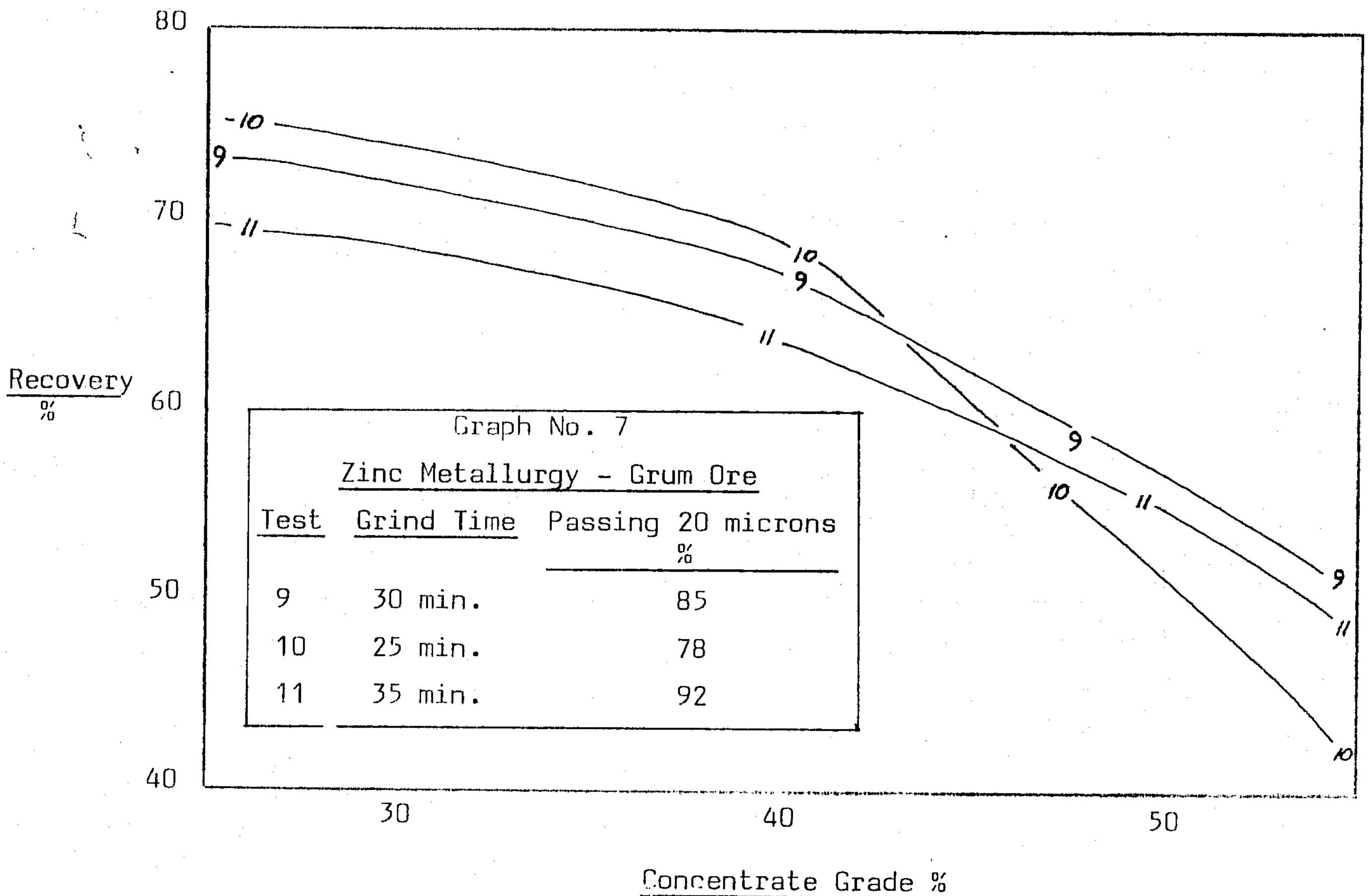


Graph No. 6

Lead Metallurgy - Grum Ore

Test	Grind Time	Passing 20 microns %
9	30 min.	85
10	25 min.	78
11	35 min.	92

From this data it would appear that some sort of optimum is attained at about 85% passing 20 microns in the primary grind. This conclusion is supported by the grade recovery curves for zinc which indicate that at grinds finer than 85% passing 20 microns metallurgical efficiency tends to diminish.



Graph No. 7

Zinc Metallurgy - Grum Ore

Test	Grind Time	Passing 20 microns %
9	30 min.	85
10	25 min.	78
11	35 min.	92

CONCLUSIONS

1. The majority of the data available from this program confirmed earlier results and demonstrated that ultrafine grinding has no deleterious effects on lead and zinc metallurgy. Most results suggested that with very fine priminary grinding, far beyond the capacity of the modified concentrator even when treating the softest ore, metallurgy will continue to improve.

2. The only results, at variance with the above conclusions were derived from two tests performed on an unusually difficult ore type. Possibly the results from these tests were influenced by the poor flotation conditions which prevailed during these tests.

APPENDIX I

DETAILS OF EQUIPMENT USED IN FLOTATION TESTS

APPENDIX I

Details of Equipment Used In Flotation Tests

A. Grinding

Rod Mill	-Steel container 21.5 cm ø x 40.5 cm. Charge 25 kg steel rods approx. 2.0 cm ø.
Ball Mill	-Steel container 21.5 cm ø x 18 cm. Charge 5 kg steel balls - graded charge 0.5 - 3.0 cm ø.
Drive for Mill	-Twin rolls, one drive, one idle. Both 12.5 ø x 122 cm.
	-Motor 0.37 KWH at 1725 RPM full load.
	-Mill speed approximately 80 RPM.

B. Flotation

Denver D2 Flotation Machine	-Used for roughing and scavenger at 1500 RPM with a 5.5 L stainless steel tank.
	-For first cleaner work with a 2.5 L stainless steel tank.
Denver D1 Flotation Machine	-Used for all cleaning stages at 1500 RPM with a 2.5 L stainless steel tank.

C. Instrumentation

Orion Specific Ion Meter 401	-Used for pH control on the rougher and scavenger circuits.
Fisher Digital pH Meter 609	-Used for pH control on the cleaning circuit.
Kalnew 12701 Microscope	-Used for microscopic examination of various minerals.

APPENDIX II

TECHNICAL DETAILS OF FLOTATION TESTS 1 - 11 INCLUSIVE

For each test are shown details of reagents used, essential test parameters, assays, a metallurgical balance and grade recovery data.

TEST NO. 1

PURPOSE: Ultrafine Grind Study

PROCEDURE: Grind Very Fine, Float and Regrind a Lead Concentrate-Clean Three Times. Float, Regrind and Clean a Zinc Concentrate

FEED: 1A4A Vangorda Ore

GRIND:

STAGE	REAGENTS ADDED g/tonne						TIME, MINUTES			pH*	
	Na_2CO_3	NaCN	Z-11	$CuSO_4$	CaO		GRIND	COND.	FROTH	START	FINISH
PRIMARY GRIND	1500	300					10				
LEAD RO/SC			70					2	7	10.4	10.3
LEAD REGRIND	500	200					15				
LEAD 1ST CLEANER			40					2	7	10.5	10.2
LEAD 2ND CLEANER			20					2	5	10.3	9.8
LEAD 3RD CLEANER			10					2	3	10.4	10.2
ZINC CONDITIONING				1000				10		11.0	11.0
ZINC RO/SC			60					2	9	11.0	11.0
ZINC REGRIND				300	500		15				
ZINC 1ST CLEANER			20					2	8	11.5	11.5
ZINC 2ND CLEANER			10					2	5	12.0	11.9
ZINC 3RD CLEANER			5					2	4	12.5	12.4

*Unless otherwise noted - pH values obtained by $Ca(OH)_2$ additions

TEST NO. 2

PURPOSE: Ultrafine Grind Study

PROCEDURE: Grind Very Fine, Float and Regrind a Lead Concentrate-Clean Three Times. Float, Regrind and Clean a Zinc Concentrate

FEED: 1A4G Vangorda Ore

GRIND:

STAGE	REAGENTS ADDED g/tonne						TIME, MINUTES			pH*	
	Na_2CO_3	NaCN	Z-11	$CuSO_4$	CaO		GRIND	COND.	FROTH	START	FINISH
PRIMARY GRIND	1500	300					20				
LEAD RO/SC			80					2	8	10.2	10.0
LEAD REGRIND	500	200					15				
LEAD 1ST CLEANER			50					2	7	10.4	10.1
LEAD 2ND CLEANER			30					2	5	10.4	10.2
LEAD 3RD CLEANER								2	3	10.4	10.3
ZINC CONDITIONING				1000				10		11.0	11.0
ZINC RO/SC			60					2	9	11.0	11.0
ZINC REGRIND				300	500		15				
ZINC 1ST CLEANER			20					2	6	11.5	11.4
ZINC 2ND CLEANER			10					2	5	12.0	11.9
ZINC 3RD CLEANER								2	4	12.5	12.4

*Unless otherwise noted - pH values obtained by $Ca(OH)_2$ additions

TEST NO. 3

PURPOSE: Ultrafine Grind Study

PROCEDURE: Grind Very Fine, Float and Regrind a Lead Concentrate-Clean Three Times. Float, Regrind and Clean a Zinc Concentrate

FEED: 1A4G Vangorda Ore

GRIND:

STAGE	REAGENTS ADDED g/tonne						TIME, MINUTES			pH*	
	Na_2CO_3	NaCN	Z-11	$CuSO_4$	CaO		GRIND	COND.	FROTH	START	FINISH
PRIMARY GRIND	1500	300					30				
LEAD RO/SC			90					2	8	10.4	10.0
LEAD REGRIND	500	200					15				
LEAD 1ST CLEANER			40					2	7	10.5	10.2
LEAD 2ND CLEANER			20					2	5	10.4	10.2
LEAD 3RD CLEANER			10					2	4	10.2	9.8
ZINC CONDITIONING				1000				10		11.0	11.0
ZINC RO/SC			60					2	8	11.0	11.0
ZINC REGRIND				300	500		15				
ZINC 1ST CLEANER			20					2	8	11.5	11.5
ZINC 2ND CLEANER			10					2	5	12.0	11.9
ZINC 3RD CLEANER								2	4	12.5	12.4

*Unless otherwise noted - pH values obtained by $Ca(OH)_2$ additions

TEST NO. 4

PURPOSE: Ultrafine Grind Study

PROCEDURE: Grind Very Fine, Float and Regrind a Lead Concentrate-Clean Three Times. Float, Regrind and Clean a Zinc Concentrate.

FEED: 2B4E Vangorda Ore

GRIND:

STAGE	REAGENTS ADDED g/tonne						TIME, MINUTES			pH*	
	Na_2CO_3	NaCN	Z-11	$CuSO_4$	CaO		GRIND	COND.	FROTH	START	FINISH
PRIMARY GRIND	2500	400					30				
LEAD RO/SC			80					2	10	10.0	9.9
LEAD REGRIND	500	300					15				
LEAD 1ST CLEANER			40					2	9	10.4	10.2
LEAD 2ND CLEANER			10					2	5	10.4	10.3
LEAD 3RD CLEANER								2	4	10.4	10.5
ZINC CONDITIONING				1000				10		11.0	11.0
ZINC RO/SC			60					2	9	11.0	11.0
ZINC REGRIND				300	500		15				
ZINC 1ST CLEANER			20					2	5	11.5	11.5
ZINC 2ND CLEANER								2	3	12.0	12.0
ZINC 3RD CLEANER											

*Unless otherwise noted - pH values obtained by $Ca(OH)_2$ additions

TEST NO. 5

PURPOSE: Ultrafine Grind Study

PROCEDURE: Grind Very Fine, Float and Regrind a Lead Concentrate-Clean Three Times. Float, Regrind and Clean a Zinc Concentrate.

FEED: 2B4E Vangorda Ore.

GRIND:

STAGE	REAGENTS ADDED g/tonne						TIME, MINUTES			pH*	
	Na_2CO_3	NaCN	Z-11	$CuSO_4$	CaO		GRIND	COND.	FROTH	START	FINISH
PRIMARY GRIND	2500	400					20				
LEAD RO/SC			90					2	8	10.0	10.0
LEAD REGRIND	500	300					15				
LEAD 1ST CLEANER			30					2	7	10.4	10.2
LEAD 2ND CLEANER			30					2	5	10.4	10.3
LEAD 3RD CLEANER								2	4	10.4	10.2
ZINC CONDITIONING				1000				10		11.0	11.0
ZINC RO/SC			60					2	9	11.0	11.0
ZINC REGRIND				300	500		15				
ZINC 1ST CLEANER			20					2	5	11.5	11.5
ZINC 2ND CLEANER								2	3	12.1	12.0
ZINC 3RD CLEANER											

*Unless otherwise noted - pH values obtained by $Ca(OH)_2$ additions

TEST NO. 6

PURPOSE: Ultrafine Grind Study

PROCEDURE: Grind Very Fine, Float and Regrind a Lead Concentrate-Clean Three Times. Float, Regrind and Clean a Zinc Concentrate.

FEED: 2B4E Vangorda Ore

GRIND:

STAGE	REAGENTS ADDED g/tonne						TIME, MINUTES			pH*	
	Na_2CO_3	NaCN	Z-11	$CuSO_4$	CaO		GRIND	COND.	FROTH	START	FINISH
PRIMARY GRIND	2500	400					10				
LEAD RO/SC			90					2	8	10.4	10.1
LEAD REGRIND	500	300					15				
LEAD 1ST CLEANER			40					2	6	10.4	10.2
LEAD 2ND CLEANER			10					2	5	10.4	10.5
LEAD 3RD CLEANER								2	4	10.4	10.3
ZINC CONDITIONING				1000				10		11.0	11.0
ZINC RO/SC			40					2	7	11.0	11.0
ZINC REGRIND				300	500		15				
ZINC 1ST CLEANER			20					2	5	11.5	11.5
ZINC 2ND CLEANER			5					2	3	12.0	12.0
ZINC 3RD CLEANER											

*Unless otherwise noted - pH values obtained by $Ca(OH)_2$ additions

TEST NO. 7

PURPOSE: Ultrafine Grind Study

PROCEDURE: Grind Very Fine, Float and Regrind a Lead Concentrate-Clean Three Times. Float, Regrind and Clean a Zinc Concentrate.

FEED: 3C4A Vangorda Ore

GRIND:

STAGE	REAGENTS ADDED g/tonne						TIME, MINUTES			pH*	
	Na_2CO_3	NaCN	Z-11	$CuSO_4$	CaO		GRIND	COND.	FROTH	START	FINISH
PRIMARY GRIND	2000	300					30				
LEAD RO/SC			70					2	9	10.3	10.0
LEAD REGRIND	2000	300					15				
LEAD 1ST CLEANER			20					2	8	10.7	10.5
LEAD 2ND CLEANER			15					2	6	10.5	10.1
LEAD 3RD CLEANER			10					2	3	10.4	10.1
ZINC CONDITIONING				1000				10		11.0	11.0
ZINC RO/SC			50					2	10	11.0	11.0
ZINC REGRIND				300	500		15				
ZINC 1ST CLEANER			20					2	5	11.5	11.5
ZINC 2ND CLEANER			10					2	4	12.0	12.0
ZINC 3RD CLEANER								2	3	12.5	12.5

*Unless otherwise noted - pH values obtained by $Ca(OH)_2$ additions

TEST NO. 8

PURPOSE: Ultafine Grind Study

PROCEDURE: Grind Very Fine, Float and Regrind a Lead Concentrate-Clean Three Times. Float, Regrind and Clean a Zinc Concentrate.

FEED: 3C4A Vangorda Ore

GRIND:

STAGE	REAGENTS ADDED g/tonne						TIME, MINUTES			pH*	
	Na_2CO_3	NaCN	Z-11	$CuSO_4$	CaO		GRIND	COND.	FROTH	START	FINISH
PRIMARY GRIND	2000	300					20				
LEAD RO/SC			80					2	9	10.3	10.1
LEAD REGRIND	2000	300					15				
LEAD 1ST CLEANER			30					2	8	10.9	10.7
LEAD 2ND CLEANER			10					2	5	10.5	10.2
LEAD 3RD CLEANER			5					2	4	10.3	10.2
ZINC CONDITIONING				1000				10		11.0	11.0
ZINC RO/SC			40					2	10	11.0	11.0
ZINC REGRIND											
ZINC 1ST CLEANER			10					2	5	11.5	11.5
ZINC 2ND CLEANER								2	3	12.0	12.0
ZINC 3RD CLEANER								2	3	12.5	12.5

*Unless otherwise noted - pH values obtained by $Ca(OH)_2$ additions

TEST NO. 9

PURPOSE: Fine Grind Effect Study

PROCEDURE: Vary Primary Grind

FEED: Grum Ore

GRIND:

STAGE	REAGENTS ADDED g/tonne						TIME, MINUTES			pH*	
	Na_2CO_3	NaCN	Z-11	$CuSO_4$	CaO		GRIND	COND.	FROTH	START	FINISH
PRIMARY GRIND	2000	150					30				
LEAD RO/SC			100					2	10	9.2	9.0
LEAD REGRIND	1000	100					15				
LEAD 1ST CLEANER			30					2	8	10.3	10.1
LEAD 2ND CLEANER			20					2	5	10.3	10.0
LEAD 3RD CLEANER			10					2	4	10.4	10.3
ZINC CONDITIONING				500				10		11.0	11.0
ZINC RO/SC			100					2	10	11.0	11.0
ZINC REGRIND				150	500		15				
ZINC 1ST CLEANER			30					2	8	11.5	11.5
ZINC 2ND CLEANER			20					2	5	12.0	12.0
ZINC 3RD CLEANER			10					2	4	12.2	12.1

*Unless otherwise noted - pH values obtained by $Ca(OH)_2$ additions

TEST NO. 10

PURPOSE: Fine Grind Effect Study

PROCEDURE: Vary Primary Grind

FEED: Grum Ore

GRIND:

STAGE	REAGENTS ADDED g/tonne						TIME, MINUTES			pH*	
	Na_2CO_3	NaCN	Z-11	$CuSO_4$	CaO		GRIND	COND.	FROTH	START	FINISH
PRIMARY GRIND	2000	150					25				
LEAD RO/SC			100					2	10	9.0	8.5
LEAD REGRIND	1000	100					15				
LEAD 1ST CLEANER			30					2	8	10.3	10.0
LEAD 2ND CLEANER			20					2	5	10.3	10.1
LEAD 3RD CLEANER			20					2	4	10.4	10.1
ZINC CONDITIONING				500				10		11.0	11.0
ZINC RO/SC			100					2	10	11.0	11.0
ZINC REGRIND				150	500		15				
ZINC 1ST CLEANER			30					2	8	11.5	11.5
ZINC 2ND CLEANER			20					2	5	12.0	12.0
ZINC 3RD CLEANER			10					2	4	12.3	12.1

*Unless otherwise noted - pH values obtained by $Ca(OH)_2$ additions

TEST NO. 11

PURPOSE: Fine Grind Effect Study

PROCEDURE: Vary Primary Grind

FEED: Grum Ore

GRIND:

STAGE	REAGENTS ADDED g/tonne						TIME, MINUTES			pH*	
	Na_2CO_3	NaCN	Z-11	$CuSO_4$	CaO		GRIND	COND.	FROTH	START	FINISH
PRIMARY GRIND	2000	150					35				
LEAD RO/SC			100					2	10	9.3	8.5
LEAD REGRIND	1000	100					15				
LEAD 1ST CLEANER			30					2	8	10.2	10.0
LEAD 2ND CLEANER			20					2	5	10.3	10.2
LEAD 3RD CLEANER											
ZINC CONDITIONING				500				10		11.0	11.0
ZINC RO/SC			100					2	10	11.0	11.0
ZINC REGRIND				150	500		15				
ZINC 1ST CLEANER			30					2	8	11.5	11.5
ZINC 2ND CLEANER			20					2	5	12.0	12.0
ZINC 3RD CLEANER			10					2	4	12.3	12.2

*Unless otherwise noted - pH values obtained by $Ca(OH)_2$ additions

TEST: 1

PRODUCT	WEIGHT	ASSAYS %				DISTRIBUTION			
	%	Pb	Zn			Pb	Zn		
Pb Cleaner Conc 3	6.09	49.13	17.81			78.55	14.47		
Pb Cleaner Tail 3	0.62	26.53	15.38			4.35	1.28		
Pb Cleaner Tail 2	0.64	16.41	12.10			2.75	1.03		
Zn Cleaner Conc 3	10.43	1.32	54.35			3.62	75.65		
Zn Cleaner Tail 3	1.10	2.99	9.58			0.87	1.41		
Zn Cleaner Tail 2	2.75	3.82	7.97			2.76	2.93		
Zn Cleaner Tail 1	7.05	1.72	1.92			3.18	1.81		
Tails	71.31	0.21	0.15			3.93	1.43		
CALCULATED HEAD	100.0	3.81	7.50			100.0	100.0		

TEST: 2

PRODUCT	WEIGHT	ASSAYS %				DISTRIBUTION			
	%	Pb	Zn			Pb	Zn		
Pb Cleaner Conc 3	5.22	56.30	14.00			81.80	9.28		
Pb Cleaner Tail 3	0.23	23.07	16.69			1.46	0.48		
Pb Cleaner Tail 2	0.28	16.85	13.19			1.30	0.46		
Zn Cleaner Conc 3	10.98	1.16	57.56			3.54	80.24		
Zn Cleaner Tail 3	1.29	6.36	23.81			2.29	3.90		
Zn Cleaner Tail 2	2.11	3.21	7.44			1.89	2.00		
Zn Cleaner Tail 1	13.50	1.27	1.63			4.77	2.79		
Tails	66.39	0.16	0.10			2.95	0.84		
CALCULATED HEAD	100.0	3.59	7.88			100.0	100.0		

TEST: 3

PRODUCT	WEIGHT	ASSAYS %				DISTRIBUTION			
	%	Pb	Zn			Pb	Zn		
Pb Cleaner Conc 3	5.04	63.04	11.60			85.19	7.56		
Pb Cleaner Tail 3	0.39	18.82	17.59			1.97	0.89		
Pb Cleaner Tail 2	0.56	13.91	15.56			2.10	1.13		
Zn Cleaner Conc 3	10.36	0.80	59.18			2.22	79.38		
Zn Cleaner Tail 3	0.48	3.34	12.13			0.43	0.75		
Zn Cleaner Tail 2	7.23	1.68	7.02			3.26	7.32		
Zn Cleaner Tail 1	0.83	2.66	9.49			0.59	1.02		
Tails	75.10	0.21	0.20			4.23	1.94		
CALCULATED HEAD	100.0	3.73	7.73			100.0	100.0		

TEST: 4

PRODUCT	WEIGHT	ASSAYS %				DISTRIBUTION			
	%	Pb	Zn			Pb	Zn		
Pb Cleaner Conc 3	7.09	49.91	6.04			83.14	9.99		
Pb Cleaner Tail 3	0.83	16.01	8.83			3.12	1.71		
Pb Cleaner Tail 2	0.72	8.05	8.99			1.37	1.52		
Zn Cleaner Conc 2	6.31	1.23	51.65			1.82	75.98		
Zn Cleaner Tail 2	0.90	2.28	5.77			0.48	1.22		
Zn Cleaner Tail 1	7.45	1.43	3.26			2.50	5.66		
Tails	76.69	0.42	0.22			7.56	3.99		
CALCULATED HEAD	100.0	4.26	4.29			100.0	100.0		

TEST: 5

PRODUCT	WEIGHT %	ASSAYS % Pb	Zn			DISTRIBUTION Pb	Zn		
Pb Cleaner Conc 3	9.26	39.19	7.20			83.71	15.16		
Pb Cleaner Tail 3	1.09	6.67	7.87			1.68	1.96		
Pb Cleaner Tail 2	2.50	5.85	7.59			3.37	4.31		
Zn Cleaner Conc 2	6.34	1.50	47.76			2.19	68.87		
Zn Cleaner Tail 2	2.36	2.14	6.51			1.16	3.49		
Zn Cleaner Tail 1	10.02	0.82	1.43			1.89	3.26		
Tails	68.43	0.38	0.19			6.00	2.96		
CALCULATED HEAD	100.0	4.34	4.40			100.0	100.0		

TEST: 6

PRODUCT	WEIGHT %	ASSAYS % Pb	Zn			DISTRIBUTION Pb	Zn		
Pb Cleaner Conc 3	8.47	44.34	7.59			79.11	15.25		
Pb Cleaner Tail 3	1.67	19.00	9.33			6.69	3.70		
Pb Cleaner Tail 2	1.48	5.02	8.04			1.56	2.82		
Zn Cleaner Conc 2	5.98	1.21	44.98			1.52	63.78		
Zn Cleaner Tail 2	1.89	1.80	7.55			0.72	3.38		
Zn Cleaner Tail 1	16.23	0.98	1.69			3.35	6.50		
Tails	64.28	0.52	0.30			7.04	4.57		
CALCULATED HEAD	100.0	4.75	4.22			100.0	100.0		

TEST: 7

PRODUCT	WEIGHT %	ASSAYS % Pb	Zn	Fe		DISTRIBUTION Pb	Zn	Fe	
Pb Cleaner Conc 3	6.13	25.50	4.51	5.14		58.98	5.83	2.85	
Pb Cleaner Tail 3	0.74	3.57	4.14	5.29		1.00	0.65	0.36	
Pb Cleaner Tail 2	0.89	5.80	4.34	8.13		1.96	0.82	0.66	
Zn Cleaner Conc 3	4.89	1.20	54.70	7.10		2.22	56.50	3.15	
Zn Cleaner Tail 3	1.66	3.03	14.54	8.58		1.90	5.10	1.29	
Zn Cleaner Tail 2	1.36	5.00	13.03	12.93		2.56	3.73	1.59	
Zn Cleaner Tail 1	9.88	4.05	11.02	13.56		15.09	22.97	12.12	
Tails	74.45	0.58	0.28	11.57		16.29	4.40	77.99	
CALCULATED HEAD	100.0	2.65	4.74	11.04		100.0	100.0	100.0	

TEST: 8

PRODUCT	WEIGHT %	ASSAYS % Pb	Zn	Fe		DISTRIBUTION Pb	Zn	Fe	
Pb Cleaner Conc 3	4.48	33.79	4.54	5.89		62.69	4.46	2.43	
Pb Cleaner Tail 3	2.92	4.41	5.29	8.32		5.32	3.38	2.23	
Pb Cleaner Tail 2	1.68	3.62	4.94	8.66		2.51	1.81	1.34	
Zn Cleaner Conc 3	6.10	1.39	53.84	7.13		3.51	71.97	4.01	
Zn Cleaner Tail 3	1.24	4.45	15.77	10.53		2.29	4.30	1.21	
Zn Cleaner Tail 2	1.72	3.88	8.31	18.70		2.77	3.14	2.97	
Zn Cleaner Tail 1	12.77	1.52	2.56	24.69		8.03	7.16	29.04	
Tails	69.09	0.45	0.25	8.92		12.87	3.78	56.77	
CALCULATED HEAD	100.0	2.42	4.57	10.85		100.0	100.0	100.0	

TEST: 9

PRODUCT	WEIGHT	ASSAYS %				DISTRIBUTION			
	%	Pb	Zn	Fe		Pb	Zn	Fe	
Pb Cleaner Conc 3	6.73	47.27	10.77	10.73		67.64	8.03	3.80	
Pb Cleaner Tail 3	3.08	14.18	14.56	23.96		9.28	4.96	3.88	
Pb Cleaner Tail 2	4.81	6.92	14.99	26.82		7.08	7.98	6.78	
Zn Cleaner Conc 3	8.46	1.09	54.70	6.57		1.96	51.22	2.92	
Zn Cleaner Tail 3	2.64	1.79	25.63	8.44		1.00	7.49	1.17	
Zn Cleaner Tail 2	3.91	2.84	19.13	20.28		2.36	8.29	4.17	
Zn Cleaner Tail 2	12.98	2.01	4.48	27.00		5.55	6.44	18.43	
Tails	57.39	0.42	0.88	19.50		5.12	5.59	58.85	
CALCULATED HEAD	100.0	4.70	9.03	19.02		100.0	100.0	100.0	

TEST: 10

PRODUCT	WEIGHT	ASSAYS %				DISTRIBUTION			
	%	Pb	Zn	Fe		Pb	Zn	Fe	
Pb Cleaner Conc 3	6.17	40.09	12.09	13.81		53.58	8.38	4.34	
Pb Cleaner Tail 3	0.70	17.66	12.83	19.67		2.68	1.01	0.70	
Pb Cleaner Tail 2	4.12	11.21	13.10	25.73		10.02	6.07	5.40	
Zn Cleaner Conc 3	6.80	1.79	54.80	6.03		2.64	41.88	2.09	
Zn Cleaner Tail 3	3.93	3.58	34.26	6.10		3.05	15.15	1.22	
Zn Cleaner Tail 2	4.12	6.44	25.08	15.91		5.76	11.62	3.34	
Zn Cleaner Tail 1	10.68	3.74	5.51	24.53		8.66	6.62	13.34	
Tails	63.46	0.99	1.30	21.53		13.61	9.27	69.57	
CALCULATED HEAD	100.0	4.61	8.90	19.64		100.0	100.0	100.0	

TEST: 11

PRODUCT	WEIGHT	ASSAYS %				DISTRIBUTION			
	%	Pb	Zn	Fe		Pb	Zn	Fe	
Pb Cleaner Conc 3	4.89	44.54	10.58	11.07		46.23	5.80	2.70	
Pb Cleaner Tail 3	4.12	17.78	15.10	22.70		15.54	6.96	4.65	
Pb Cleaner Tail 2	5.57	8.31	15.77	24.31		9.81	9.83	6.73	
Zn Cleaner Conc 3	7.97	1.54	54.90	6.25		2.60	48.99	2.48	
Zn Cleaner Tail 3	2.09	4.91	28.10	10.11		2.18	6.58	1.05	
Zn Cleaner Tail 2	4.16	5.64	16.86	18.10		4.97	7.85	3.74	
Zn Cleaner Tail 1	9.69	3.50	5.67	22.24		7.19	6.15	10.72	
Tails	61.50	0.88	1.14	22.20		11.48	7.85	67.92	
CALCULATED HEAD	100.0	4.72	8.94	20.10		100.0	100.0		

APPENDIX III

ANDREASEN PIPET PROCEDURES & RESULTS OF SUB-SEIVE SIZING

In this appendix are to be found details of the Andreasen Pipet procedures and the results of sub-seive sizing on the tailings samples from the laboratory tests.

Table III - 1 is a summary of all pertinent data.

TABLE III - 1

Ultrafine Particle Sizing - KM022

Test No.	Grind Time minutes	Passing 20 microns %
1	10	77
2	20	83
3	30	93
4	30	84
5	20	76
6	10	66
7	30	85
8	20	77
9	30	85
10	25	78
11	35	92

ANDREASEN SEDIMENTATION PIPET

The Andreasen Sedimentation Pipet is used for the determination of sub-seive grain sizes according to Stokes' Law. From the data collected a characteristic curve for the material under study also may be plotted to determine the percentage by weight of any grain size in the sample. The apparatus is not practical for separations by gravity below 0.5 microns because of the time required and because Stokes' Law becomes inoperative. The Andreasen Method is correct within 2 to 5%.

Procedure

1. Weigh out sufficient sample so that on dilution in the sedimentation vessel--to the 20 cm graduation mark (550 ml) --the concentration would be about 1% by volume.

2. On a separate sample determine the moisture content to correct to the true powder weight.

3. Make up the suspension in the selected medium, using a technique which will give reproducible results with as high a degree of dispersion as possible.

4. Transfer the dispersed sample to the sedimentation vessel, and adjust the volume to the 20 cm mark with distilled water.

5. Insert the stopper carrying the pipet and place the apparatus in a constant temperature bath for 15 to 30 minutes.

6. After the apparatus has come to the temperature of the bath, remove it, cover the small vent in the stopper with a finger and shake the apparatus by hand for 2 minutes.

7. Note the exact time that shaking was stopped and replace the apparatus in the bath.

8. Take the first sample immediately by drawing 10 ml up into the pipet bulb with aspirator suction at a slow rate. A reasonably sampling time would be 20 seconds.

9. Drain the sample rapidly into a weighing vessel, dry and weigh. The weight of the first sample gives the initial powder weight.

10. Withdraw later samples at successive time intervals. Withdraw all samples at the same rate and record the time at which the sample was taken.

11. Dry and weigh all samples.

Calculations

1. The grain sizes are calculated from Stokes' Law according to the falling velocity of the particles. Each sample drawn has a smaller size of grain that that corresponding to the falling velocity because all particles of large size will have fallen below the level of the pipet tip. Stokes' Law may be expressed as follows:

$$r = \sqrt{\frac{9\ hn}{2\ (D_1 - D_2)\ gt}}$$

Where r = radius of spherical particles (cm)
n = viscosity of suspending medium (poises)
h = distance between liquid surface and pipet tip when sample is drawn (cm).
D_1 = true specific gravity of particles
D_2 = true specific gravity of suspending medium
g = gravitation constant
t = time from start of test (sec.)

2. From the weight of the dried samples, calculate the percentages by weight of the original sample.

3. Plot the results in a smooth curve with grain size as the abscissae and percentage by weight as the ordinate. From this basic curve, the percentage by weight of any graing size in the sample may be obtained.

SUB-SIEVE ANALYSIS

Andreasen Sedimentation Pipet

Identification: KM022 - 1

Sample Weight: 20 g

Specific Gravity of Sample: D_1 4.68

Specific Gravity of Distilled Water @20°C: D_2 .9982

Viscosity of Water @20°C: .01002 poise

Settling time t - sec	Pipet Depth h - cm	Paricle radius r - um	Withdrawn Sample Wt. g	Weight % total sample
0	-	-	0.3287	-
90	19.2	16.2	0.2283	69.5
180	18.7	11.3	0.0346	10.5
300	18.3	8.7	0.0100	3.0

$$r = 1 \times 10^4 \sqrt{\frac{9\,hn}{2(D_1-D_2)\,gt}}$$

SUB-SIEVE ANALYSIS

Andreasen Sedimentation Pipet

Identification: KM022 - 2

Sample Weight: 20 g

Specific Gravity of Sample: D_1 4.32

Specific Gravity of Distilled Water @20^{o}C: D_2 .9982

Viscosity of Water @20^{o}C: .01002 poise

Settling time t - sec	Pipet Depth h - cm	Paricle radius r - um	Withdrawn Sample Wt. g	Weight % total sample
0	-	-	0.3490	-
90	19.2	17.8	0.2694	77.2
180	18.7	11.9	0.0342	9.8
300	18.3	9.1	0.0092	2.6

$$r = 1 \times 10^4 \sqrt{\frac{9\ hn}{2(D_1-D_2)\ gt}}$$

SUB-SIEVE ANALYSIS

Andreasen Sedimentation Pipet

Identification: KM022 - 3

Sample Weight: 20 g

Specific Gravity of Sample: D_1 4.24

Specific Gravity of Distilled Water @20°C: D_2 .9982

Viscosity of Water @20°C: .01002 poise

Settling time t - sec	Pipet Depth h - cm	Paricle radius r - um	Withdrawn Sample Wt. g	Weight % total sample
0	-	-	0.3189	-
90	19.2	17.3	0.2844	89.2
180	18.7	12.1	0.0382	12.0
300	18.3	9.2	0.0111	3.5

$$r = 1 \times 10^4 \sqrt{\frac{9\ hn}{2(D_1 - D_2)\ gt}}$$

SUB-SIEVE ANALYSIS

Andreasen Sedimentation Pipet

Identification: KM022 - 4

Sample Weight: 20 g

Specific Gravity of Sample: D_1 4.28

Specific Gravity of Distilled Water @20°C: D_2 .9982

Viscosity of Water @20°C: .01002 poise

Settling time t - sec	Pipet Depth h - cm	Paricle radius r - um	Withdrawn Sample Wt. g	Weight % total sample
0	-	-	0.3176	-
90	19.2	17.2	0.1717	54.1
180	18.7	12.0	0.0282	8.9
300	18.3	9.2	0.0099	3.1

$$r = 1 \times 10^4 \sqrt{\frac{9\ hn}{2(D_1 - D_2)\ gt}}$$

SUB-SIEVE ANALYSIS

Andreasen Sedimentation Pipet

Identification: KM022 - 5

Sample Weight: 20 g

Specific Gravity of Sample: D_1 4.18

Specific Gravity of Distilled Water @20°C: D_2 .9982

Viscosity of Water @20°C: .01002 poise

Settling time t - sec	Pipet Depth h - cm	Paricle radius r - um	Withdrawn Sample Wt. g	Weight % total sample
0	-	-	0.3001	-
90	19.2	17.5	0.1800	59.9
180	18.7	12.2	0.0300	10.0
300	18.3	9.3	0.0107	3.6

$$r = 1 \times 10^4 \sqrt{\frac{9\,h\eta}{2(D_1-D_2)\,gt}}$$

SUB-SIEVE ANALYSIS

Andreasen Sedimentation Pipet

Identification: KM022 - 6

Sample Weight: 20 g

Specific Gravity of Sample: D_1 4.04

Specific Gravity of Distilled Water @20°C: D_2 .9982

Viscosity of Water @20°C: .01002 poise

Settling time t - sec	Pipet Depth h - cm	Paricle radius r - um	Withdrawn Sample Wt. g	Weight % total sample
0	-	-	0.2770	-
90	19.2	17.8	0.1780	64.3
180	18.7	12.5	0.0558	20.1
300	18.3	9.5	0.0143	5.2

$$r = 1 \times 10^4 \sqrt{\frac{9\,hn}{2(D_1-D_2)\,gt}}$$

SUB-SEIVE ANALYSIS

Andreasen Sedimentation Pipet

Identification: KM022 - 7

Sample Weight: 20 g

Specific Gravity of Sample: D_1 3.00

Specific Gravity of Distilled Water @20°C: D_2 .9982

Viscosity of Water @20°C: .01002 poise

Settling time t - sec	Pipet Depth h - cm	Particle radius r - um	Withdrawn Sample Wt g	Weight % -44μ sample	Weight % ttl sample
0	-	-	0.3514	-	
90	19.2	22	0.3210	91.4	86.3
180	18.7	15	0.2181	62.1	58.7
300	18.3	12	0.0184	52.2	5.0

$$r = 1 \times 10^4 \sqrt{\frac{9\,hn}{2\,(D_1-D_2)\,gt}}$$

SUB-SEIVE ANALYSIS

Andreasen Sedimentation Pipet

Identification: KH022 - 8

Sample Weight: 20 g

Specific Gravity of Sample: D_1 3.00

Specific Gravity of Distilled Water @20°C: D_2 .9982

Viscosity of Water @20°C: .01002 poise

Settling time t - sec	Pipet Depth h - cm	Particle radius r - um	Withdrawn Sample Wt g	Weight % -44µ sample	Weight % ttl sample
0	-	-	0.3467	-	-
90	19.2	22	0.3186	91.9	78.8
180	18.7	15	0.2172	62.7	53.7
300	18.3	12	0.0236	6.8	5.8

$$r = 1 \times 10^4 \sqrt{\frac{9\ hn}{2\ (D_1 - D_2)\ gt}}$$

SUB-SEIVE ANALYSIS

Andreasen Sedimentation Pipet

Identification: KHU22 - 9

Sample Weight: 20 g

Specific Gravity of Sample: D_1 3.45

Specific Gravity of Distilled Water @20°C: D_2 .9982

Viscosity of Water @20°C: .01002 poise

Settling time t - sec	Pipet Depth h - cm	Particle radius r - um	Withdrawn Sample Wt g	Weight % -44μ sample	Weight % ttl sample
0	-	-	0.3459	-	-
90	19.2	20	0.3097	89.5	86.5
180	18.7	14	0.0537	15.5	15.0
300	18.3	11	0.0120	3.5	3.4

$$r = 1 \times 10^4 \sqrt{\frac{9\ hn}{2\ (D_1 - D_2)\ gt}}$$

SUB-SEIVE ANALYSIS

Andreasen Sedimentation Pipet

Identification: KM022 - 10

Sample Weight: 20 g

Specific Gravity of Sample: D_1 3.45

Specific Gravity of Distilled Water @20°C: D_2 .9982

Viscosity of Water @20°C: .01002 poise

Settling time t - sec	Pipet Depth h - cm	Particle radius r - um	Withdrawn Sample Wt g	Weight % -44μ sample	Weight % ttl sample
0	-	-	0.3333	-	-
90	19.2	20	0.2691	80.7	76.2
180	18.7	14	0.0426	12.8	12.1
300	18.3	11	0.0101	3.0	2.9

$$r = 1 \times 10^4 \sqrt{\frac{9\ hn}{2\ (D_1 - D_2)\ gt}}$$

SUB-SEIVE ANALYSIS

Andreasen Sedimentation Pipet

Identification: KM022 - 11

Sample Weight: 20 g

Specific Gravity of Sample: D_1 2.07

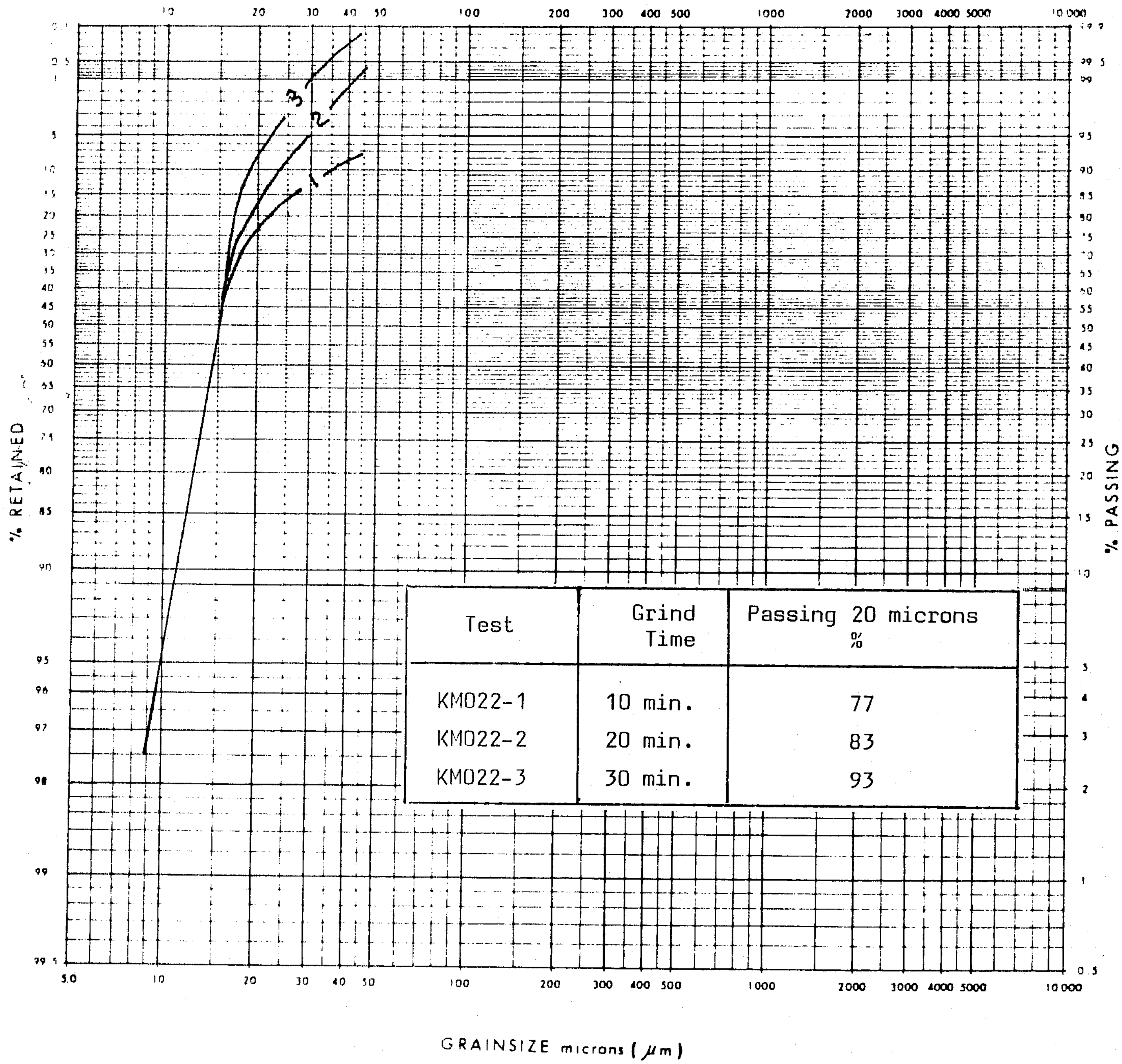
Specific Gravity of Distilled Water @20°C: D_2 .9982

Viscosity of Water @20°C: .01002 poise

Settling time t - sec	Pipet Depth h - cm	Particle radius r - um	Withdrawn Sample Wt g	Weight % -44µ sample	Weight % ttl sample
0	-	-	0.3443	-	-
90	19.2	20	0.3132	90.9	-
180	18.7	14	0.0431	12.5	-
300	18.3	11	0.0099	2.9	-

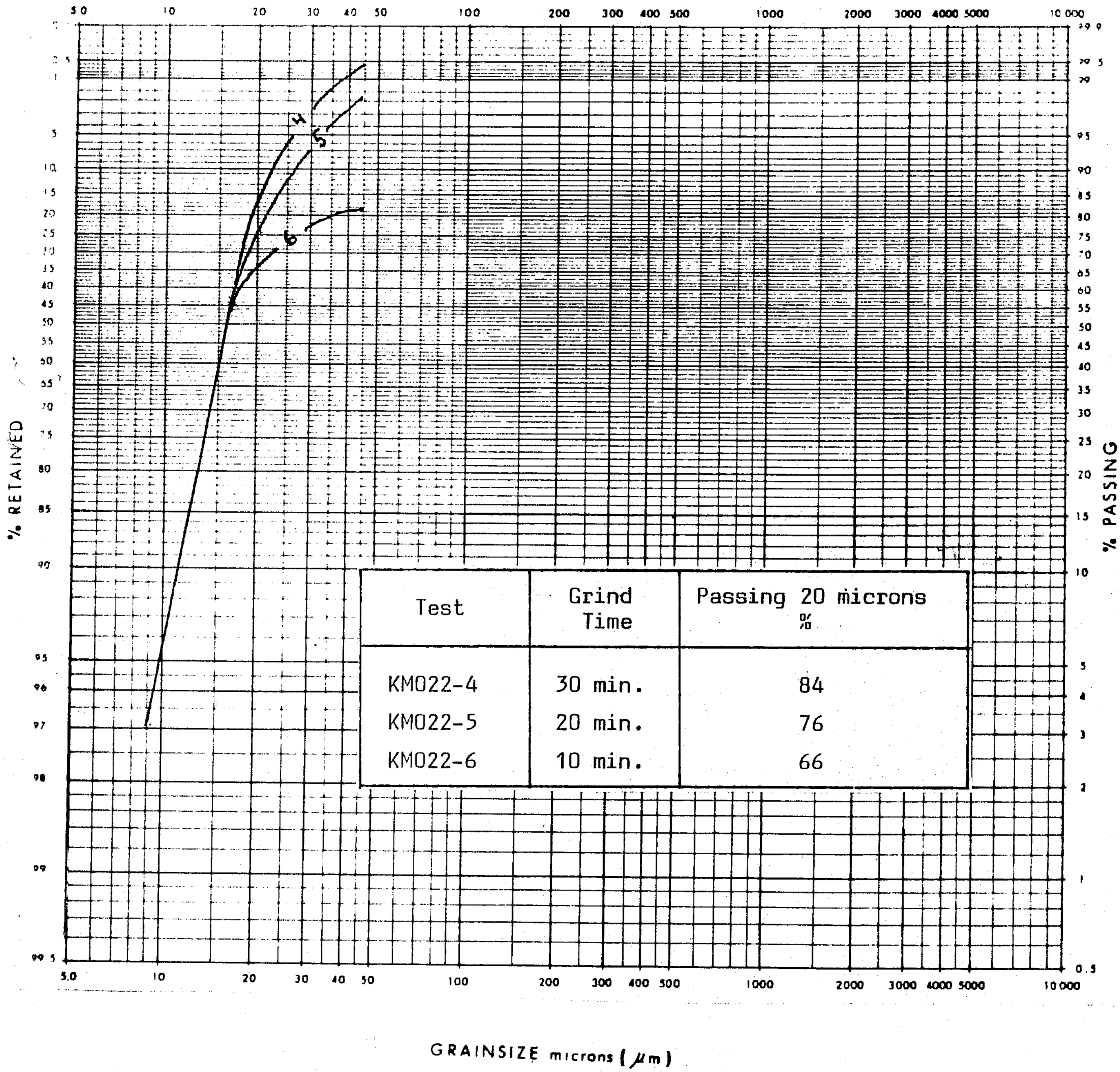
$$r = 1 \times 10^4 \sqrt{\frac{9\ hn}{2\ (D_1-D_2)\ gt}}$$

SIZE DISTRIBUTION CURVE



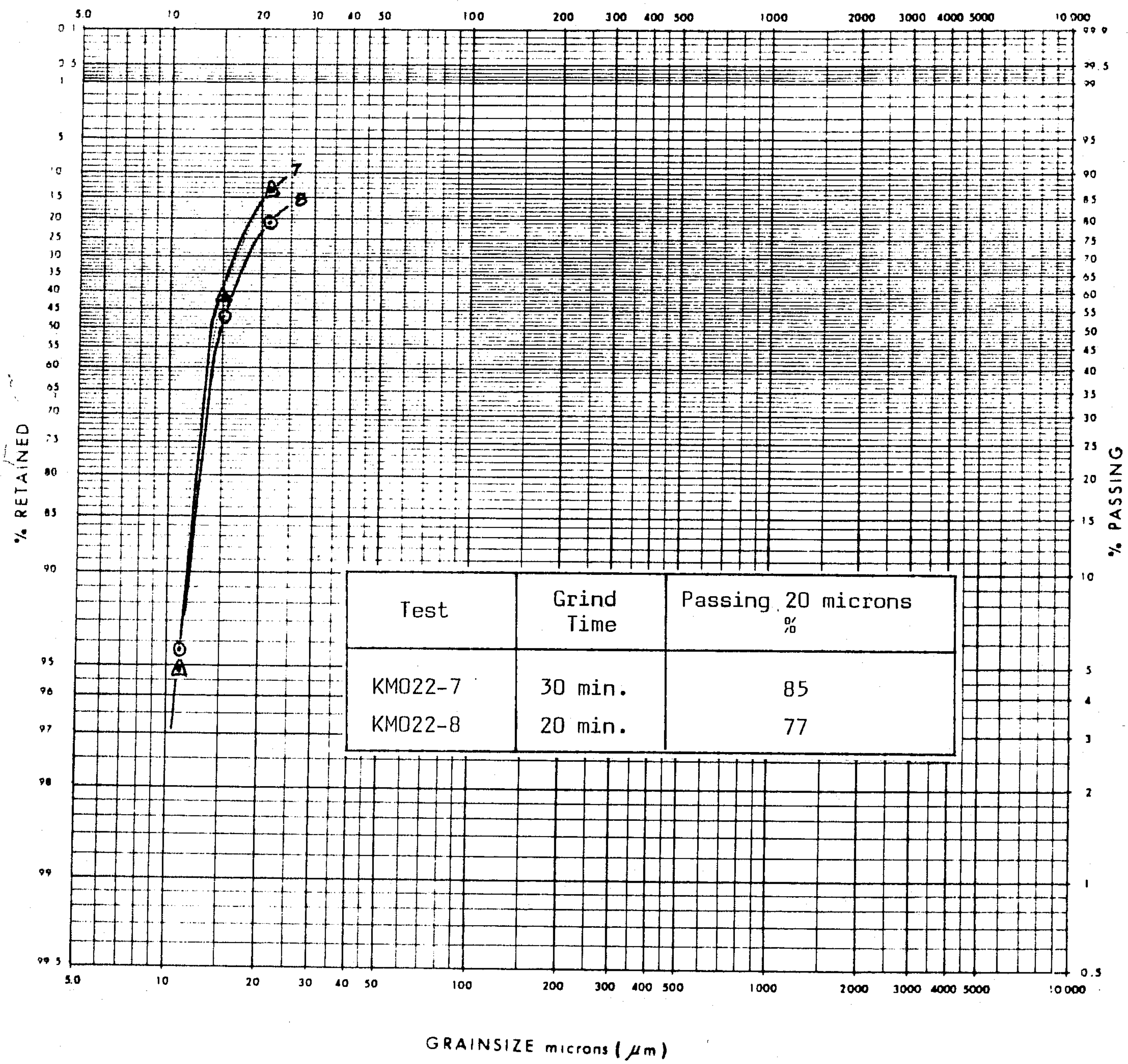
Test	Grind Time	Passing 20 microns %
KM022-1	10 min.	77
KM022-2	20 min.	83
KM022-3	30 min.	93

SIZE DISTRIBUTION CURVE



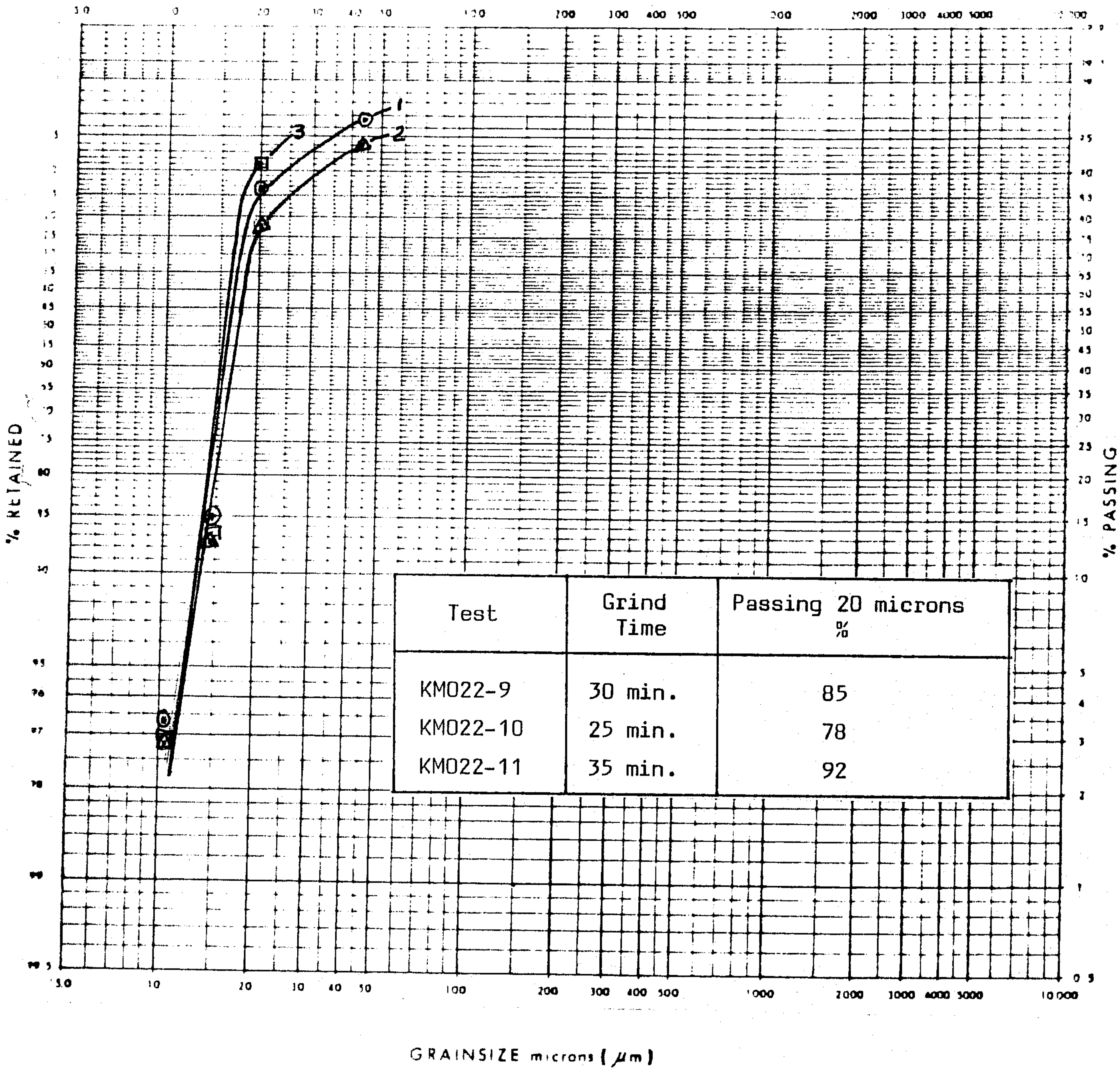
Test	Grind Time	Passing 20 microns %
KM022-4	30 min.	84
KM022-5	20 min.	76
KM022-6	10 min.	66

SIZE DISTRIBUTION CURVE



Test	Grind Time	Passing 20 microns %
KM022-7	30 min.	85
KM022-8	20 min.	77

SIZE DISTRIBUTION CURVE



Test	Grind Time	Passing 20 microns %
KM022-9	30 min.	85
KM022-10	25 min.	78
KM022-11	35 min.	92