RECENT ADVANCES
IN
COAL SPIRAL DEVELOPMENT

By

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Abstract. The use of spiral separators for the beneficiation of fine coal typically in the size range -2+0.1mm is now well established process technology. Developments during the mid 1980's resulted in the production of cost effective, efficient large diameter coal spiral separators.

Recent developments and research have been geared to optimise metallurgical performance, materials handling and equipment geometry of large diameter coal spiral separators.

Introduction

The high capacity LD4 coal spiral (of nominally 1m diameter) was the result of many years of development utilising computer simulation studies and laboratory testwork to verify the expected beneficiation capabilities. The LD4, released in the mid 1980's, quickly proved in the field to be far superior to the existing low capacity units in terms of performance, cost effectiveness and equipment engineering.

Notwithstanding the success of this equipment questions arose pertaining to both coarse and slime fraction materials handling, cutpoint limitations and spiral trough length. Coal technologists began to offer evidence to support the concepts that a reduced spiral trough length may not be significantly detrimental to separation efficiency (MacNamara, 1995 & 1996). Considerable research has been completed by ***MD mineral technologies*** to investigate the application of shorter and multi-stage compound spirals.

Optimisation of Trough Geometry

The objectives in the development of a new large diameter coal spiral were to, improve the materials handling characteristics in order to minimise the effect of tramp oversize on separation efficiency, improve the transport of reject material and reduce the trough length to simplify installation engineering. The new spiral (designated the LD7) was developed with significant changes made to the trough pitch and the profile of the separating surface. During development visual confirmation of satisfactory materials handling characteristics was considered appropriate to warrant advancing to the second phase of development where trough length was to be optimised.

Optimisation of Trough Length

The basis for the metallurgical assessment of the LD7 prototype test spirals was generally a comparison of the Down Grade Ratio (DGR) plotted against clean coal yield. The DGR is calculated by the following formula:

$$DGR = \frac{\text{Clean Coal Ash\%}}{\text{Feed Ash\%}}$$

The coal fraction analysed for this work was nominally -1.4mm deslimed at 0.1mm, Figure 1 illustrates the results achieved from the investigation of trough length.

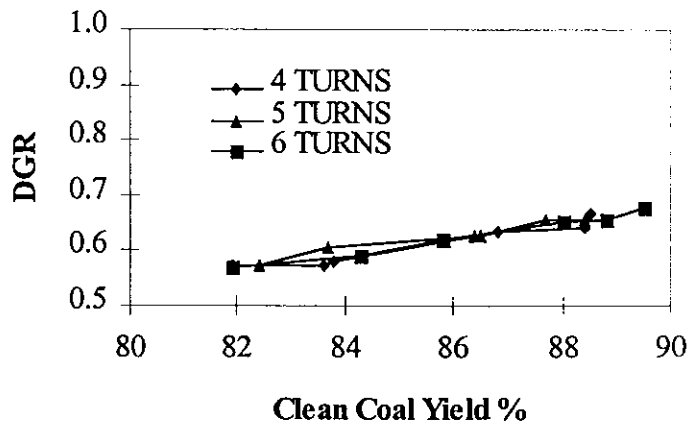


Figure 1.: DGR plots for 4, 5 and 6 turn coal spirals.

It is evident that for the coal treated there is no significant difference in the performance as measured by the DGR and it was concluded that the four (4) turn configuration of the LD7 would meet the performance criteria objectives. This conclusion was further ratified by subsequent testing on a second coal feed type. The DGR curves achieved with both the new LD7 and the LD4E spiral separators are plotted in Figure 2.

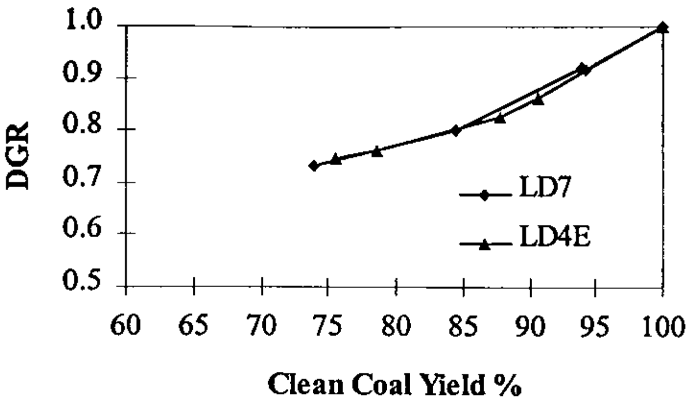


Figure 2.: DGR curves for the 5 turn LD4E and 4 turn LD7 coal spirals

These data confirm that, within the accuracy of experimental error, the LD7 design does not compromise on the metallurgical performance expected from a modern high capacity spiral.

Shorter Spirals

Two and Three Turns

The development program for the new high capacity spiral was guided somewhat by previous research at ***MD mineral technologies*** (Foote, 1994). In this work, involving investigations using two-stage systems of shortened LD4 coal spirals, it was concluded that the performance of two-turn and four-turn versions of the LD4 was inferior to the standard production length (5 turn) spiral. Furthermore the test results indicated that compound combinations of the two-turn units configured for both clean coal re-treatment and refuse scavenging were also inferior to the standard machine. The findings are illustrated by the plots of DGR in Figure 3. It was on this basis that the LD7 development was restricted to four turns and compound arrangements were not pursued.

A re-examination of the shorter two-turn and three-turn spiral options in 1996 involved the new LD7 profile and pitch geometry. The results for the two-turn and three-turn versions of the LD7 (Figure 4) clearly show the effect on yield that occurs when the trough length is shortened to fewer than four turns.

Notwithstanding this evidence it is considered likely that some coal types and applications may be suited to shorter spirals. However there can be expected to be an underlying performance reduction. For most modern export based and large domestic operations recovery efficiency is paramount, therefore short spirals will not normally be a viable option. It is also worth considering the insurance that the more efficient longer spirals offer in compensating for the effects of poor distributor performance on the overall separation efficiency within a bank of spirals.

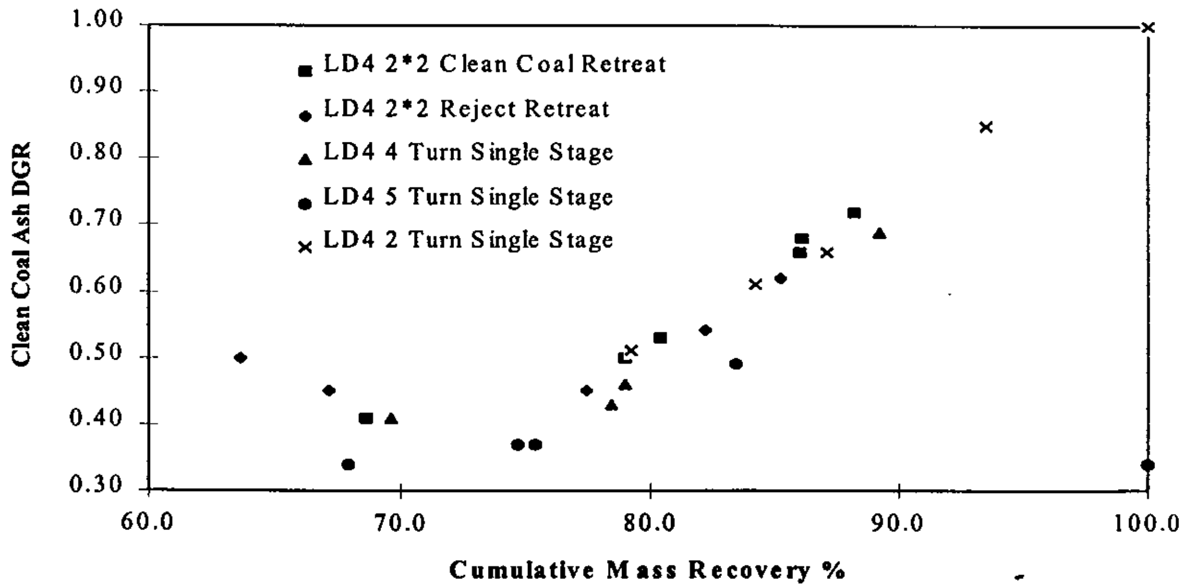


Figure 3.: LD4E Two Turn Spiral and 2 + 2 Turn Compound Spiral Performance (after Foote, 1994)

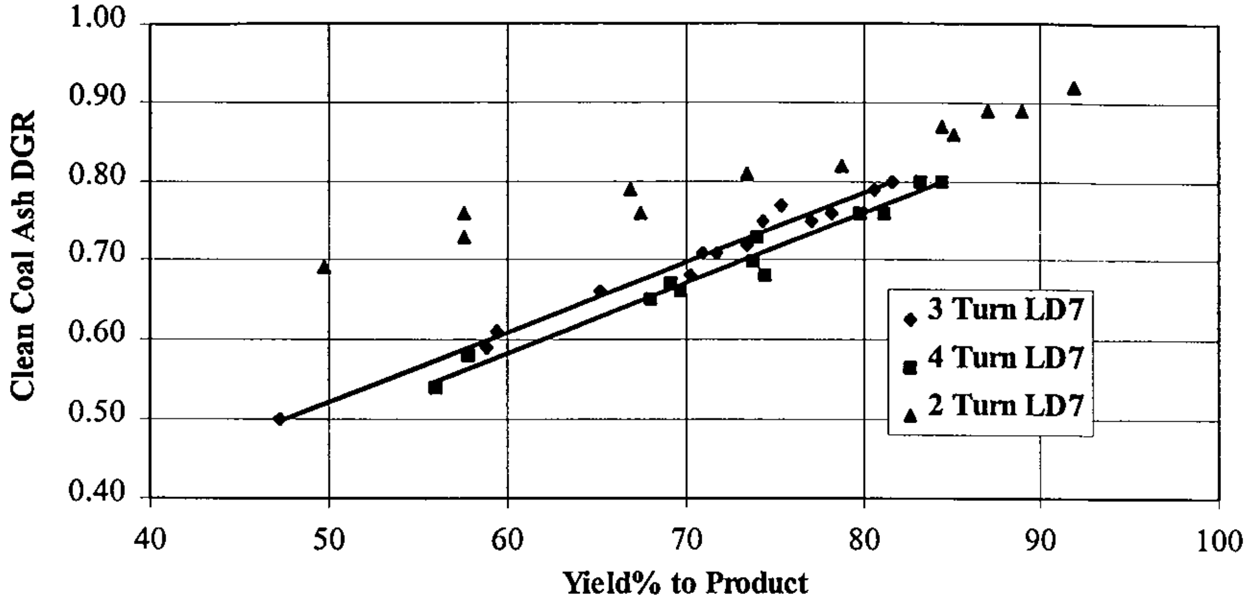
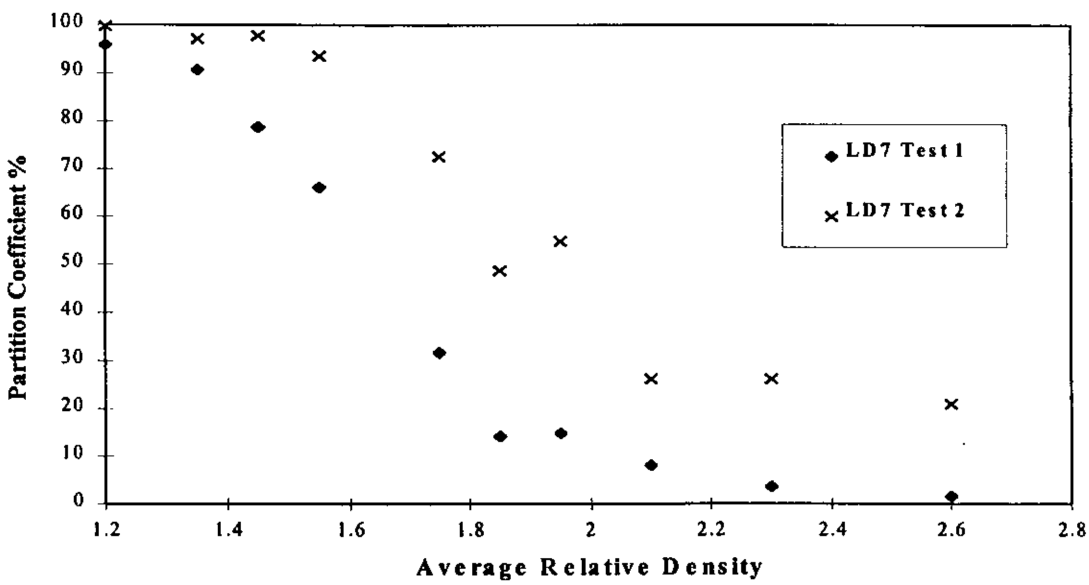


Figure 4.: Clean Coal DGR vs Yield % - Feed Rate 0.8t/h to 3.0t/h

Partition Characteristics

The DGR is a useful and inexpensive analytical tool for assessment of metallurgical performance, however partition analysis is an internationally recognised means for assessing beneficiation performance. Since the release of the LD7 spiral separator a number of partitioning tests have been conducted to confirm the high efficiency of the 4-turn LD7 spiral. Figure 5 illustrates two typical partition analyses.

The washability data for the feed coal used in the tests 1 and 2 are contained in Table 1 and Table 2.



	d_{50} R.D.	Ep	Clean Coal Yield Wt%	Clean Coal Ash %
Test 1	1.62	0.14	82.8	5.4
Test 2	1.91	0.18	91.1	6.6

Figure 5.: LD7 Spiral Partition Data

Table 1 Washability Data for Test 1 Nominal Size: -1.4mm+0.106mm				
Relative Density	Fractional		Cumulative	
	Wt%	Ash%	Wt%	Ash%
F1.30	74.5	3.2	74.5	3.2
S1.30 F1.40	9.6	14.3	84.1	9.5
S1.40 F1.50	0.9	22.1	85.0	4.7
S1.50 F1.60	1.8	30.2	86.8	5.2
S1.60 F1.70	0.3	38.0	87.1	5.3
S1.70 F1.80	0.9	44.3	88.0	5.7
S1.80 F1.90	0.3	50.5	88.3	5.9
S1.90 F2.00	0.6	55.5	88.9	6.2
S2.00 F2.20	1.5	65.8	90.4	7.2
S2.20 F2.40	1.4	77.2	91.8	8.3
S2.40	8.2	86.8	100.0	14.7

Table 2 Washability Data for Test 2 Nominal Size: -1.4mm+0.106mm				
Relative Density	Fractional		Cumulative	
	Wt%	Ash%	Wt%	Ash%
F1.30	80.0	3.6	80.0	3.6
S1.30 F1.40	4.2	12.0	84.2	4.1
S1.40 F1.50	3.4	19.3	87.6	4.7
S1.50 F1.60	2.1	31.5	89.7	5.3
S1.60 F1.70	0.1	37.3	89.8	5.3
S1.70 F1.80	0.7	45.3	90.5	5.6
S1.80 F1.90	0.4	51.3	90.9	5.8
S1.90 F2.00	0.6	56.7	92.5	6.1
S2.00 F2.20	1.0	75.0	93.5	7.0
S2.20 F2.40	1.0	76.4	94.5	7.7
S2.40	6.5	86.1	100.0	12.8

Two Stage Spiral Circuits

It is common practice in coal preparation plants to utilise multi-staged spiral circuits to maximise the recovery of clean coal. This concept can be particularly effective when utilising spirals to wash fine coals at reduced cutpoints (nominally below RD 1.7). Reducing the feed rate to coal spirals can result in a lowering of the clean coal ash (Holland-Batt, 1994). However this lowering of the cutpoint is normally accompanied by an increase of the misplaced clean coal to the middlings fraction. The partition analysis illustrated in Figure 12 shows a low cutpoint of RD 1.56 has been achieved, however the misplaced material of relative densities in the range 1.5 to 1.3 is significant.

Conventional spiral circuit design would involve a middlings re-treatment stage at a cutpoint of RD 1.90 (refer Figure 5). Under this operating regime reduced losses of coal in the range RD 1.50 to 1.30 would occur and the circuit would approach maximum yield to clean coal product.

Testing Compound Spiral Principles

To Replace Two Stage Circuits

Although it had been concluded during the course of earlier testwork (Foote 1994) that compound arrangements of two-turn spirals would not achieve the separation efficiency of a standard single stage spiral, work by others (MacNamara, 1995, 1996) on compound arrangements utilising shortened spiral troughs had shown that reasonable performance could be achieved.

The ability to provide multiple stages on a single column unit with overall physical dimensions similar to conventional high capacity spirals would offer several advantages if the level of efficiency achieved by such a hybrid exceeded that achieved in a single stage unit. The advantages would include potentially lower cutpoints, reduced plant floor space, elimination of interstage pumping and improved clean coal recovery.

Spiral Configuration

To test this concept a prototype unit was constructed by incorporating a two-turn three-start LD7 primary stage and a single start LD4 secondary stage of three turns to treat the primary stage middlings fraction. A triple-start primary stage was selected to create a reasonable solids flow to the second stage. Moreover, the alternative of only a twin-start primary stage would cancel any advantage of equipment cost and plant footprint reductions as the unit capacity would be reduced. The three-turn second stage was selected on the basis that the primary stage middlings fraction would contain a greater proportion of near gravity material and therefore need the greater effort to produce a comparable low ash clean coal fraction.

Testing Philosophy

The objectives of the test program were to compare the separation efficiency of the prototype compound spiral with that of the LD7 coal spiral over a range of feed rates and thereby include both high and low cutpoint separations. The testwork was conducted using a closed circuit test rig to ensure tight control of feed conditions. Sampling was achieved using a system which provided for simultaneous full-stream sampling of the spiral fractions. On the compound spiral, the first stage was fitted with a production splitter arrangement to generate three fractions, the second stage was fitted with a multiple outlet product box for fractionation into five streams.

The coal used for the test program was nominally sized -2.0mm deslimed at 0.1mm. Washability data for the coal are tabulated in Table 10.

Clean Coal Ash vs DGR Comparisons

The DGR results of the tests conducted are illustrated in Figures 6, 8 and 10 on the following pages.

A number of interesting phenomenon were concluded from these data. For example the standard LD7 spiral achieved a superior DGR at the higher end of the yield to clean coal and although the compound unit ultimately achieved similar DGR's this was only at the lower yields.

A second observation of interest was the change in fundamental separation performance for the compound spiral related to the first stage splitter setting. This is illustrated by tests 63 and 64 which were conducted at the same feed rate (approximately 2.2 tonnes per hour per start) and at the same pulp density. The only difference between the tests was the positioning of the splitters on the first spiral stage. For the compound spiral this change of splitter setting on the first stage produced two distinct performance curves, unlike the standard LD7 spiral where the points from the two tests (67 and 68) fell on one smooth curve. This phenomenon also occurred for compound spiral tests 61 and 62 and, to a lesser degree, in tests 57 and 58.

In the tests 62 and 63 the yield of the clean coal recovered from the first stage was reduced in an attempt to achieve minimum ash and a lower cutpoint. This procedure proved ineffective and the cumulative ash of the first stage and second stage clean coal products resulted in a relatively poor yield/DGR relationship. The fall in performance is clearly illustrated in the following partition data.

Partition Analysis

A total of nine tests were selected for partition analysis. For the compound spiral tests the first stage product was combined with the first clean coal fraction from the multiple outlet splitter on the second stage. The LD7 spiral partition is for the clean coal splitter cut.

The performance criteria values are summarised in Table 9. Contrary to expectations, the compound spiral did not achieve a cutpoint below RD 1.76 and, as discussed above, attempts to reduce the yield and thereby lower the cutpoint had the effect of degrading the separation efficiency.

The separation efficiencies determined for the compound spiral were acceptable at higher RD cutpoints when the first stage mass yield was maintained at a relatively high level. However the performance fell significantly when lower cutpoints were attempted (tests 62 and 63), with the Ep rising to 0.26. These results concur with those reported by MacNamara (1996).

The LD7 achieved good separation efficiencies across all feed rates and cutpoints down to RD 1.56 were achieved with an Ep of 0.17, at a feed rate of 2.2 tonnes per hour. The misplaced material, as measured by the partition number at average RD 1.25 increased with decreasing feed rate and cutpoint. This phenomenon is understood by coal spiral designers and users, and it reinforces the need for two stages of full sized spirals for high efficiency at lower cutpoints.

For the compound spiral the relationship between cutpoint and partition number at RD 1.25 is clearly influenced significantly by the splitter settings on the first stage. Tests 62 and 63 attained cutpoints of RD 1.90. However the partition curve indicated partition numbers of 92.6 and 87.3 at RD 1.25 for tests 62 and 63 respectively. At the high density end of the partition curve the compound spiral partition numbers at the average RD 2.5 were consistently greater than those for the LD7 at similar cutpoints.

Conclusions

The LD7 coal spiral has been demonstrated to be metallurgically equal to the older generation model LD4 spiral. No measurable differences in yield or clean coal DGR are evident for the coal types tested, and the partition data generated for the LD7 spiral are of the order expected for a 1m high-capacity coal spiral. Spiral trough length has been demonstrated to be a critical parameter in coal spiral performance with performance deteriorating as trough length is reduced to fewer than four turns.

Although the results of this work tend to support the concept that a spiral trough length of four turns is the optimum length for most applications, it could be postulated that variations in coal washability may give rise to acceptable clean coal recovery being achieved with a shorter spiral trough.

The compound spiral based on the shorter trough lengths did not out perform the LD7 spiral, and did not achieve the lower cutpoints expected. The compound spiral operation proved to be extremely sensitive to the splitter position combinations and it's performance has been demonstrated as acceptable only within a very narrow range. It follows that the compound spiral is not an appropriate option to replace a two-stage LD7 spiral circuit where a low cutpoint is required. For higher cutpoints the LD7 spiral will be equally efficient as the compound spiral, but in addition the LD7 will be more tolerant of splitter and feed rate variations and have a superior solids loading capacity at equivalent RD cutpoints.

References

Foote, P.,1994, "Two Stage Coal Spiral" MD mineral technology internal report.

Holland-Batt, A. B., 1994, "The Effect of Feed Rate on the Performance of Coal Spirals", Coal Preparation, 1994 Vol. 14, pp199-222

MacNamara et al, 1995, "The Application of New Configurations of Coal Spirals," Coal Prep 95 May 2-4, Lexington, Kentucky.

MacNamara et al, 1996, "On Site Testing of the Compound Spiral," Coal Prep 96 April 30-May 2, Lexington, Kentucky.

Table 3
2.2t/h Feed Rate Test Series
Deslime (0.106mm) Clean Coal Ash DGR Vs Cumulative Mass Recovery

LD7 Test 67/68 Cumulative Mass Recy%	DGR	COMPOUND Test 63 Cumulative Mass Recy%	DGR	COMPOUND Test 64 Cumulative Mass Recy%	DGR
71.4	0.51	25.6	0.43	74.1	0.51
84.6	0.55	78.5	0.59	85.4	0.52
91.1	0.62	80.4	0.62	86.8	0.54
92.9	0.67	92.5	0.77	87.1	0.55
100	1.00	93.1	0.78	89.5	0.61
		97.6	0.91	91.0	0.67
		100.0	1.00	100.0	1.00

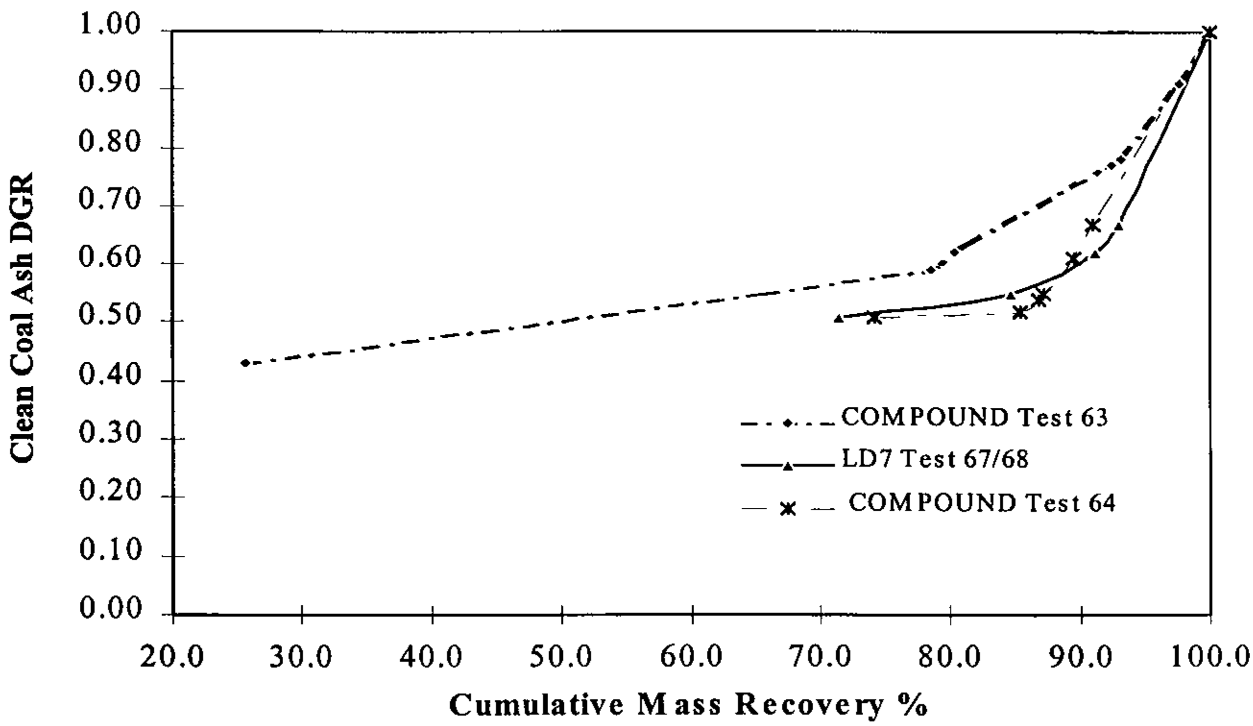


Figure 6. 2.2t/h Feed Rate Test Series
Data Plot: Deslime (0.106mm) Clean Coal Ash DGR Vs Cumulative Mass Recovery

Table 4
2.2t/h Feed Rate Test Series
Deslime (0.106mm) Clean Coal Ash Vs Cumulative Mass Recovery

LD7 Test 67/68 Cumulative Mass Recy%	Ash%	COMPOUND Test 63 Cumulative Mass Recy%	Ash%	COMPOUND Test 64 Cumulative Mass Recy%	Ash%
71.4	6.9	25.6	6.8	74.1	7.7
84.6	7.5	78.5	9.5	85.4	7.9
91.1	8.4	80.4	9.9	86.8	8.2
92.9	9.0	92.5	12.3	87.1	8.3
100	13.5	93.1	12.5	89.5	9.2
		97.6	14.5	91.0	10.2
		100.0	16.0	100.0	15.2

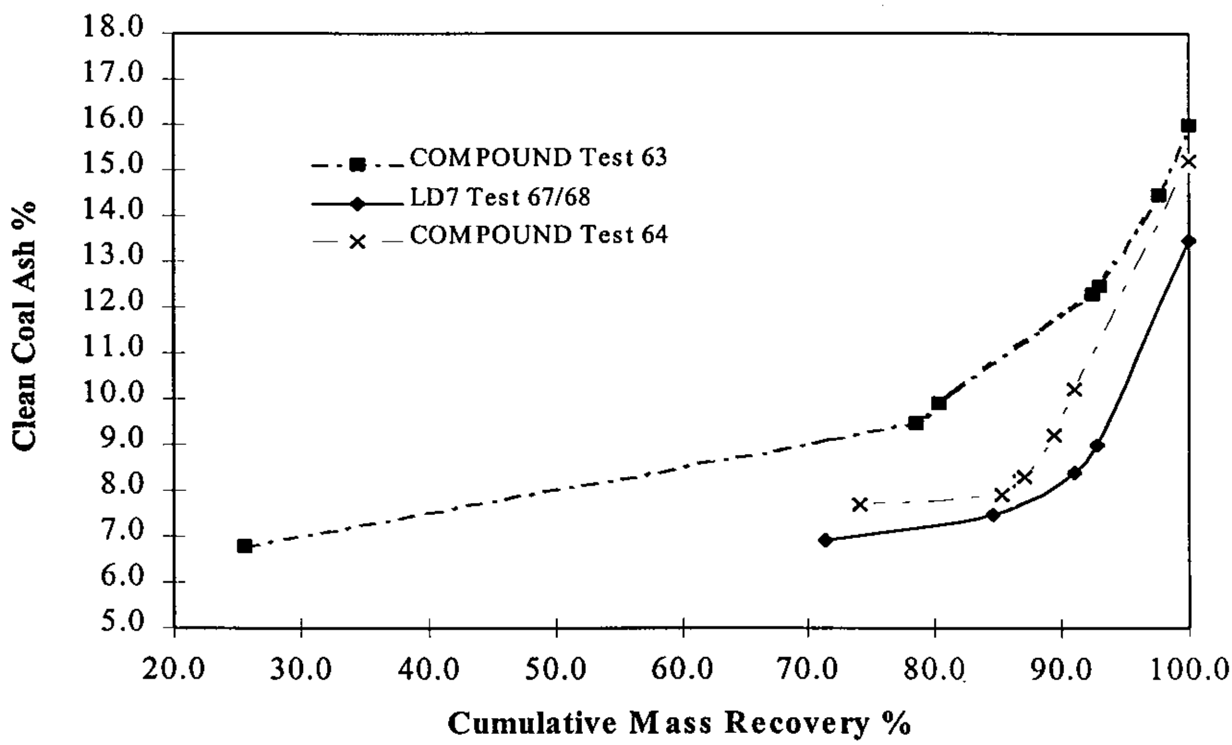


Figure 7. 2.2t/h Feed Rate Test Series
Data Plot: Deslime (0.106mm) Clean Coal Ash% Vs Cumulative Mass Recovery

Table 5
3.2t/h Feed Rate Test Series
Deslime (0.106mm) Clean Coal Ash DGR Vs Cumulative Mass Recovery

LD7 Test 71/72 Cumulative Mass Recy%	DGR	COMPOUND Test 61 Cumulative Mass Recy%	DGR	COMPOUND Test 62 Cumulative Mass Recy%	DGR
73.4	0.50	84.9	0.59	54.9	0.55
83.8	0.48	90.2	0.60	84.8	0.64
92.4	0.65	91.1	0.61	93.6	0.78
93.6	0.68	91.3	0.62	94.9	0.90
100	1.00	94.6	0.76	95.3	0.81
		97.1	0.88	98.6	0.93
		100.0	1.00	100.0	1.00

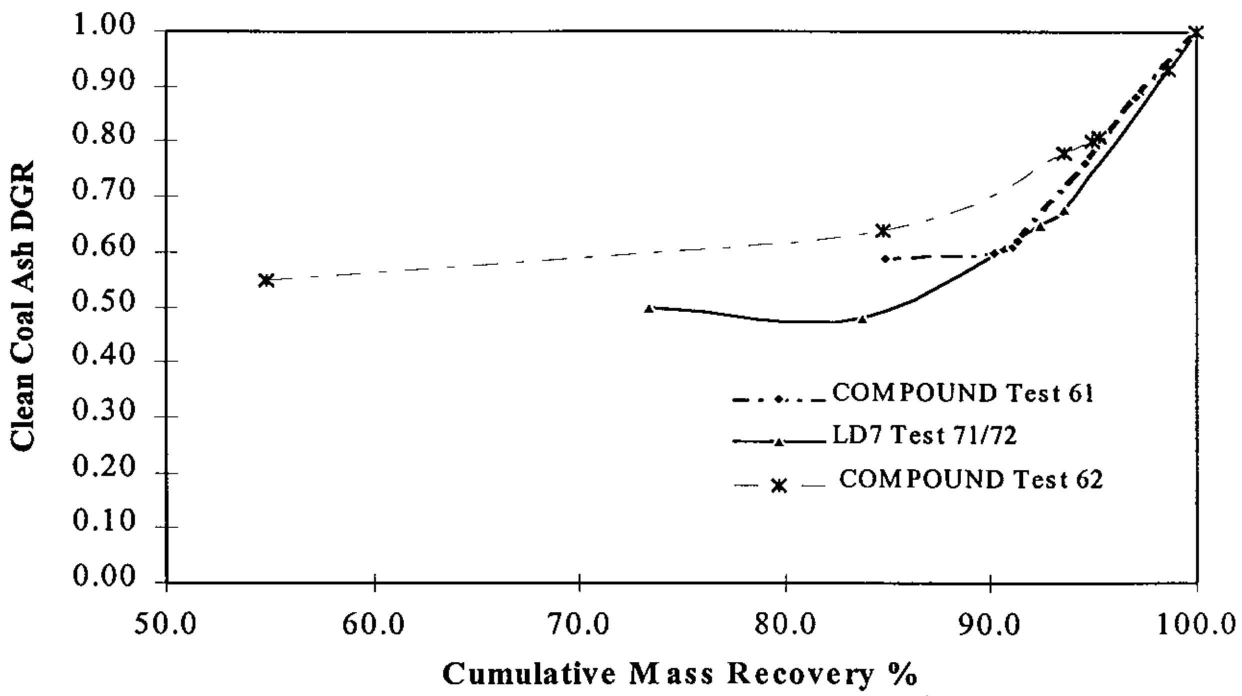


Figure 8. 3.2t/h Feed Rate Test Series
Data Plot: Deslime (0.106mm) Clean Coal Ash DGR Vs Cumulative Mass Recovery

Table 6
3.2t/h Feed Rate Test Series
Deslime (0.106mm) Clean Coal Ash% Vs Cumulative Mass Recovery

LD7 Test 71/72 Cumulative Mass Recy%	Ash%	COMPOUND Test 61 Cumulative Mass Recy%	Ash%	COMPOUND Test 62 Cumulative Mass Recy%	Ash%
73.4	7.4	84.9	8.2	54.9	7.6
83.8	7.3	90.2	8.4	84.8	8.8
92.4	9.0	91.1	8.6	93.6	10.7
100	14.5	91.3	8.6	94.9	11.0
		94.6	10.5	95.3	11.1
		97.1	12.3	98.6	12.8
		100.0	13.9	100.0	13.7

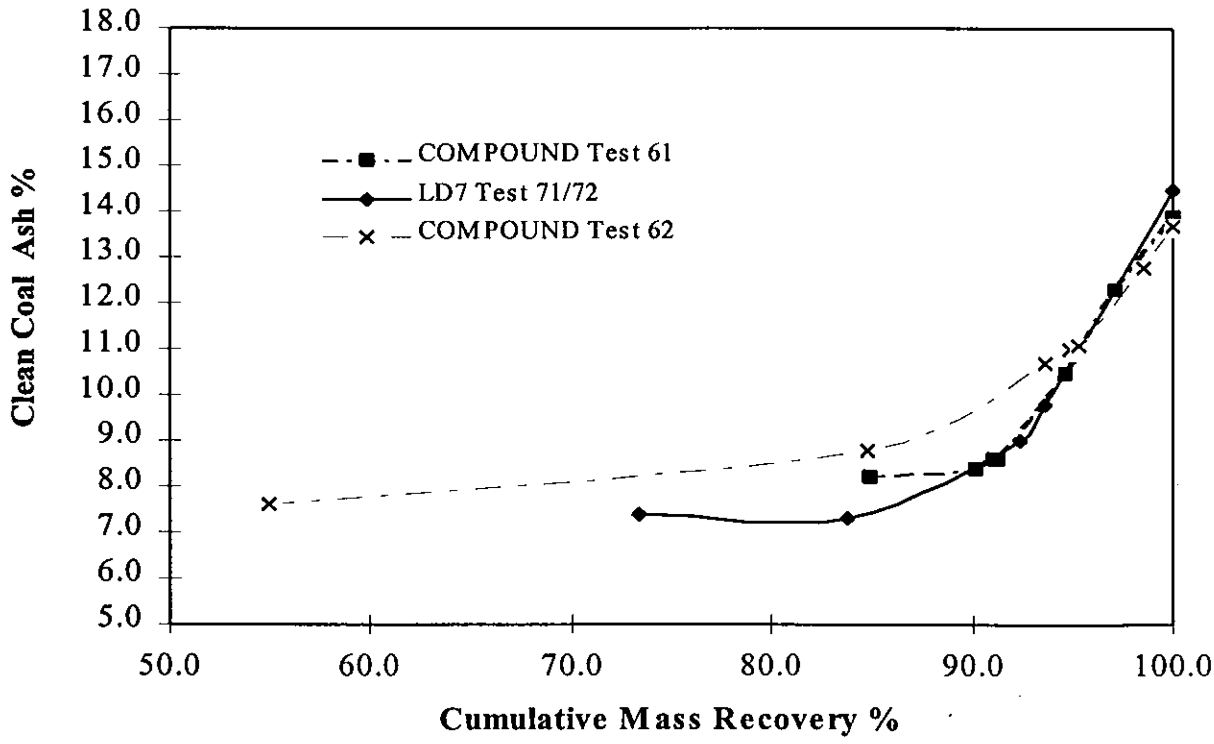


Figure 9. 3.2t/h Feed Rate Test Series
Data Plot: Deslime (0.106mm) Clean Coal Ash% Vs Cumulative Mass Recovery

Table 7
4.0-4.5t/h Feed Rate Test Series
Deslime (0.106mm) Clean Coal Ash DGR Vs Cumulative Mass Recovery

LD7 Test 69/70		COMPOUND Test 57		COMPOUND Test 58	
Cumulative Mass Recy%	DGR	Cumulative Mass Recy%	DGR	Cumulative Mass Recy%	DGR
79.5	0.57	88.1	0.64	72.2	0.55
88.9	0.61	90.0	0.64	86.9	0.56
93	0.68	91.3	0.65	87.8	0.57
94.2	0.73	91.5	0.65	88.1	0.58
100	1.00	94.9	0.79	89.6	0.62
		96.8	0.88	90.7	0.67
		100.0	1.00	100.0	1.00

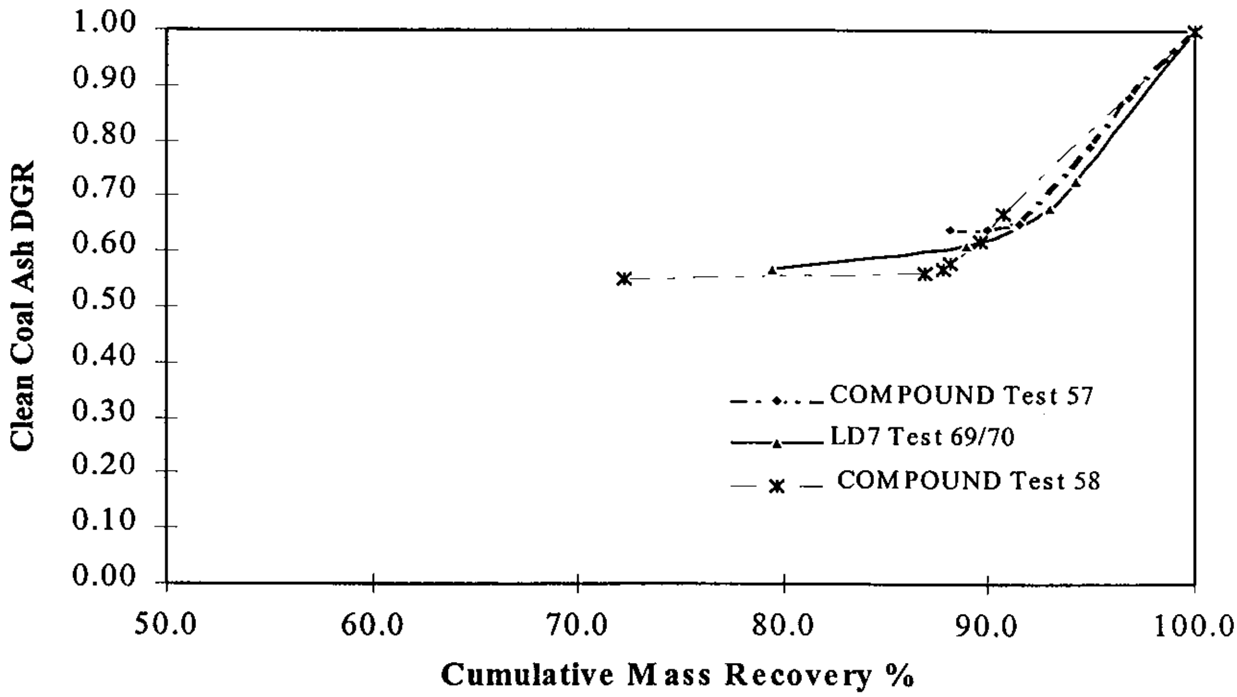


Figure 10. 4.0-4.5t/h Feed Rate Test Series
Data Plot: Deslime (0.106mm) Clean Coal Ash DGR Vs Cumulative Mass Recovery

Table 8
4.0-4.5t/h Feed Rate Test Series
Deslime (0.106mm) Clean Coal Ash% Vs Cumulative Mass Recovery

LD7 Test 69/70 Cumulative Mass Recy%	Ash%	COMPOUND Test 57 Cumulative Mass Recy%	Ash%	COMPOUND Test 58 Cumulative Mass Recy%	Ash%
79.5	7.8	88.1	9.8	72.2	8.6
88.9	8.2	90.0	9.8	86.9	8.7
93	9.2	91.3	9.9	87.8	8.9
94.2	10.0	91.5	9.9	88.1	9.1
100	13.6	94.9	12.0	89.6	9.7
		96.8	13.3	90.7	10.5
		100.0	15.2	100.0	15.7

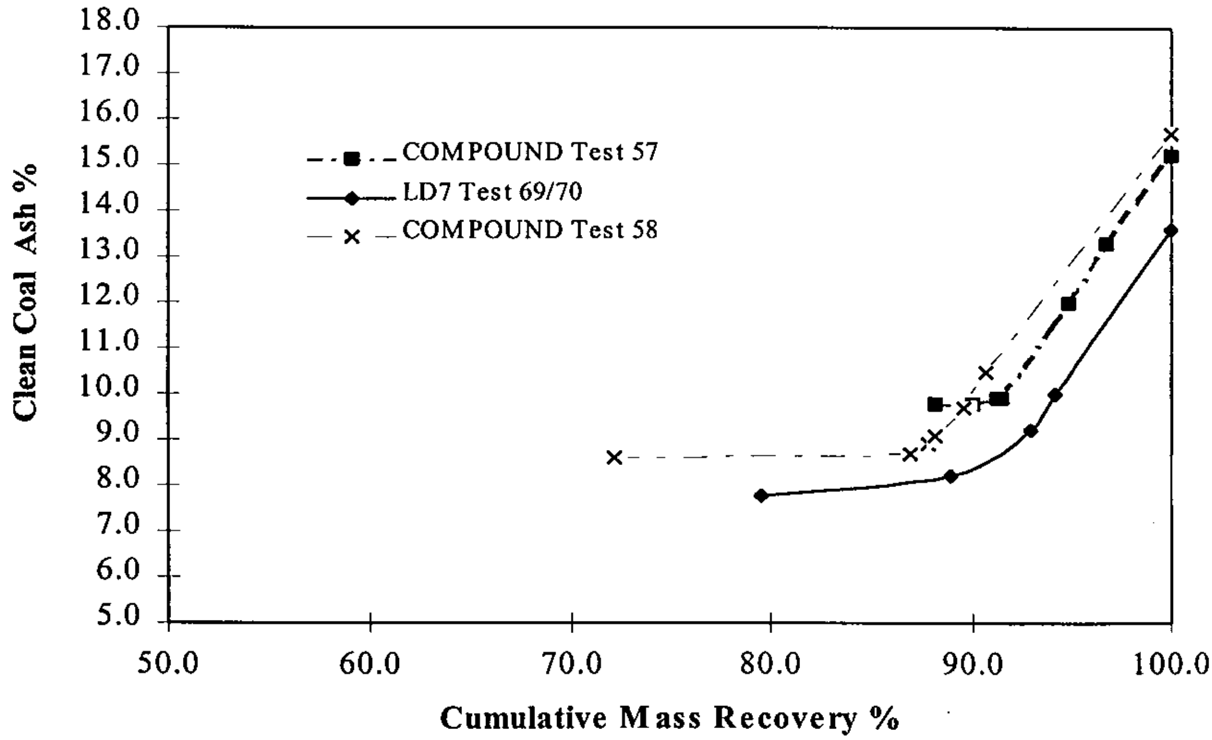


Figure 11. 4.0-4.5t/h Feed Rate Test Series
Data Plot: Deslime (0.106mm) Clean Coal Ash% Vs Cumulative Mass Recovery

Summary of Partition Curve Data Size Fraction -2.00mm+0.106mm							
Test No.	**61**	**62***	**71**	**63***	**64**	**67**	**68**
Spiral Type	Comp	Comp	LD7	Comp	Comp	LD7	LD7
Feed Rate	3.1	3.2	3.2	2.0	2.2	2.3	2.4
Ash +0.106	8.4	8.8	7.4	9.5	7.9	6.9	7.5
Yield +0.106	91.1	84.9	83.8	78.5	85.4	71.4	84.6
Partition No. at mean Rd of 1.25	98.9	92.6	95.9	87.3	95.8	83.4	95.7
d_{50}	1.88	1.90	1.72	1.90	1.76	1.56	1.68
Ep	0.17	0.26	0.12	0.26	0.14	0.17	0.14
Partition No. at mean Rd of 2.5	8.0	11.0	2.4	10	3.0	1.0	1.5
Feed Ash	13.9	13.7	14.9	16.0	15.2	13.5	13.4
Reject Ash	65.1	40.9	52.8	40.0	57.7	30.0	46.2

Table 9

Feed Washability Size Fraction Nominal -2.00mm+0.106mm								
Relative	**Total**			**Cum. Floats**		**Cum. Sinks**		**Rel.**
Density	**Wt.**	**Assay**	**Distn.**	**Wt.**	**Assay**	**Wt.**	**Assay**	**Dens.**
Fractions	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**+/-0.1**
F1.30	56.96	1.00	56.96	56.96	1.00	100.00	1.00	0.00
S1.30 F1.40	15.03	1.00	15.03	72.00	1.00	43.04	1.00	23.60
S1.40 F1.50	8.57	1.00	8.57	80.57	1.00	28.00	1.00	14.61
S1.50 F1.60	6.04	1.00	6.04	86.60	1.00	19.43	1.00	7.60
S1.60 F1.70	1.56	1.00	1.56	88.17	1.00	13.40	1.00	2.61
S1.70 F1.80	1.05	1.00	1.05	89.22	1.00	11.83	1.00	1.91
S1.80 F1.90	0.86	1.00	0.86	90.07	1.00	10.78	1.00	1.44
S1.90 F2.00	0.58	1.00	0.58	90.65	1.00	9.93	1.00	1.11
S2.00 F2.20	1.07	1.00	1.07	91.72	1.00	9.35	1.00	1.29
S2.20 F2.40	1.52	1.00	1.52	93.24	1.00	8.28	1.00	0.00
S2.40	6.76	1.00	6.76	100.00	1.00	6.76	1.00	0.00
Total	100.00	1.00	100.00					

Table 10

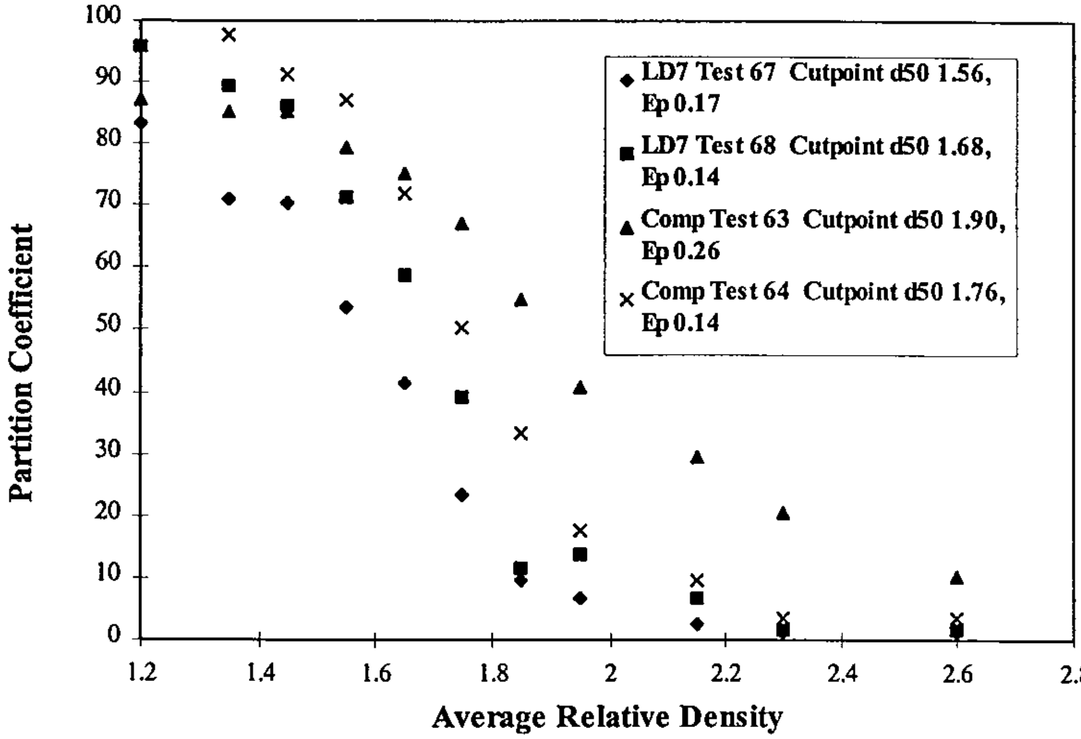


Figure 12.: Partition Curves for LD7 and Compound Spirals - Feed Rate Range 2.0 to 2.4t/h

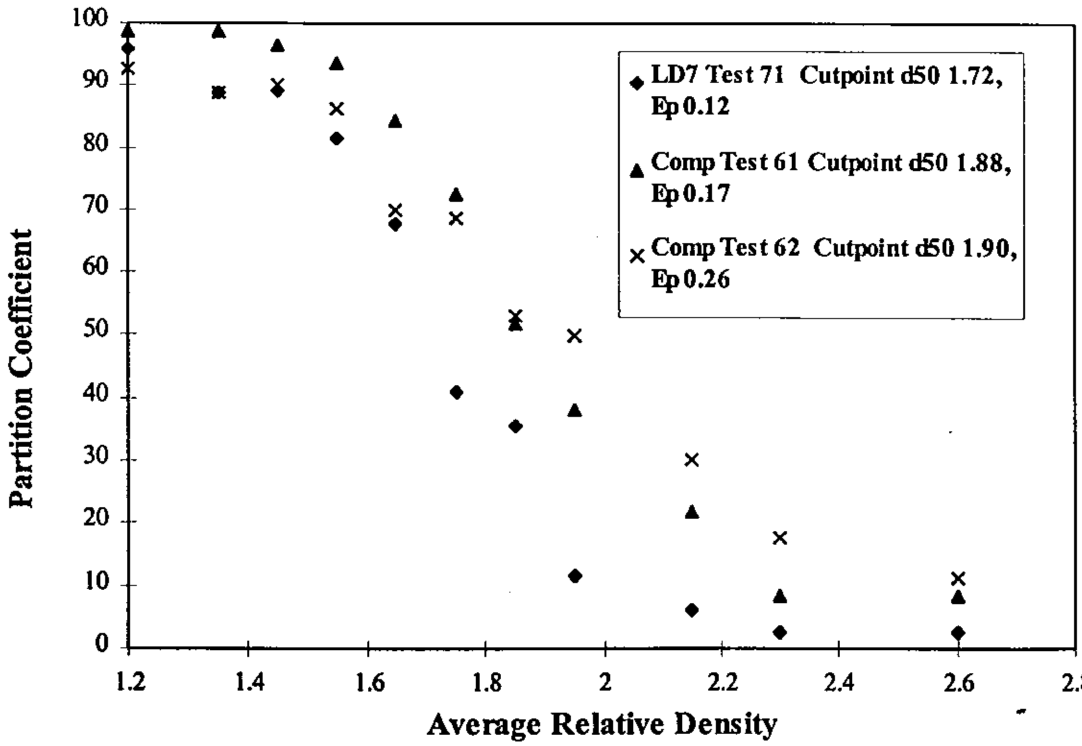


Figure 13.: Partition Curves for LD7 and Compound Spirals - Feed Rate Range 3.1 to 3.3t/h

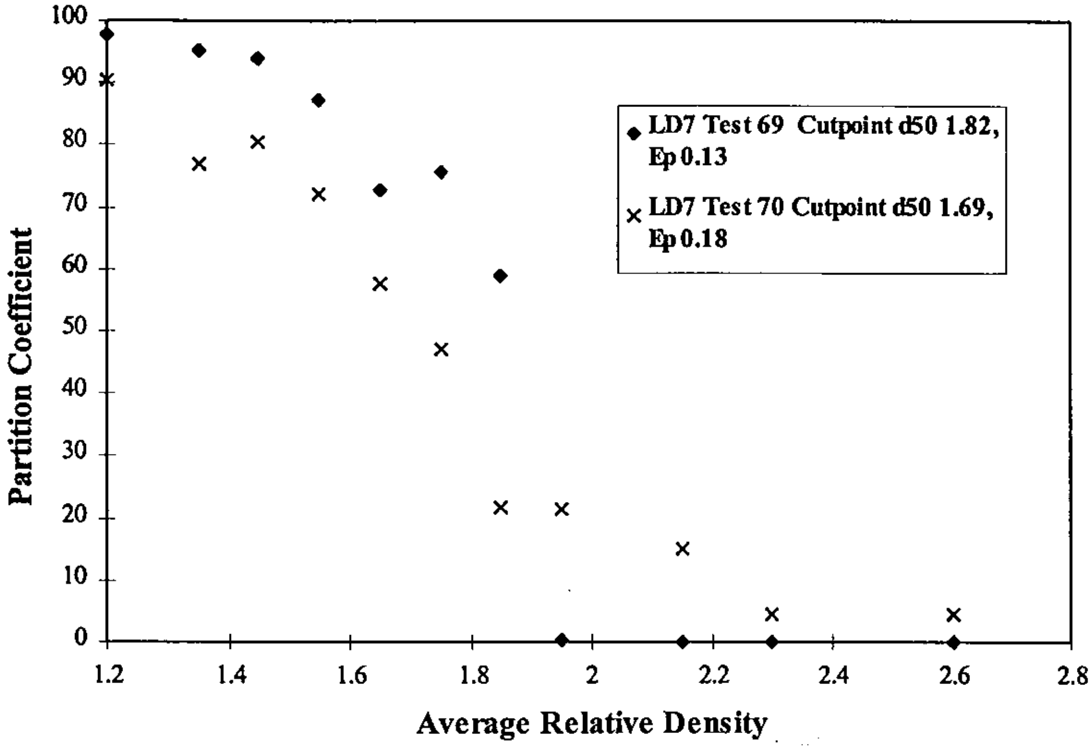


Figure 14.: Partition Curves for LD7 Spiral - Feed Rate Range 4.4 to 4.7t/h