CHAPTER 3
RESULTS AND DISCUSSION

3.1 Introduction

Simulated and experimental comparisons were carried out on the three common release analysis procedures: timed release analysis, simplified release analysis, and tree analysis. These comparisons were conducted to determine which procedure produced the best result and most nearly approximated an ideal flotation separation. This chapter presents the results of this investigation beginning with the computer simulations. In this instance, computer simulations are very useful in comparing the various procedures because they make it possible to look at the process without effects of operator bias. In many cases, small differences in a procedure may be masked by the statistical noise created by the operator. In this case, the noise is eliminated by the ideal nature of a simulation. The following sections summarize the simulated and experimental results obtained in this investigation.

3.2 Simulation

3.2.1 Timed Release Analysis

Simulated results from the timed release analysis simulations are shown in Figures 7 and 8. The first thing to be noted in comparing the two coals is that the yield-vs.-ash curve for the simulated Beckley seam extends farther into the low-ash region and tends to have a sharper elbow than the simulated Stockton seam. The shape of the yield-vs.-ash curve for the simulated Beckley seam is indicative of a coal that is well liberated or, in essence, black and white. On the other hand, the gradual curve of the yield-vs.-ash plot for the simulated Stockton seam is indicative of a coal with a high middlings content.

The comparison of the two methods for performing timed release analysis, i.e., the original method of Dell and the later method of Cavallaro and Deurbrouck, indicate little difference in the results obtained. This is not surprising since the modifications made by Cavallaro and Deurbrouck were largely for experimental convenience. It is interesting to note that the reduced times used by Cavallaro and Deurbrouck seem to allow their version of the timed release analysis procedure to extend farther into the low-ash, low-yield region of the curve.

3.2.2 Simplified Release Analysis

The results obtained from the simulations of the simplified release analysis procedure are shown in Figures 9 - 12. In addition to the comparison between the two coal types, simulations were conducted to study the effect of flotation time and number of floats used in the first stage separation of floatable material from non-floatable material. Since this separation is a key factor in the simplified release analysis test, it

was expected that these parameters would have the greatest impact on the resulting yield-vs.-ash curve.

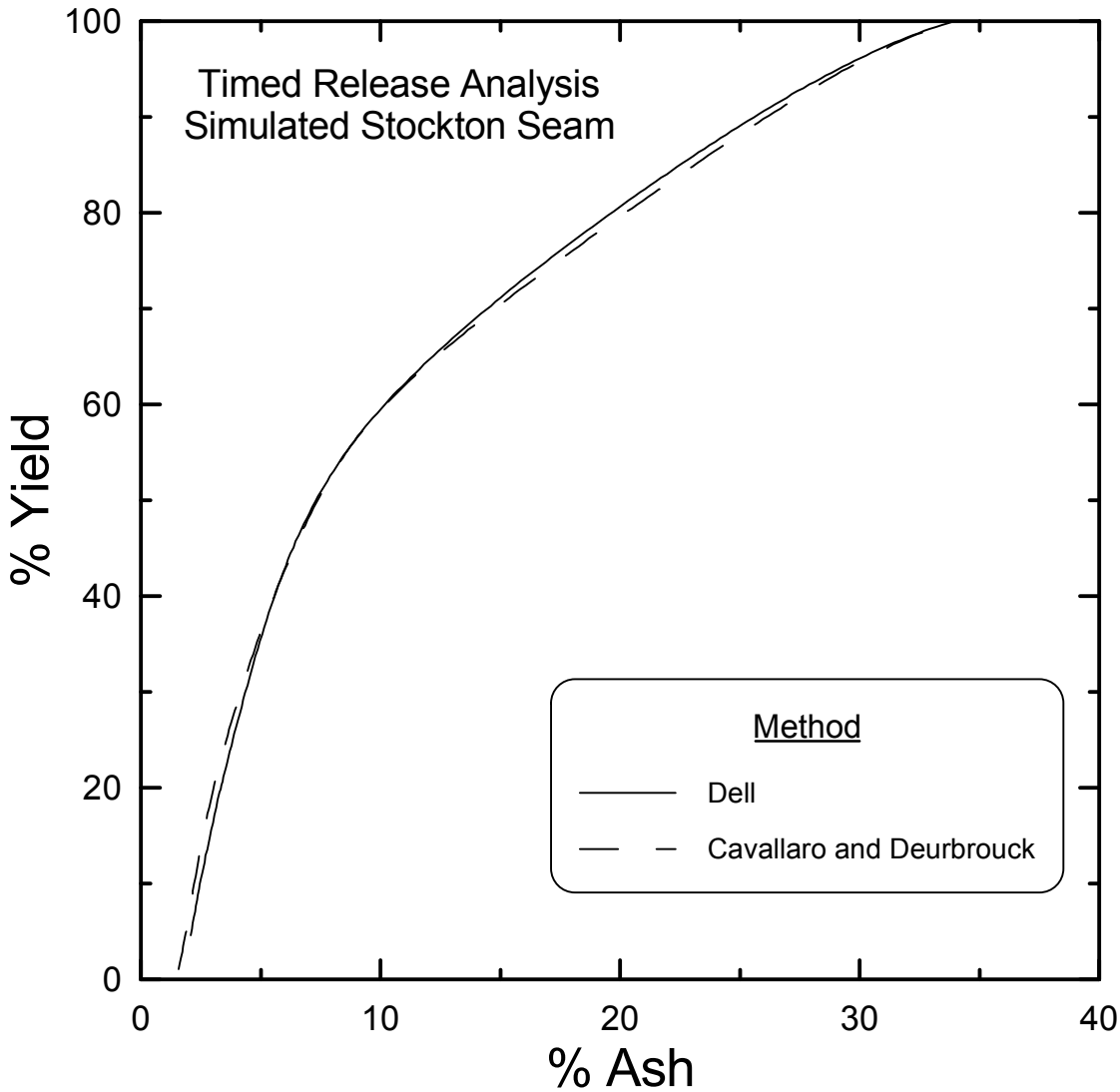

Figure 7. Simulated comparison of two timed release analysis techniques for a simulated Stockton seam coal.

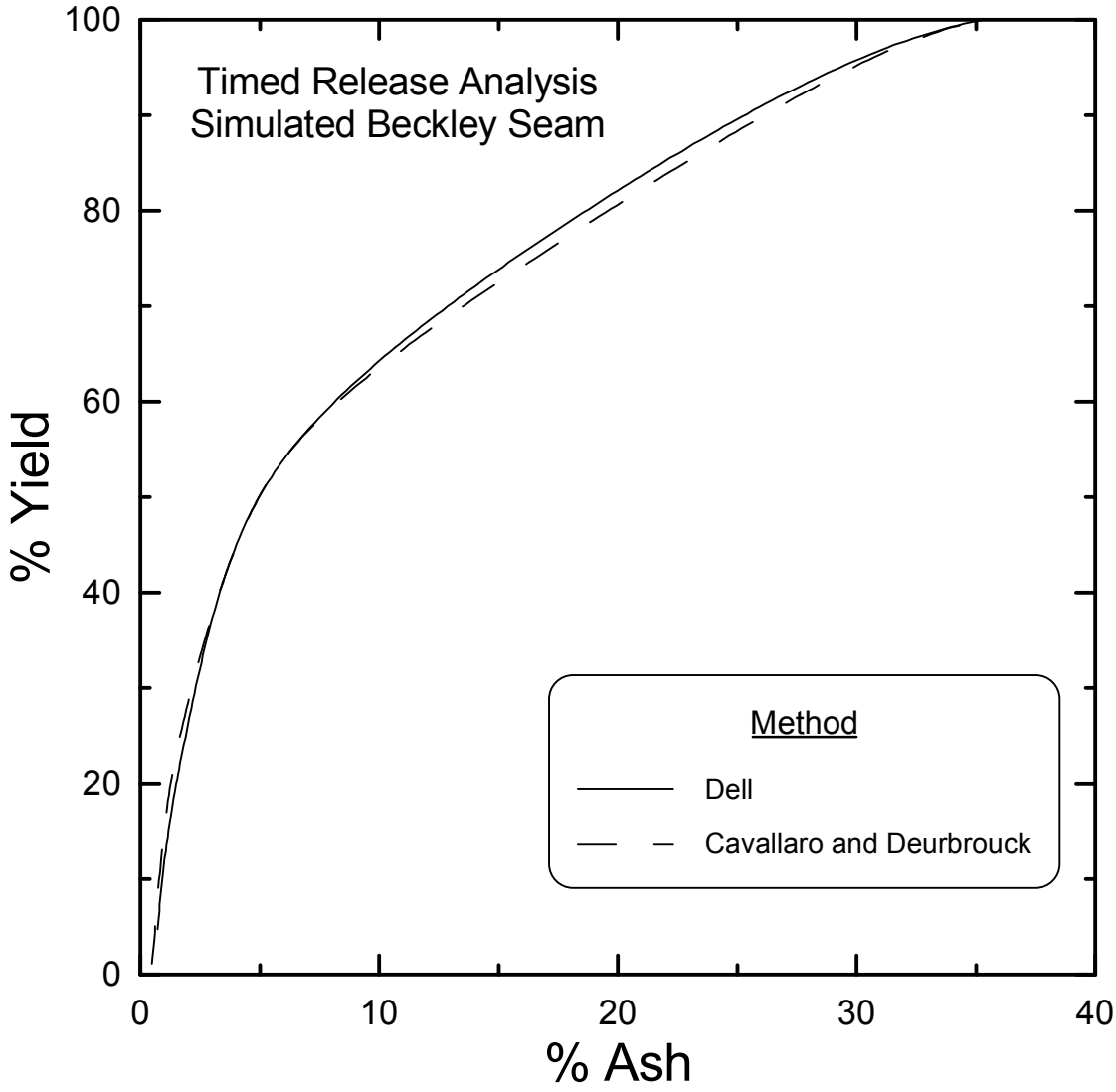

Figure 8. Simulated comparison of two timed release analysis techniques for a simulated Beckley seam coal.

Figure 9 shows the effect of first stage flotation time on the yield-vs.-ash curve obtained for the simulated Stockton seam coal. As shown, a short flotation time (e.g., 10 minutes) seems to move the curve farther to the left; however, this movement comes at the expense of the elbow. The movement in the yield-vs.-ash curve is due to the fact that a short flotation time allows high-ash middlings particles (i.e., floatable material) to remain in the first stage tailings. As a result, the feed to the second stage is lower in ash than it should be, and it is now possible to obtain a lower ash result in the second stage. Unfortunately, this lower ash result is at the expense of a lower yield in the high-ash region of the curve (i.e., the elbow). As flotation time is increased, a better separation between floatable and non-floatable material is achieved and the elbow of the curve is lifted. As flotation time approaches 20 minutes, there appears to be little further improvement in the elbow. Thus, a 15 minute flotation time, as is normally used in

practice, appears to be suitable for locating the elbow of the curve, while giving a reasonable representation of the low-ash, low-yield region.

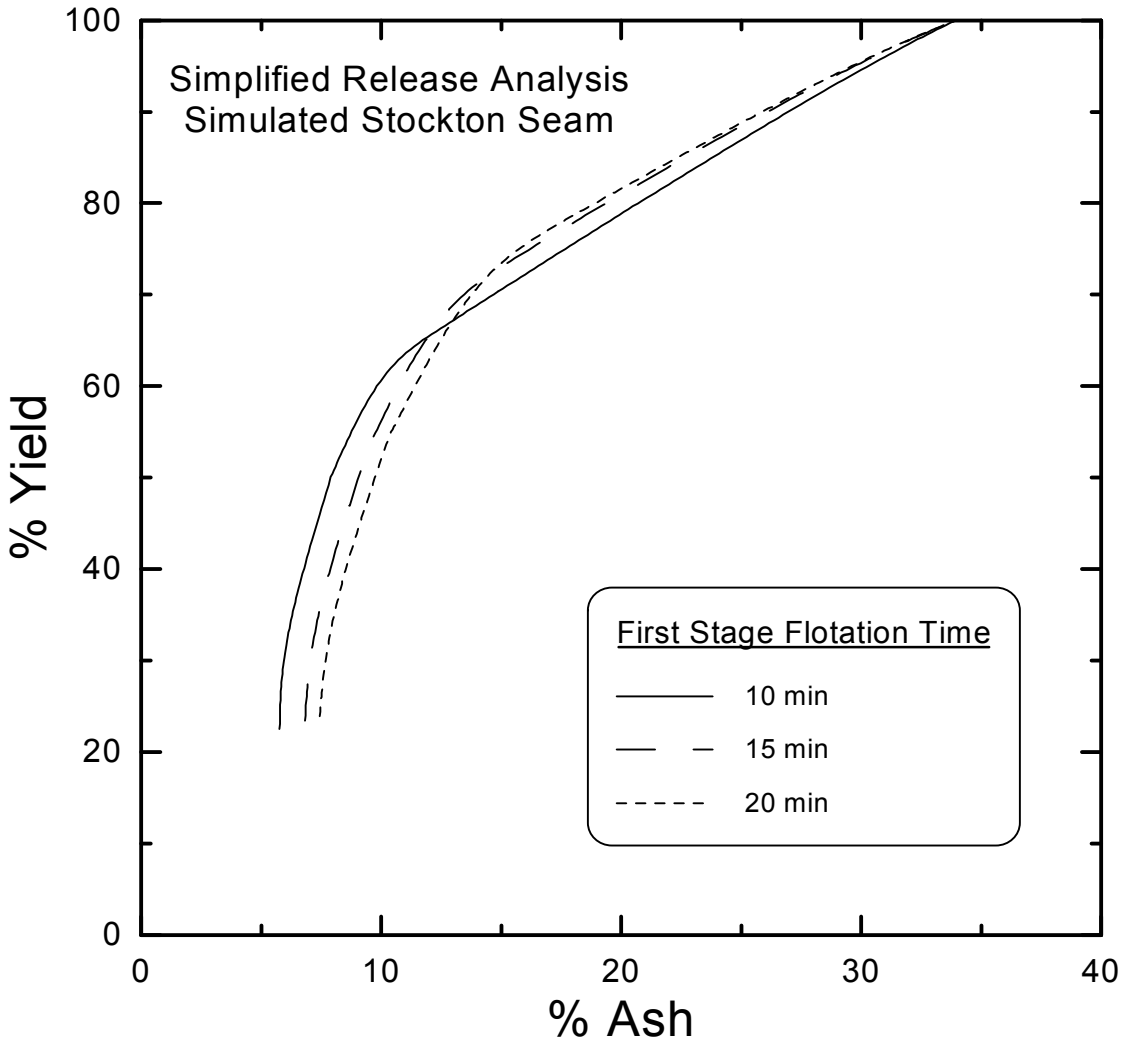

Figure 9. Simulated result showing the effect of first stage flotation time on the yield-vs.-ash curve obtained using simplified release analysis on a simulated Stockton seam coal.

The effect of the number of first stage floats on the yield-vs.-ash curve obtained for the simulated Stockton seam coal is shown in Figure 10. As shown, the curve appears to improve as the number of first stage floats increases. This is due to the continued removal of entrained mineral matter with each additional float. However, the overall change is relatively minor as compared to the change observed with first stage flotation time. Furthermore, the change is almost insignificant after three floats. Thus, the simulations appear to agree with the current practice of using three to four floats in the first stage of the test.

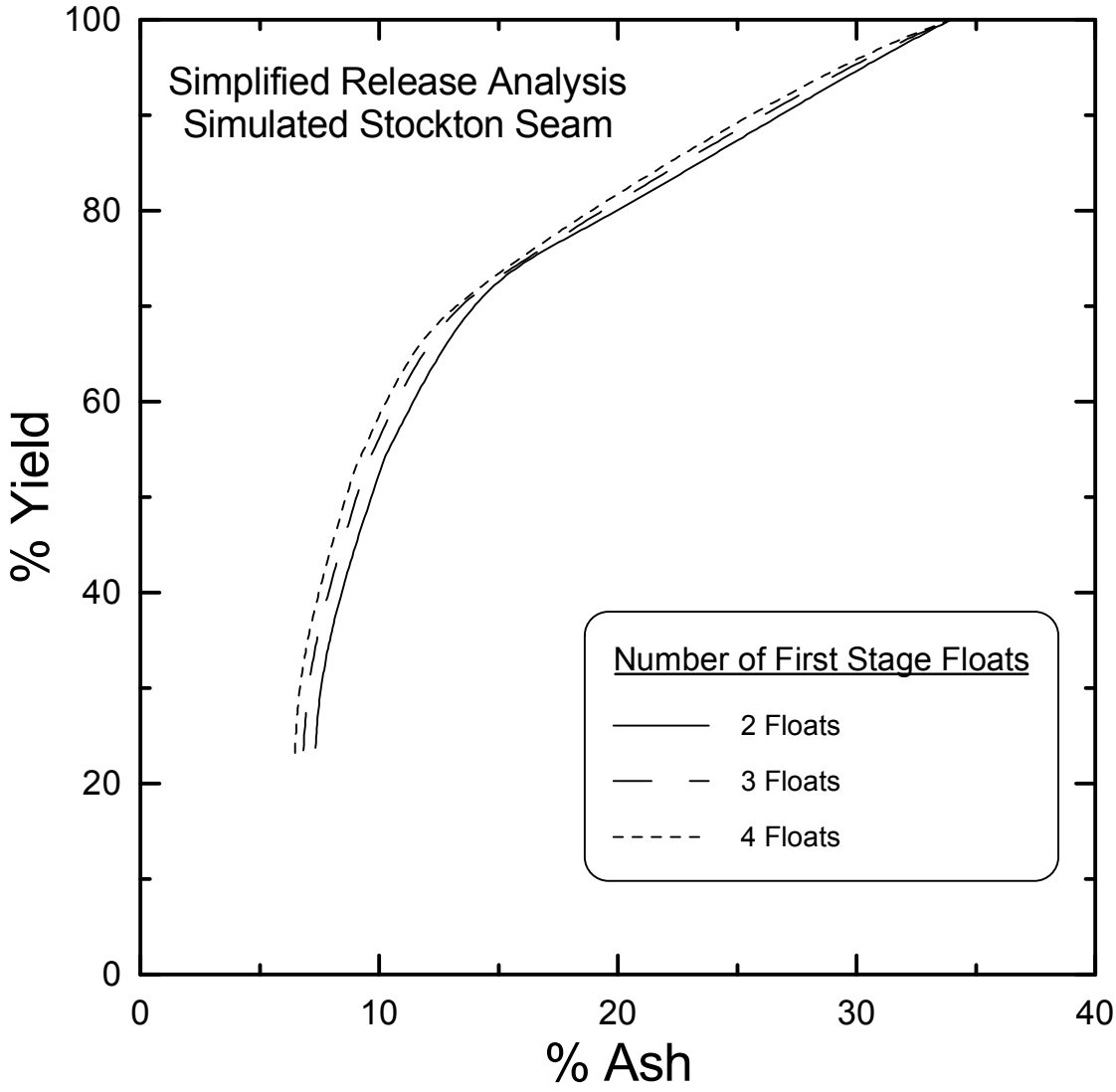

Figure 10. Simulated result showing the effect of number of first stage floats on the yield-vs.-ash curve obtained using simplified release analysis on a simulated Stockton seam coal.

The same simulations conducted on the simulated Stockton seam coal were also performed on the simulated Beckley seam coal to determine if the state-of-release of the coal would make a significant difference in the conclusions. These results are shown in Figures 11 and 12. As shown, the basic conclusions are still the same. When the first stage flotation time is short, the yield-vs.-ash curve extends farther to the left, but the accuracy at the elbow is sacrificed. Once again, a 15 minute flotation time appears to be the most appropriate. In terms of the number of first stage floats, when the number of floats is increased, the yield-vs.-ash curve improves due to the continued removal of entrained mineral matter. In this case, the improvement seems to be greater than was seen with the simulated Stockton seam coal. This is probably due to the fact that the

simulated Beckley seam coal is well-liberated and contains more free or nearly free mineral matter to be entrained. The simulated Stockton seam coal, on the other hand, has a much higher middlings content. Thus, the distinction between the curves is not as great.

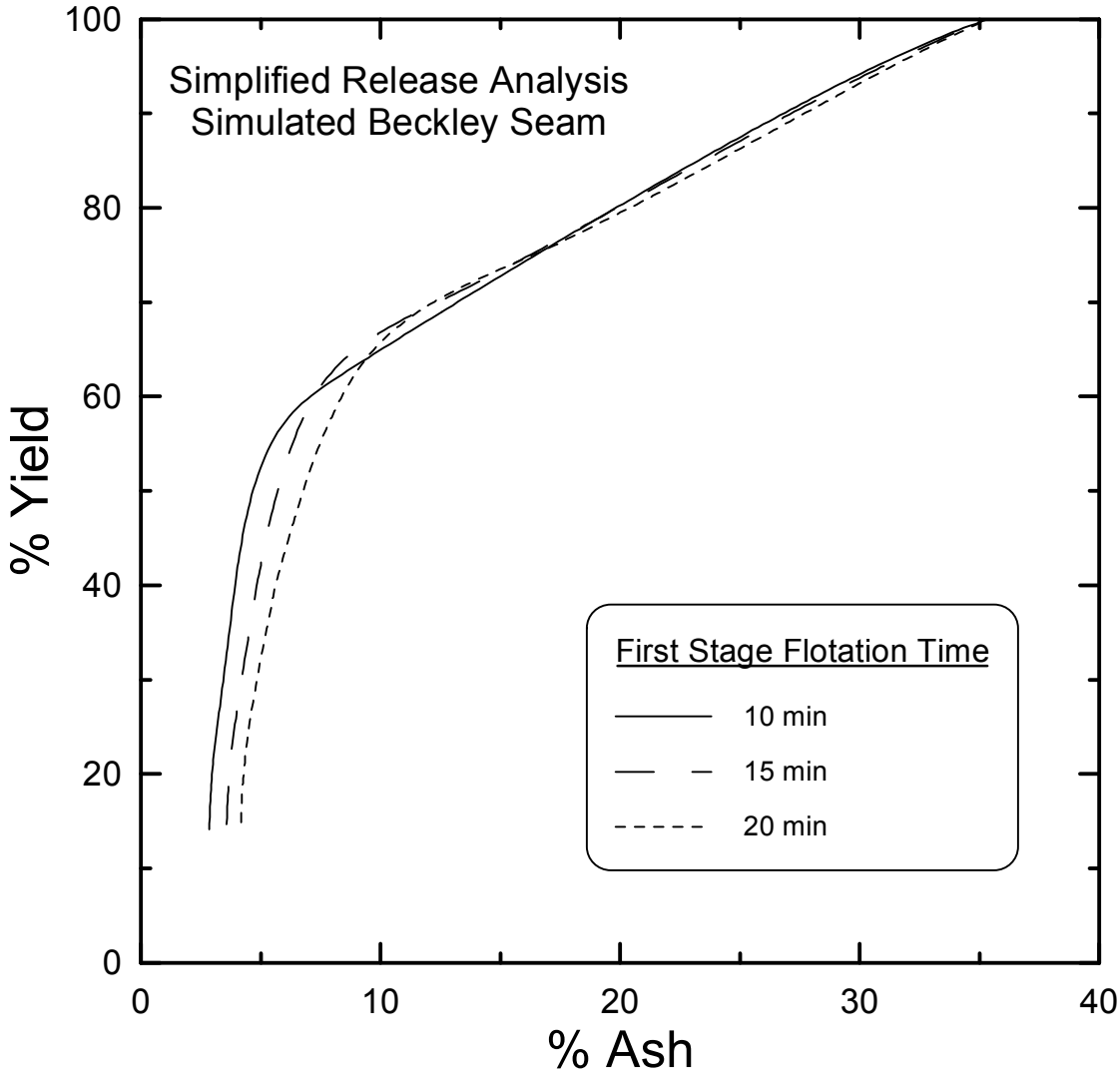

Figure 11. Simulated result showing the effect of first stage flotation time on the yield-vs.-ash curve obtained using simplified release analysis on a simulated Beckley seam coal.

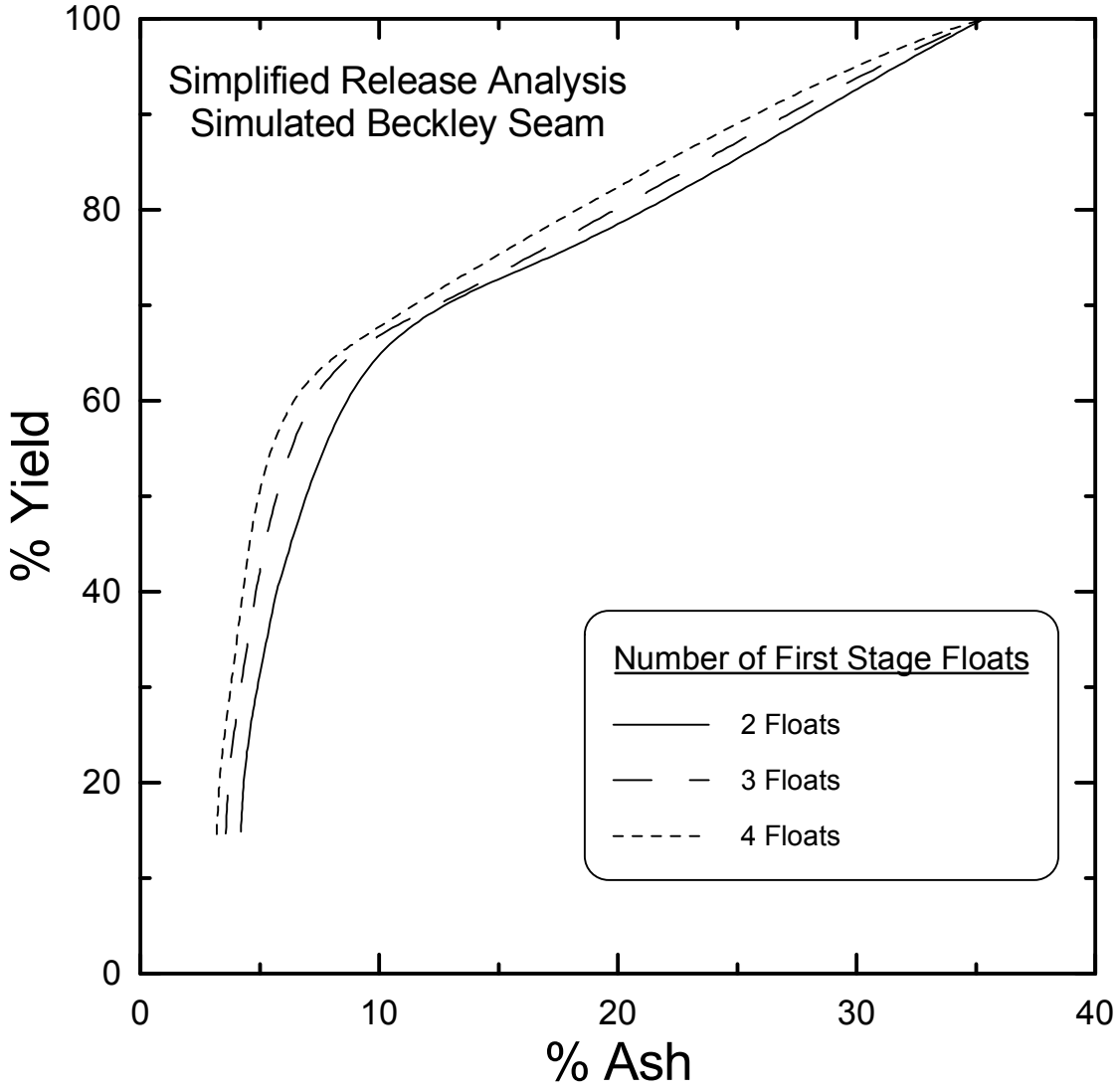

Figure 12. Simulated result showing the effect of number of first stage floats on the yield-vs.-ash curve obtained using simplified release analysis on a simulated Beckley seam coal.

3.2.3 Tree Analysis

The results obtained from the simulations of the tree analysis procedure are shown in Figures 13 - 16. In addition to the comparison between the two coal types, simulations were conducted to study the effect of the number of levels in the tree and the flotation time used in each float.

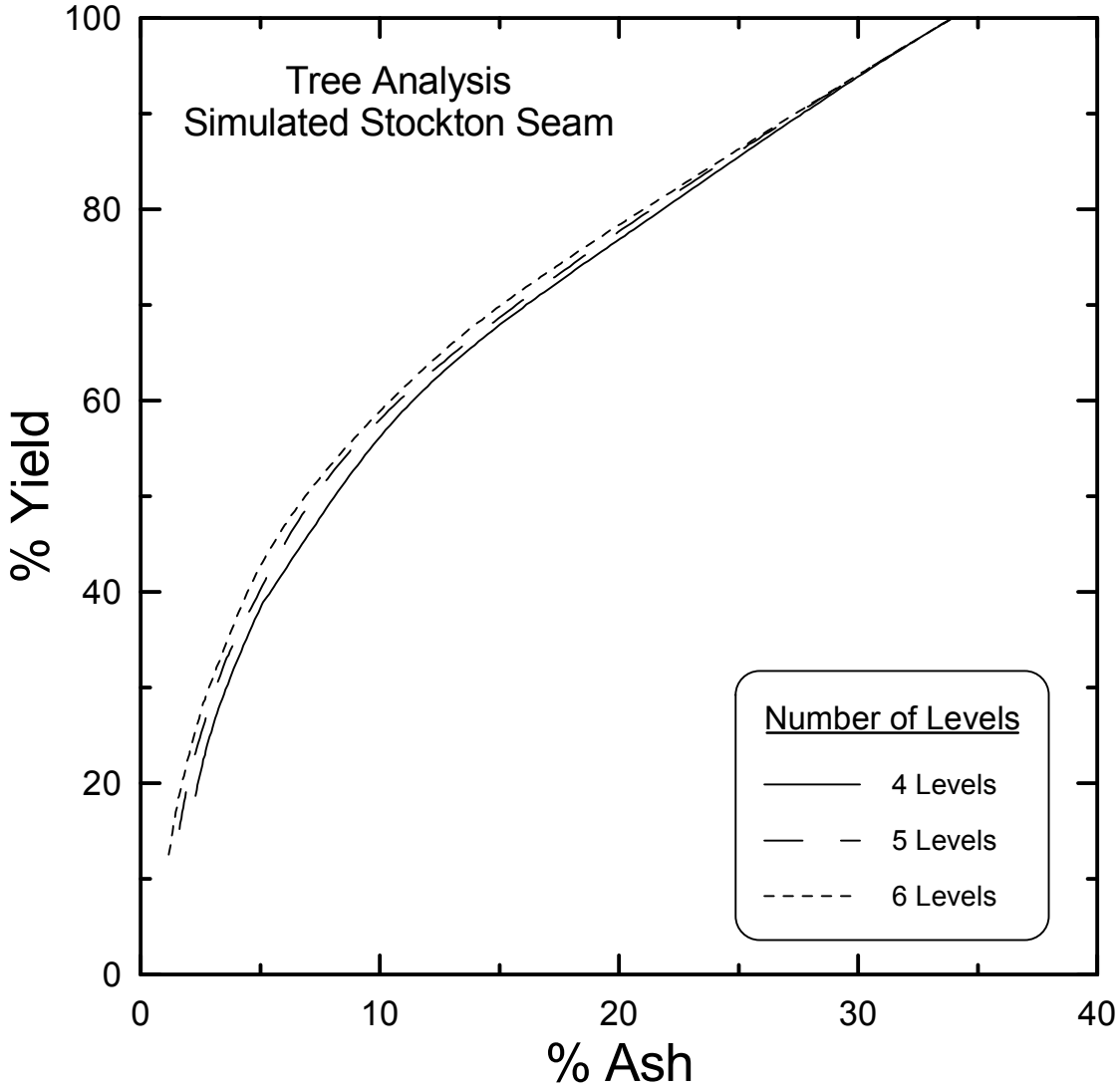

Figure 13. Simulated result showing the effect of number of levels on the yield-vs.-ash curve obtained using tree analysis on a simulated Stockton seam coal.

As shown in Figures 13 and 15, the yield-vs.-ash curve generally improves as the number of levels increases. This is true for both coal samples; although the amount of improvement is relatively small, especially when going from 5 to 6 levels. The improvement in the curve is due to the fact that the sample is being subdivided into smaller and smaller fractions. In theory, it should be possible to continue increasing the number of levels until the sample is divided into individual particles. In such a case, it should be possible to obtain an ideal separation curve. Unfortunately, the number of levels required to achieve this separation would approach infinity. In practice, the procedure is continued until each product contains less than 2% of the original feed. The simulations performed here indicate that this would require at least 5 or 6 levels of

flotation, or 32 to 64 fractions. It is interesting to note from the simulations that a feature of tree analysis is its ability to extend the yield-vs.-ash curve down into the low-ash, low-yield region.

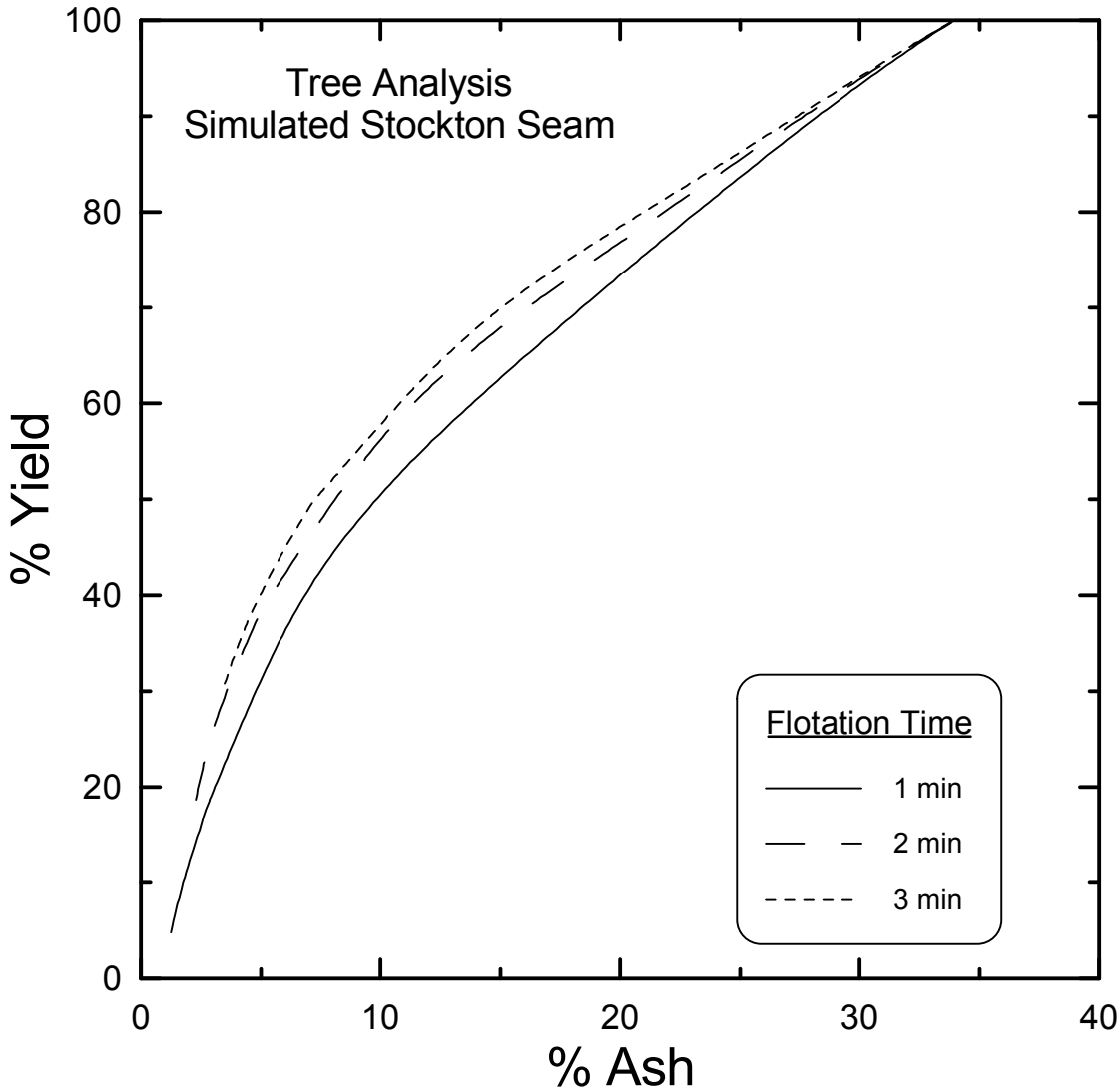

Figure 14. Simulated result showing the effect of flotation time on the yield-vs.-ash curve obtained using tree analysis on a simulated Stockton seam coal.

The effect of flotation time on the tree analysis procedure is shown in Figures 14 and 16. As shown, the yield-vs.-ash curve generally improves as flotation time increases. This is due to the fact that more low-ash material is being shifted to the appropriate side of the tree right from the start. At short flotation times, some low-ash material is misplaced to the reject side of the tree, and this material never makes it back to the proper side. Unfortunately, as flotation time increases, it becomes more difficult to produce low-ash, low-yield points. Thus, this part of the curve tends to move up. Since the biggest jump in the curve appears to occur between flotation times of 1 and 2

minutes, it appears that a 2-minute flotation time is appropriate for this test. In general, there is little difference in any of the conclusions as a function of coal type.

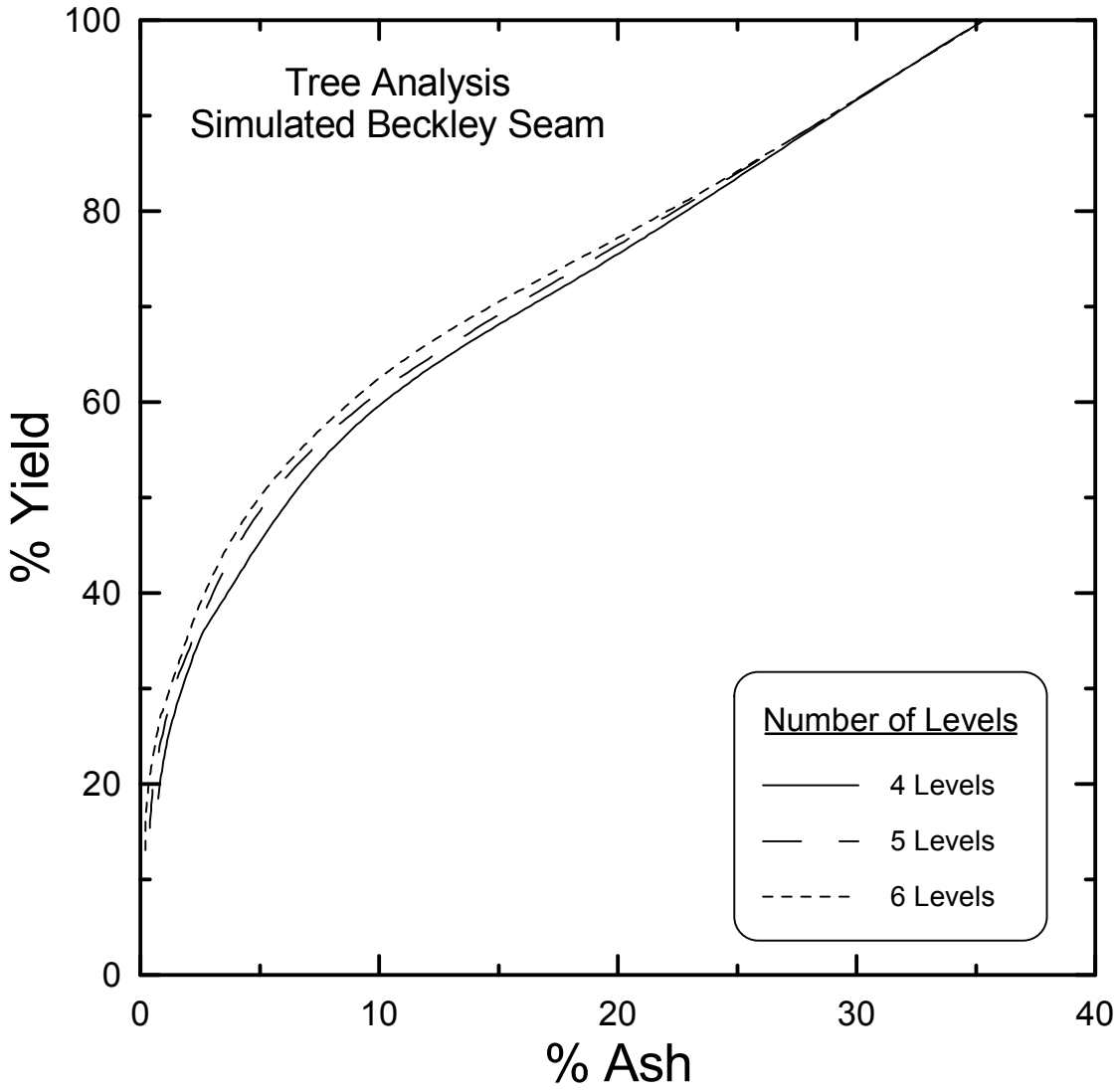

Figure 15. Simulated result showing the effect of number of levels on the yield-vs.-ash curve obtained using tree analysis on a simulated Beckley seam coal.

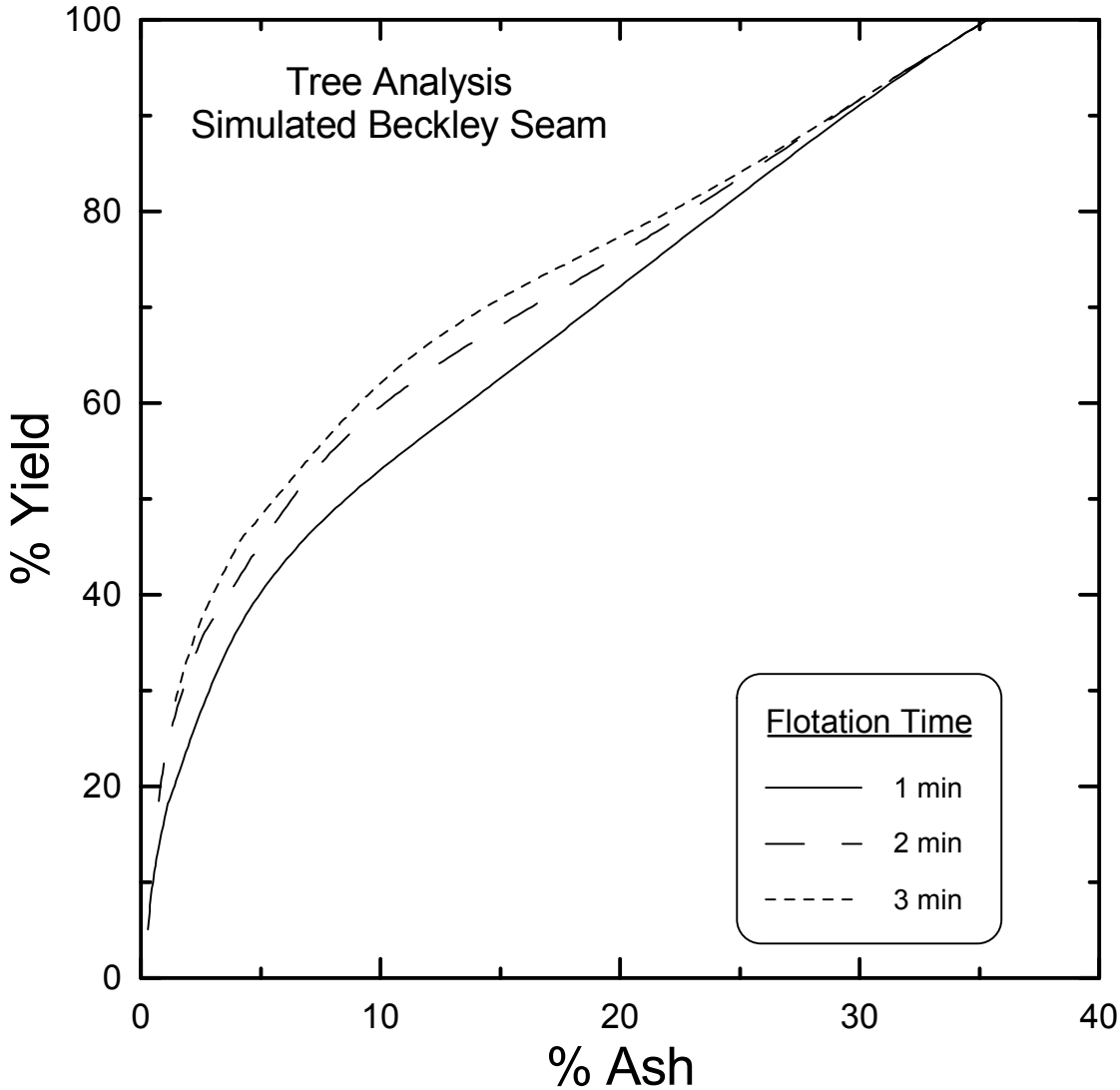

Figure 16. Simulated result showing the effect of flotation time on the yield-vs.-ash curve obtained using tree analysis on a simulated Beckley seam coal.

3.2.4 Comparison

In order to correspond to the experimental comparison, which will be discussed in the following section, the comparison of the simulated results was based on the following criteria. The Cavallaro and Deurbrouck approach was used for the timed release analysis simulation. The simplified release analysis simulation was based on three floats in the first stage with 15 minutes of flotation time in each float. Finally, the tree analysis

simulation was based on a 4 level tree with a 2-minute flotation time for each float. With this as the basis for the comparison, the simulated results are shown in Figures 17 and 18.

As shown in Figure 17 for the simulated Stockton seam coal, the timed release analysis procedure appears to give the best curve overall. Although it is slightly low at the elbow, it extends well out into the low-ash, low-yield region. The simplified release analysis procedure seems to predict a slightly higher yield at the elbow, but it badly misses the low-ash, low-yield end of the curve. This is likely due to the fact that even under the "light" flotation conditions used in the first float of the second stage of this procedure, some high-ash particles still have a finite probability of floating. As a result, the low-ash product from this test can never be as good as is actually possible. This might be the reason why some flotation columns are reported to beat release analysis under low-ash, low-yield conditions (Honaker, Mohanty and Ho, 1995). The timed release analysis procedure, on the other hand, provides more opportunities for this misplaced material to be rearranged into the appropriate fraction due to the successive refloating of timed fractions. The tree procedure also provides multiple opportunities for misplaced material to be rearranged; however, it requires an inordinate amount of tests. Furthermore, misplaced material in the early stages of the tree tends to cause this technique to badly miss the elbow of the optimal yield-vs.-ash curve. This phenomenon was observed experimentally by Pratten, Bensley and Nicol (1989).

In the case of the simulated Beckley seam coal (Figure 18), the conclusions are essentially the same, although the poor performance of the tree procedure at the elbow of the curve is even more pronounced. This may be due to the black-and-white nature of this sample and the fact that the misplaced particles in this case consist predominantly of free mineral matter as opposed to middlings particles.

In general, the simulation results appear to suggest that timed release analysis provides the best overall curve of the three techniques, while simplified release analysis is best around the elbow of the yield-vs.-ash curve. Tree analysis is good at extending into the low-ash, low-yield region of the curve, but it is essentially no better than timed release analysis in this region and it is much worse around the elbow of the curve.

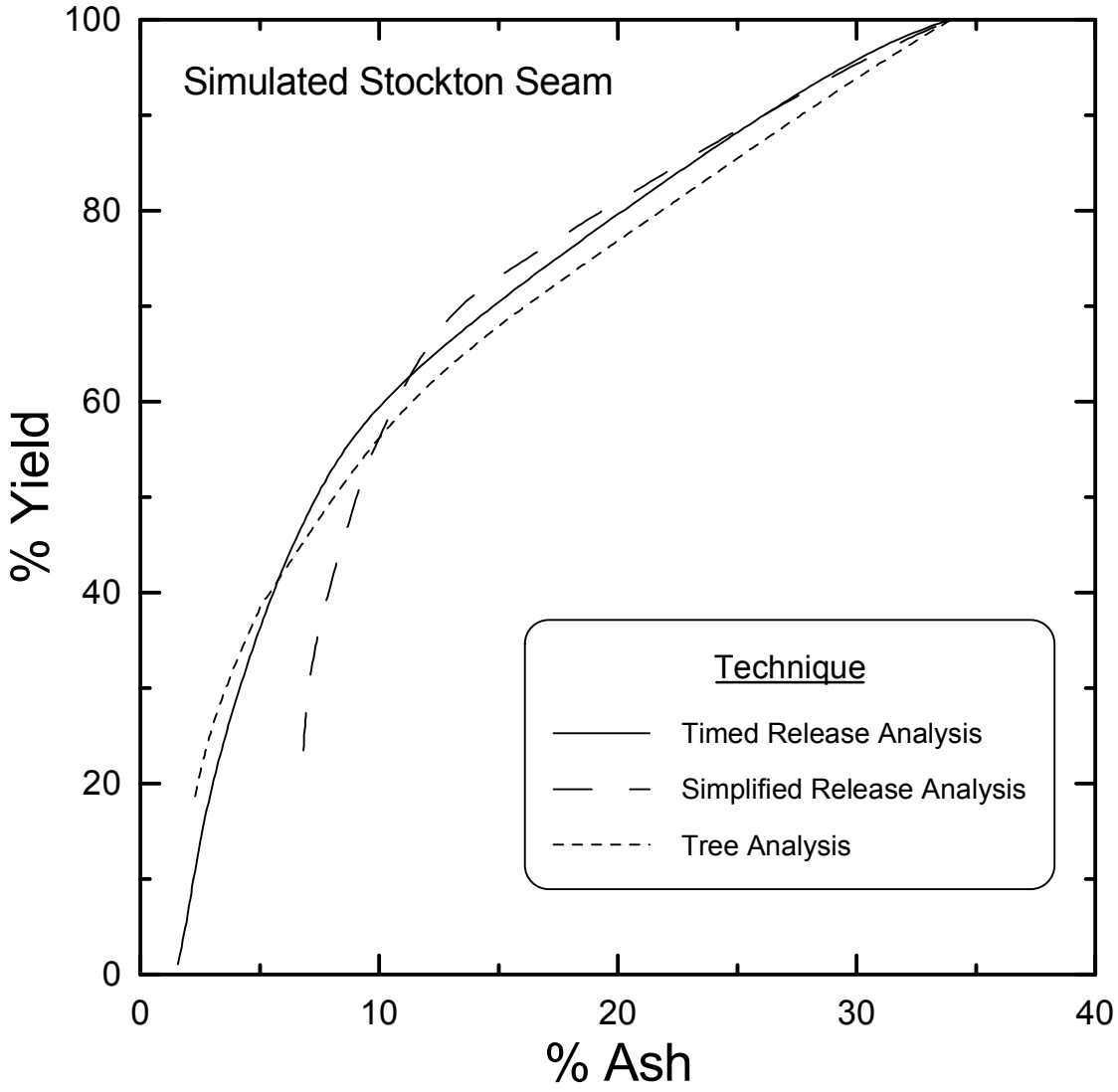

Figure 17. Comparison of yield-vs.-ash curves obtained using simulated timed release analysis (Cavallaro and Deurbrouck procedure), simplified release analysis (3 floats, 15 minute flotation time), and tree analysis (4 levels, 2 minute flotation time) on a simulated Stockton seam coal.

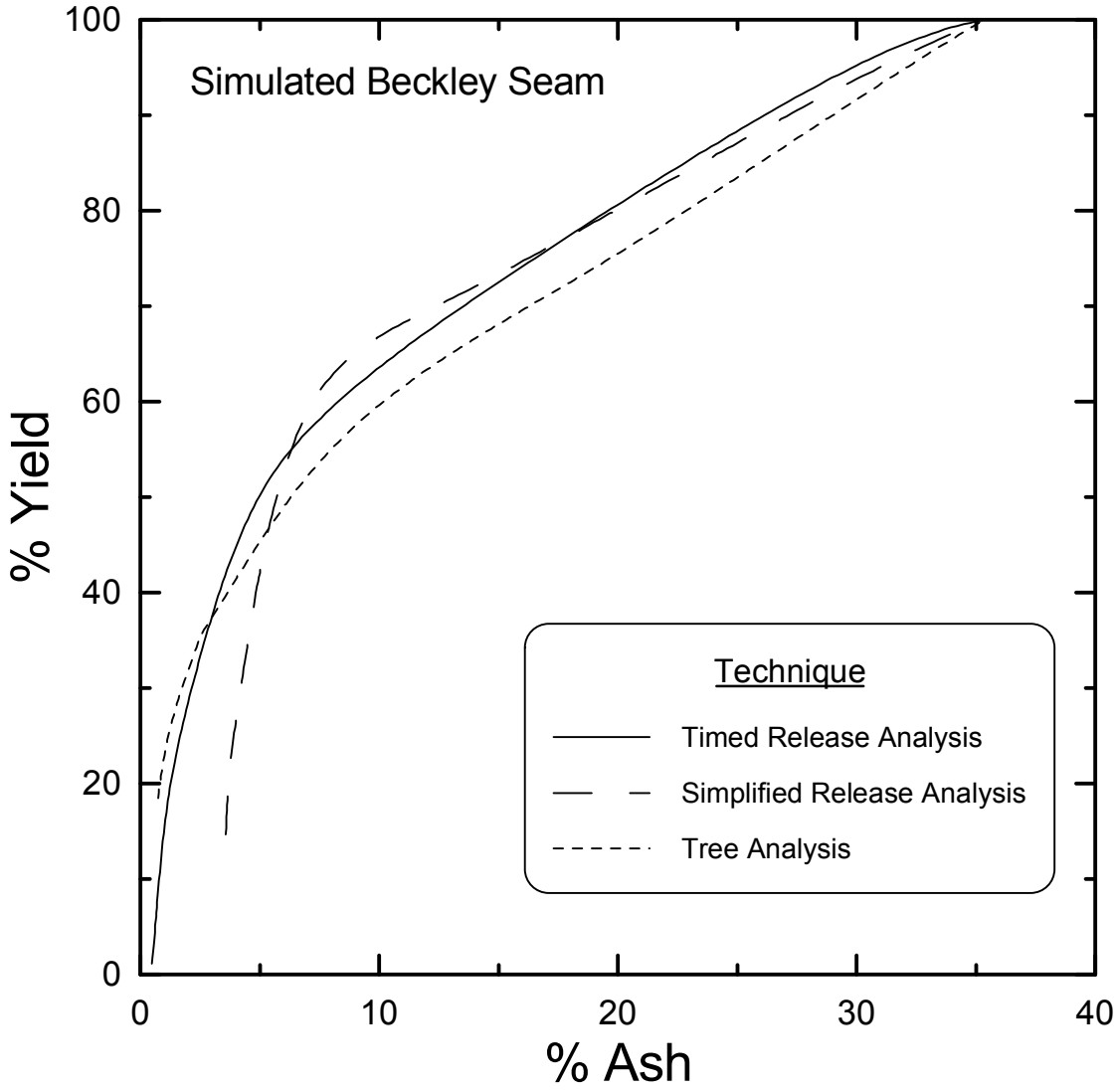

Figure 18. Comparison of yield-vs.-ash curves obtained using simulated timed release analysis (Cavallaro and Deurbrouck procedure), simplified release analysis (3 floats, 15 minute flotation time), and tree analysis (4 levels, 2 minute flotation time) on a simulated Beckley seam coal.

3.3 Experimental

3.3.1 Timed Release Analysis

The experimental results for timed release analysis, performed on samples from the Stockton and Beckley seams, are shown in Figures 19 and 20. In each case, three

tests were conducted to ensure reproducibility. As shown, the tests were very consistent and reproducible with the exception of two low-ash points on the Beckley seam plot (Figure 20). The general shape of the curves supports the findings discussed earlier. That is that the Stockton seam coal is generally considered to have a relatively high middlings content while the Beckley seam coal is generally considered to be well liberated. The previously discussed simulated results (Figures 7 and 8) appear to produce curves that extend farther into the low-ash, low-yield region; however, the general shape of each curve is essentially the same as seen experimentally.

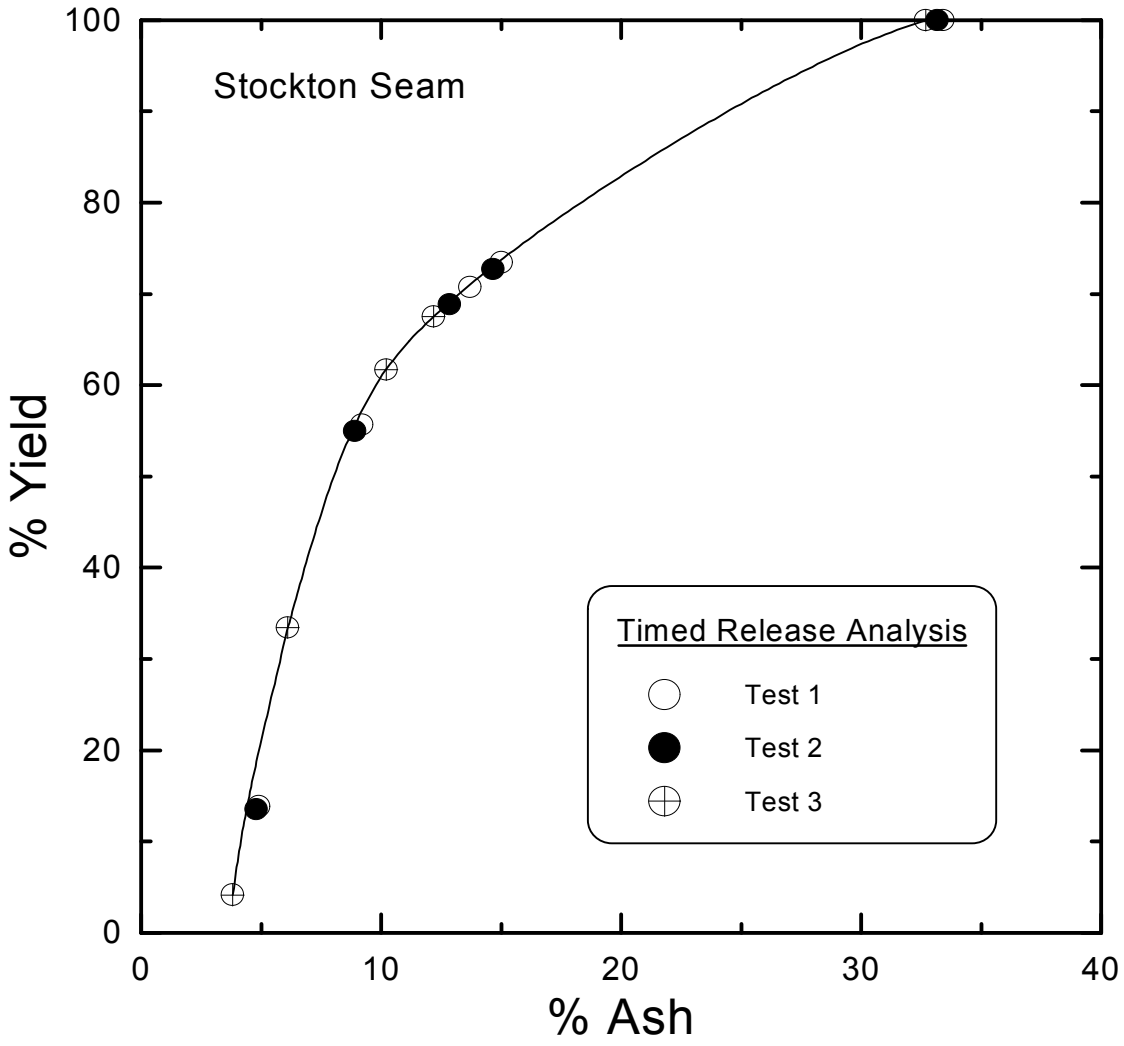

Figure 19. Yield-vs.-ash curve produced from timed release analysis of Stockton seam coal.

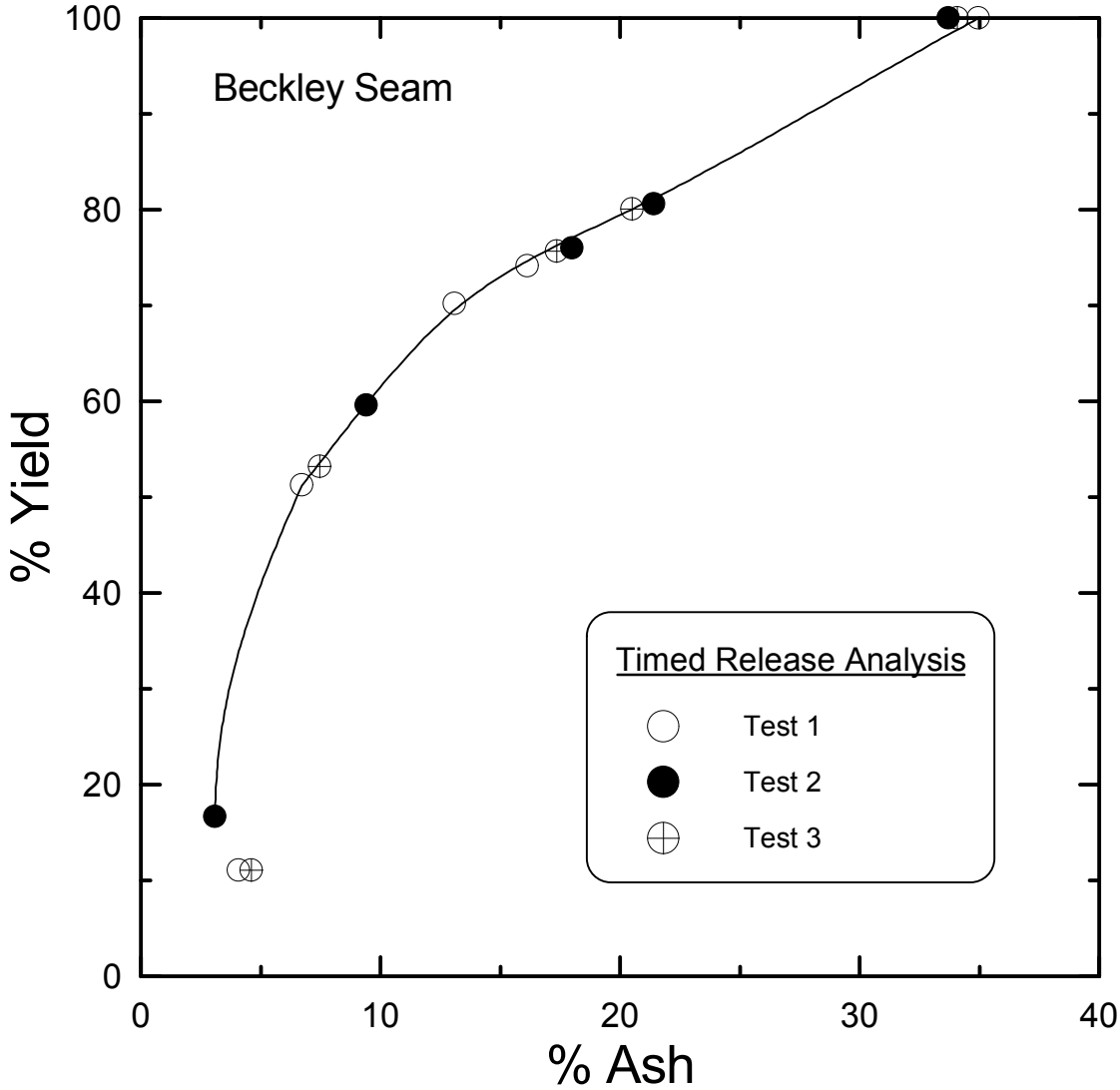

Figure 20. Yield-vs.-ash curve produced from timed release analysis of Beckley seam coal.

3.3.2 Simplified Release Analysis

The experimental results from the simplified release analysis tests are shown in Figures 21 and 22. Once again, with the exception of three low-ash points on the Stockton seam plot (Figure 21), the consistency and reproducibility is remarkable. In this case, the difference in shape of the yield-vs.-ash curves obtained for the two coal

samples is much more pronounced. The gentle curve of the Stockton seam sample indicates a gradual change in particle composition and the presence of middling particles. The abrupt change in the Beckley seam curve is indicative of a black-and-white sample with a high clay content. As compared to the simulated results (Figures 9 - 12), the shapes of the curves are very similar.

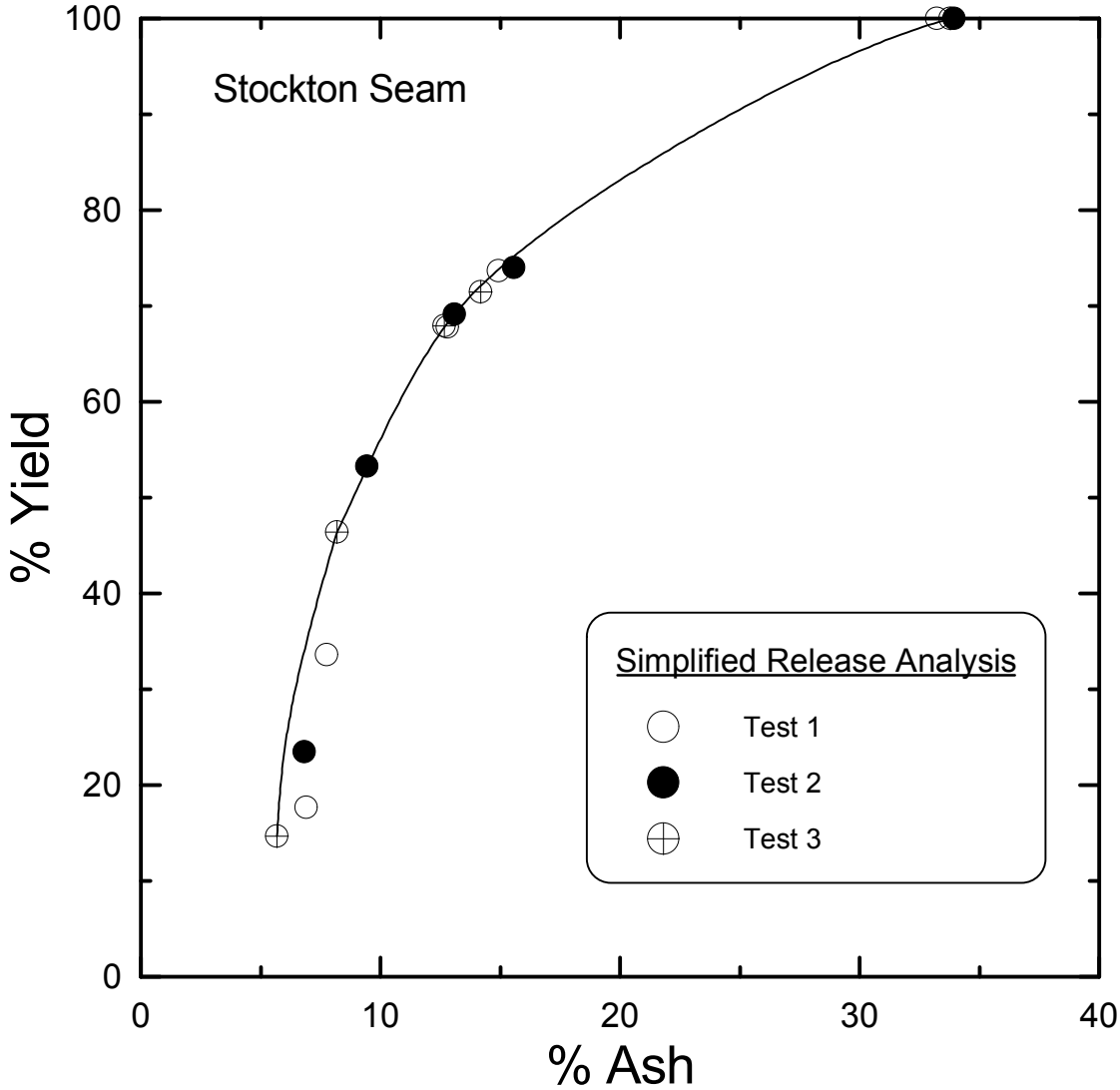

Figure 21. Yield-vs.-ash curve produced from simplified release analysis of Stockton seam coal.

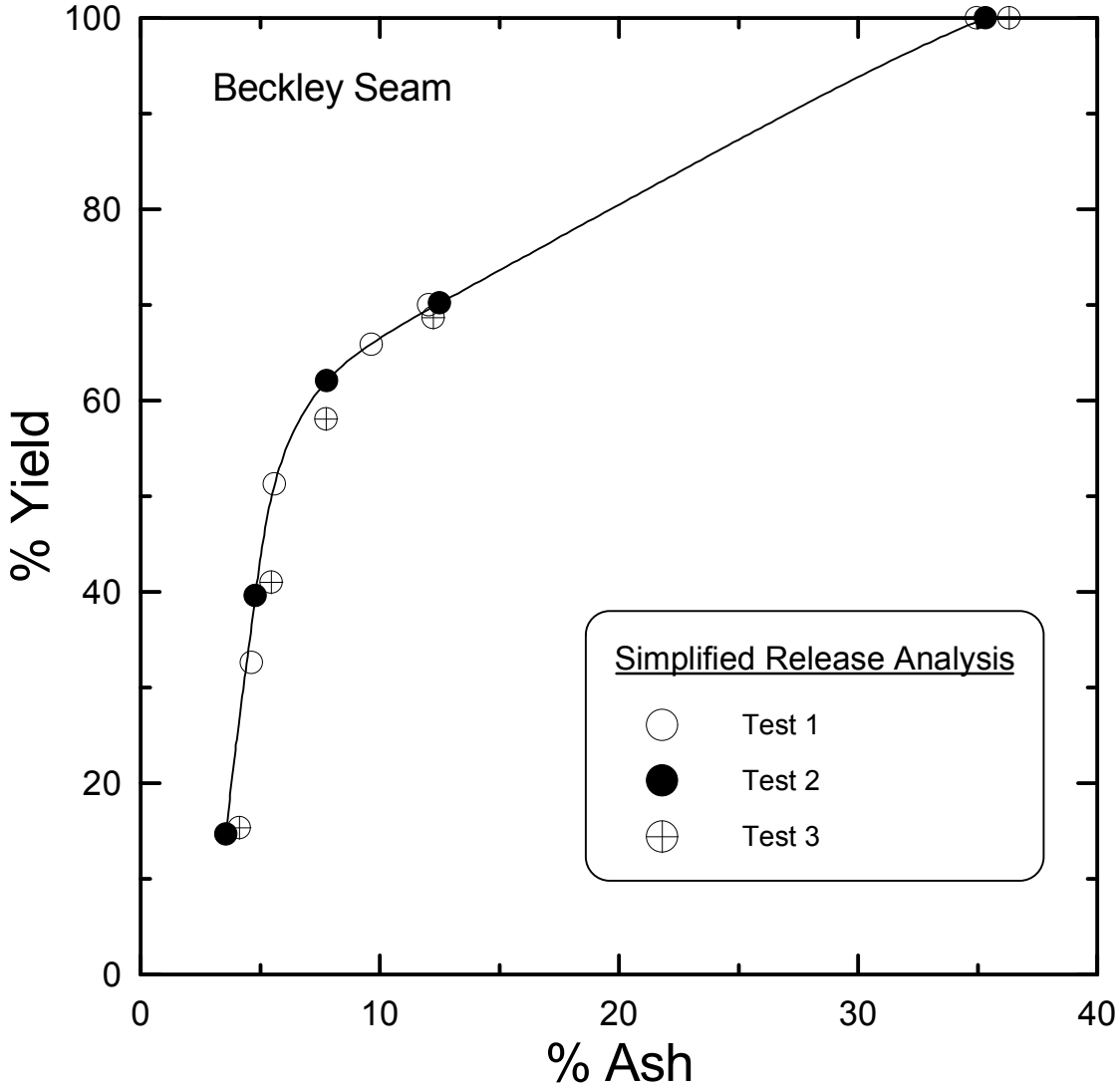

Figure 22. Yield-vs.-ash curve produced from simplified release analysis of Beckley seam coal.

3.3.3 Tree Analysis

The experimental results from the tree analysis tests are shown in Figures 23 and 24. In this case, a four-level tree was used. As shown, the consistency and reproducibility are not nearly as good as with the other two procedures. This is primarily because of the large number of products which must be generated, filtered, weighed, and

analyzed. Each time a product is handled there is room for additional experimental error. With 16 products in each test, this can result in significant data scatter. It is also interesting to note that the four-level tree is not sufficient to push the yield-vs.-ash curve into the low-ash, low-yield region. In fact, both curves are truncated somewhere around 40 - 50% yield. It should be noted that a proper tree analysis requires separating the sample into fractions containing less than 2% of the original sample weight. For these coal samples, a five-level tree or possibly a six-level tree would be required.

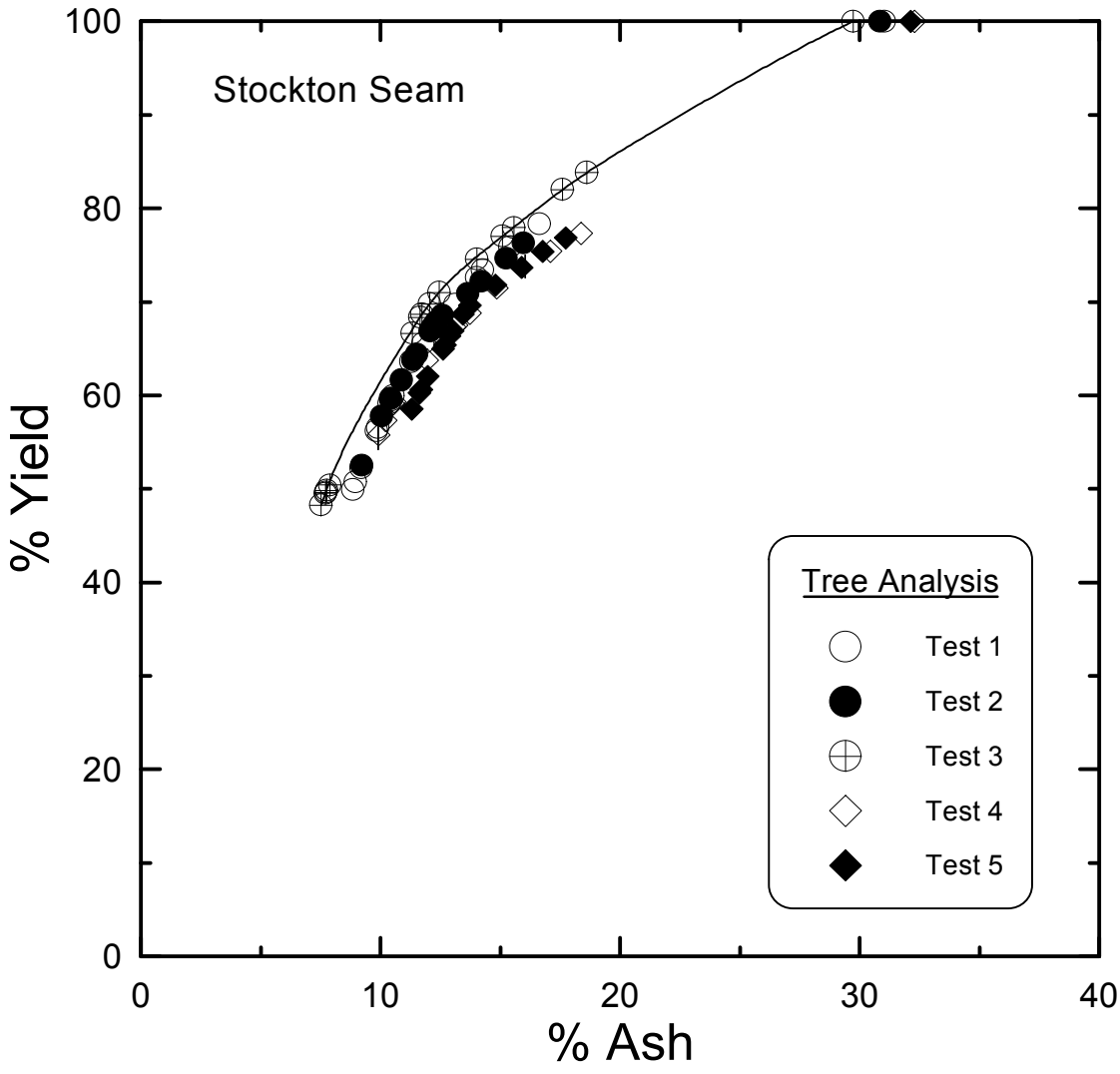

Figure 23. Yield-vs.-ash curve produced from tree analysis of Stockton seam coal.

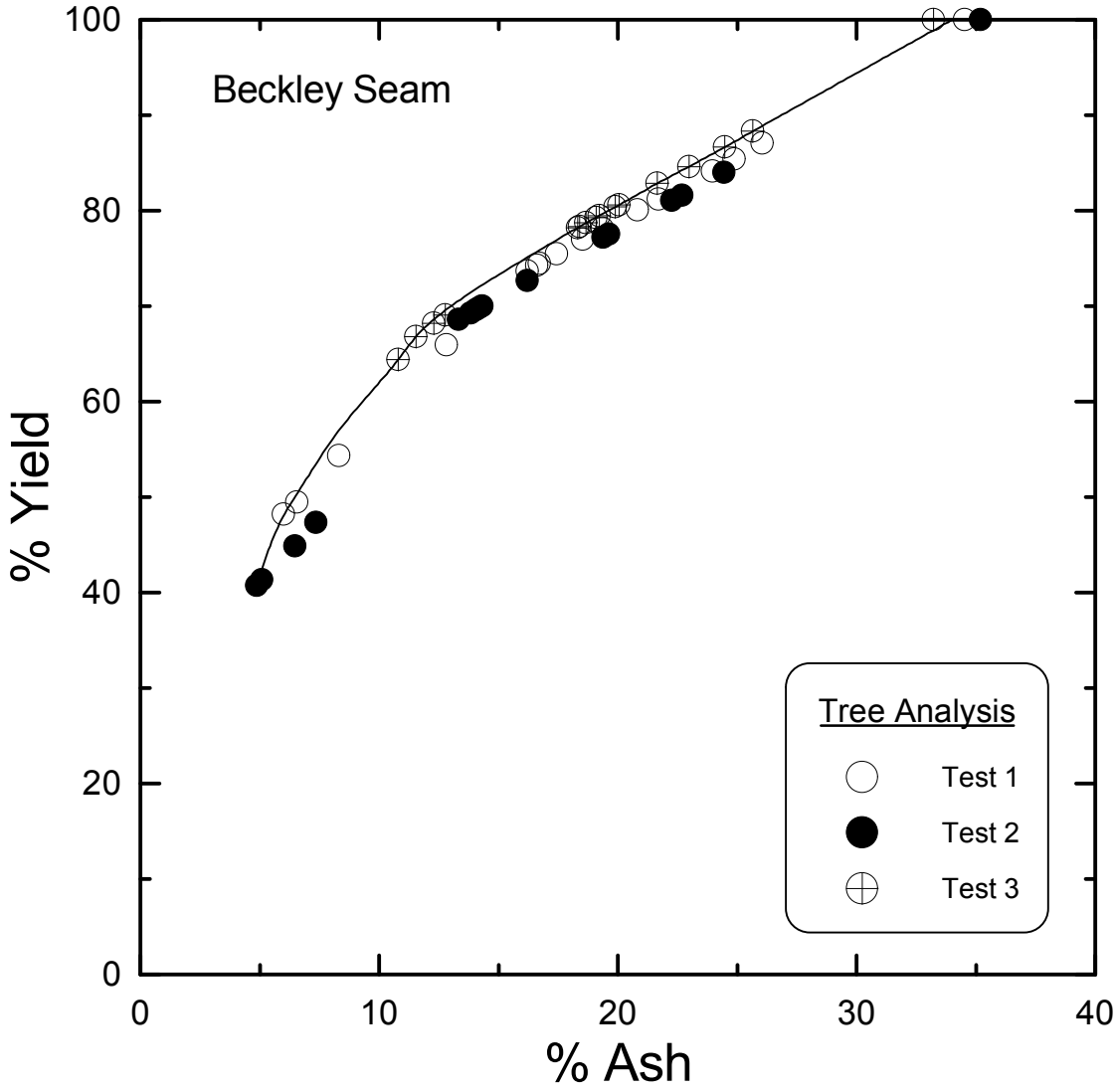

Figure 24. Yield-vs.-ash curve produced from tree analysis of Beckley seam coal.

3.3.4 Comparison

A comparison of all the experimental results for the two coal samples is shown in Figures 25 and 26. Although these figures are somewhat difficult to interpret due to all the experimental data points, it is clear that for the Stockton seam (Figure 25), timed release analysis gives the best result. The tree analysis technique clearly misses the

elbow of the curve and falls short on the low-ash, low-yield end due to the limitations of a four-level tree. The simplified release analysis technique appears to match the timed release procedure up to the elbow, but drops off quickly in the low-ash, low-yield region. These trends can be seen more clearly if the data points are removed and lines are used to represent three tests that have approximately the same feed ash content (Figure 27). As shown, the basic conclusions drawn from the simulations are validated by the experimental results.

For the Beckley seam (Figure 26), the trend is somewhat similar to the simulation but it is not exactly the same. For example, the timed release analysis technique appears to miss the elbow of the curve to a greater extent than is predicted by simulation. Furthermore, the timed release analysis result does not extend as far into the low-ash, low-yield region as one might expect based on simulation. It should be noted, however, that because this coal is well liberated, the points at the low-ash end of the curve are already below 5% ash. Thus, the exaggerated difference that can be seen in a computer simulation, may be difficult to see in an actual experiment. Once again, as was the case with the Stockton seam sample, the tree analysis technique misses the elbow of the curve and is truncated prior to the low-ash, low-yield region. Although it is not as far below the other curves, as predicted by simulation, it still appears to be inferior. These results can be more clearly seen in Figure 28 where the data points have been removed.

In this instance, the timed release analysis technique would be preferred by simulation, but the simplified release analysis technique appears better from the experimental result. This may be due to the well-liberated nature of the Beckley sample, and good performance in the first stage of the simplified release analysis procedure in separating the floatable material from the non-floatable material.

In short, the experimental results suggest that timed release analysis provides the best overall curve for the Stockton sample, while simplified release analysis appears better for the Beckley sample. In both cases, simplified release analysis is good at locating the elbow of the yield-vs.-ash curve. The four-level tree analysis procedure appears to be inferior to both techniques since it falls well below the elbow of the yield-vs.-ash curve and is truncated prior to the low-ash, low-yield region of the curve.

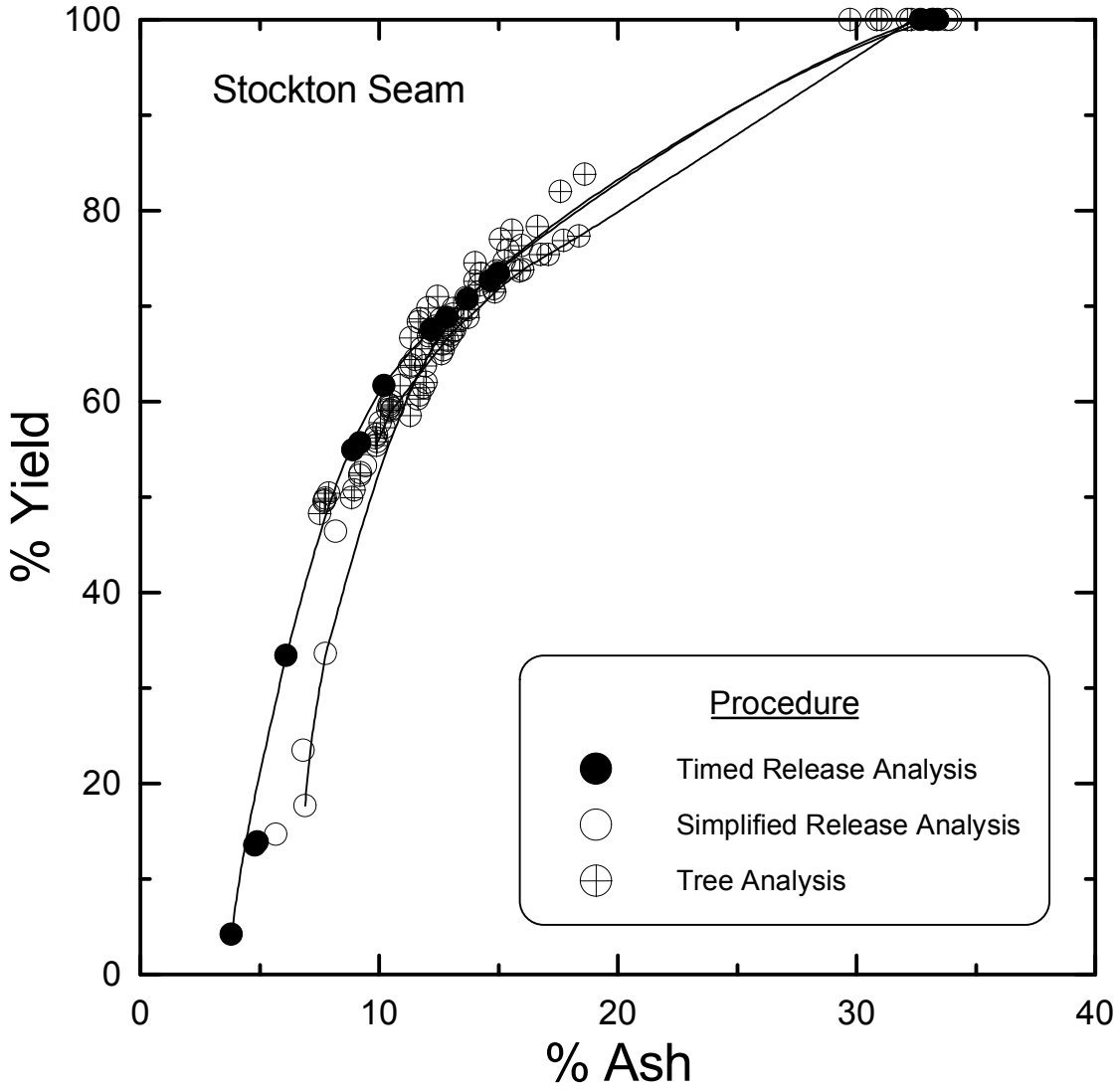

Figure 25. Comparison of yield-vs.-ash curves obtained using timed release analysis, simplified release analysis, and tree analysis on Stockton seam coal.

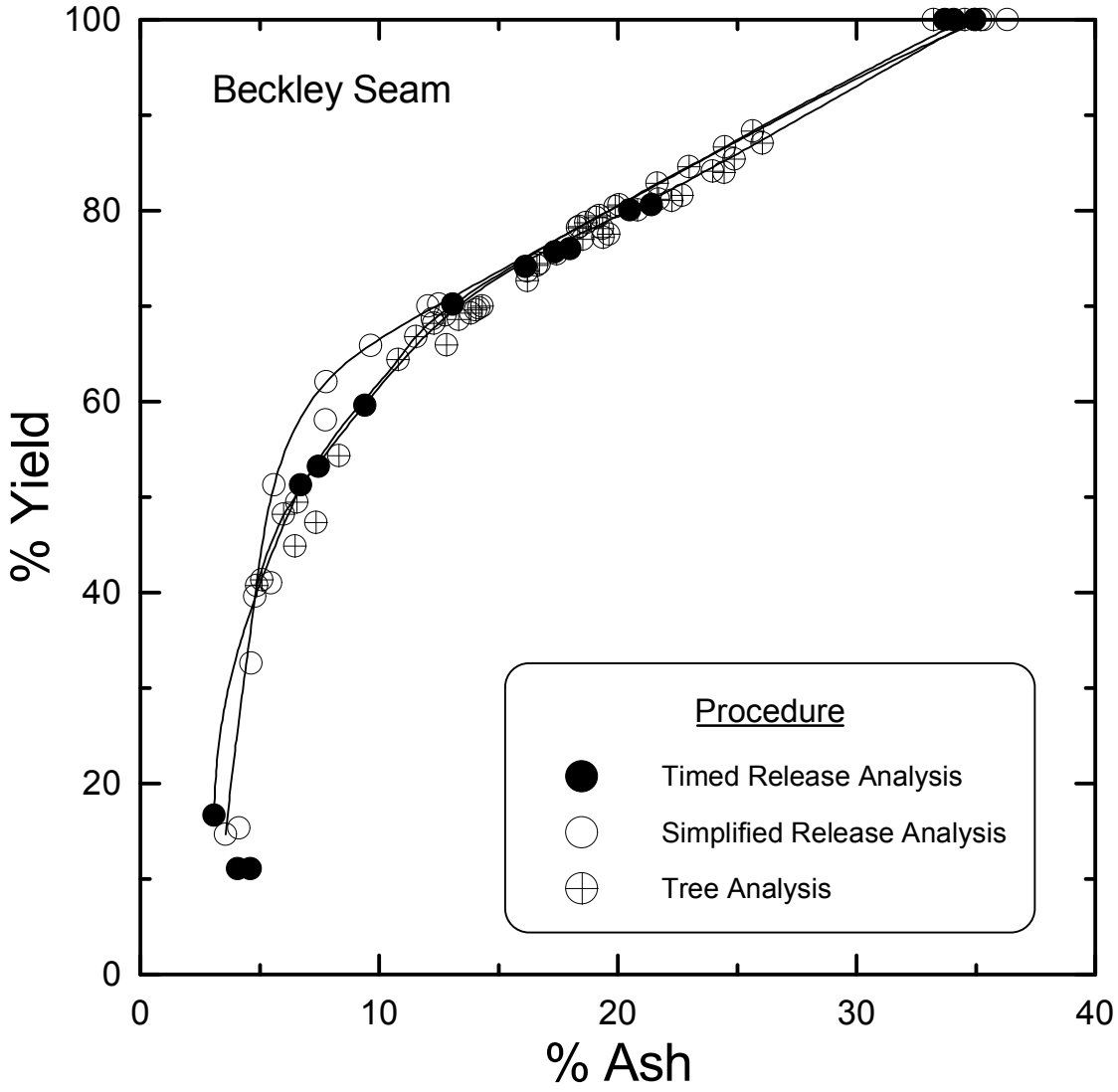

Figure 26. Comparison of yield-vs.-ash curves obtained using timed release analysis, simplified release analysis, and tree analysis on Beckley seam coal.

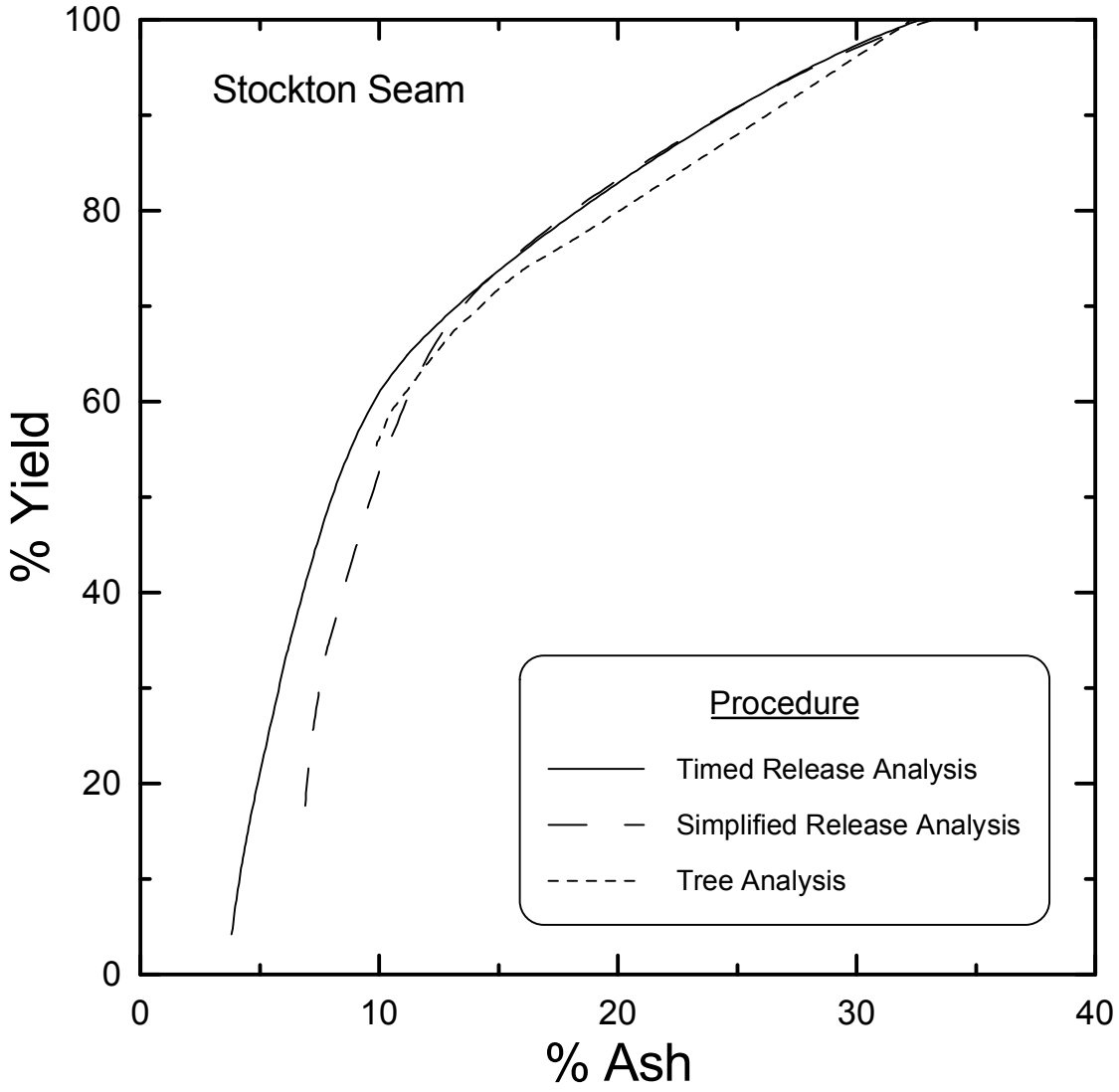

Figure 27. Comparison of yield-vs.-ash curves obtained using timed release analysis, simplified release analysis, and tree analysis on Stockton seam coal (experimental data points removed).

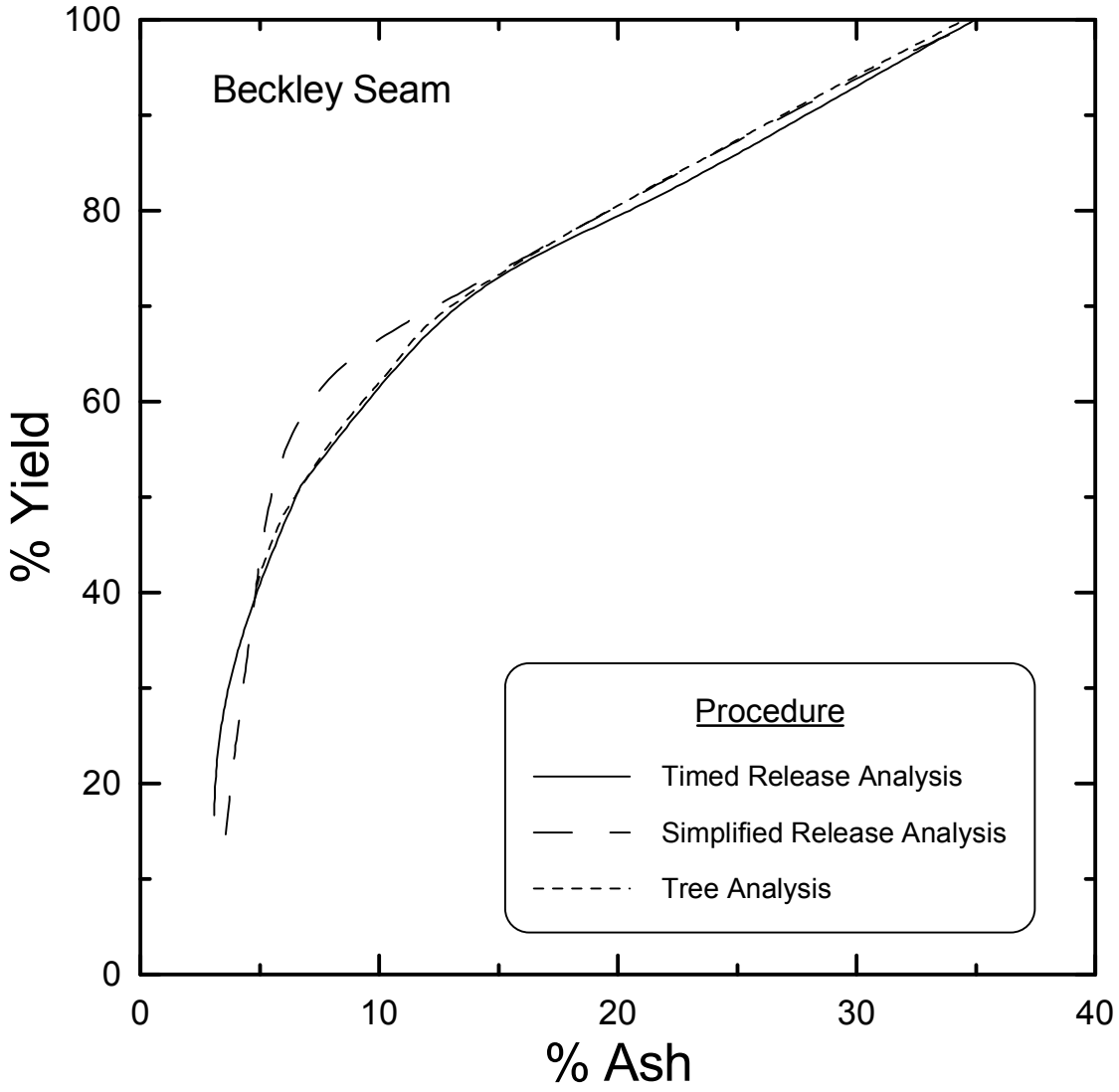

Figure 28. Comparison of yield-vs.-ash curves obtained using timed release analysis, simplified release analysis, and tree analysis on Beckley seam coal (experimental data points removed).

3.4 Comparison of Simulated and Experimental Results

A comparison of the experimental and simulated release curves for all of the different procedures tested is shown in Figures 29 and 30. As shown, the agreement in the general trends of the curves and even in the magnitudes of the numbers is remarkable considering the rather simple modeling approach used in this investigation. The major findings from this comparison can be summarized as follows.

1. Timed release analysis provides the best overall release curve from the simulated results and from the experimental results obtained for the Stockton seam sample. The timed release analysis procedure is able to extend the yield-vs.-ash curve well into the low-ash, low-yield region. While it may produce a curve that is slightly below the simplified release analysis curve at the elbow, this difference is generally small.

2. Simplified release analysis tends to give the highest yield at the elbow of the yield-vs.-ash curve in both the simulations and the experimental tests. Unfortunately, this procedure tends to drop of very fast in the low-ash, low-yield region. This tendency is due to the fact that even a high-ash particle has a finite probability of floating with the best fraction of the simplified release analysis procedure. Thus, this procedure has an inherent problem in generating the proper curve in the low-ash, low-yield region. The simplified release analysis procedure seems to work best with well-liberated samples. This statement is supported by the fact that it produced the best result in experimental tests conducted on the well-liberated Beckley seam sample.

3. Tree analysis is capable of generating yield-vs.-ash curves which extend into the low-ash, low-yield region; however, this requires a tree with many levels (i.e., 5 or 6). A four-level tree tends to produce yield-vs.-ash curves that are truncated at relatively high yields. This is more evident in the experimental results than in the simulations, although it is evident in both cases. Both the simulations and the experimental tests show that the tree procedure is not good for locating the elbow of the curve. This conclusion was also noted by Pratten, Bensley and Nicol (1989).

4. In general, timed release analysis appears to be the best procedure, followed by simplified release analysis and tree analysis.

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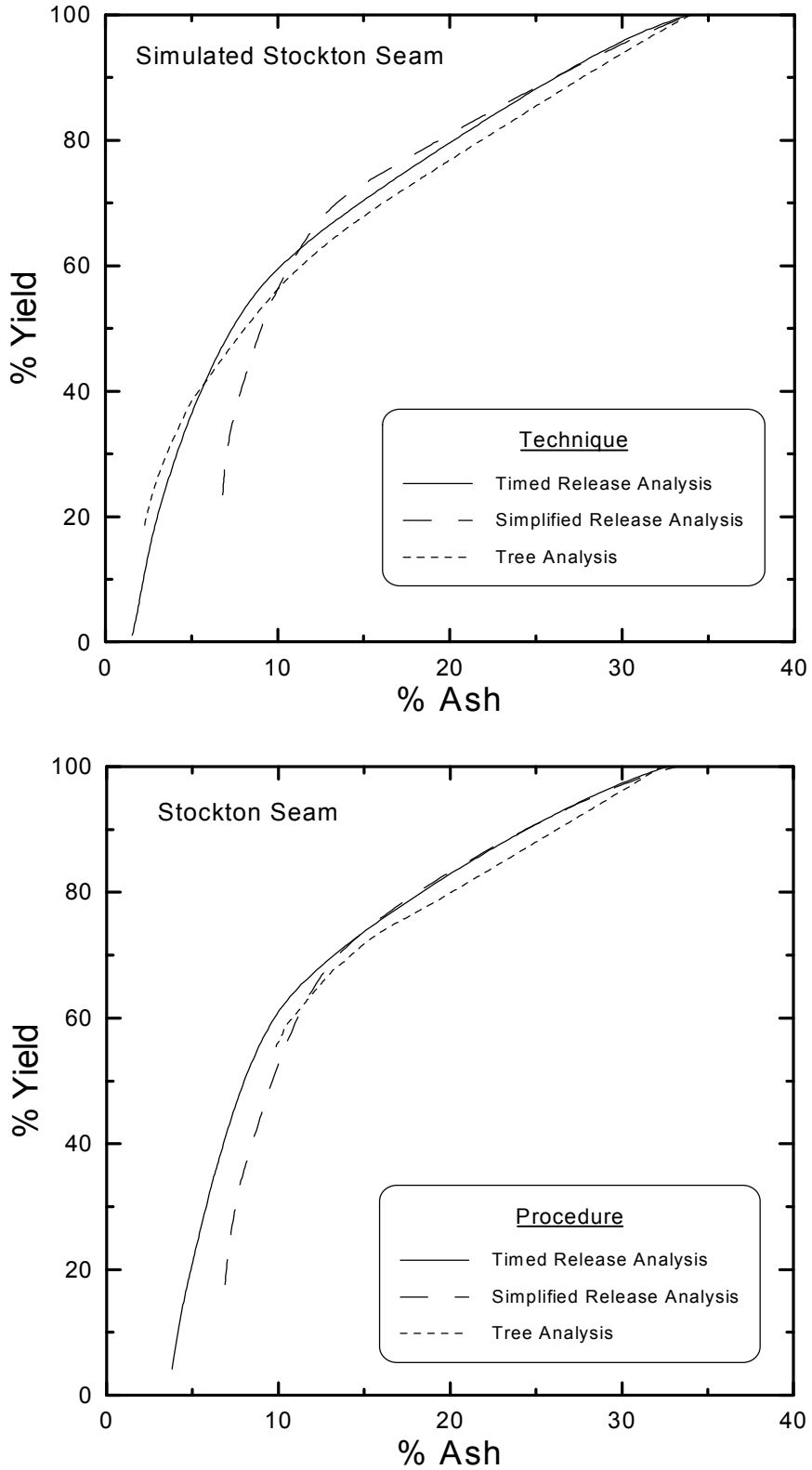

Figure 29. Comparison of simulated and experimental release analysis procedures for Stockton seam coal.

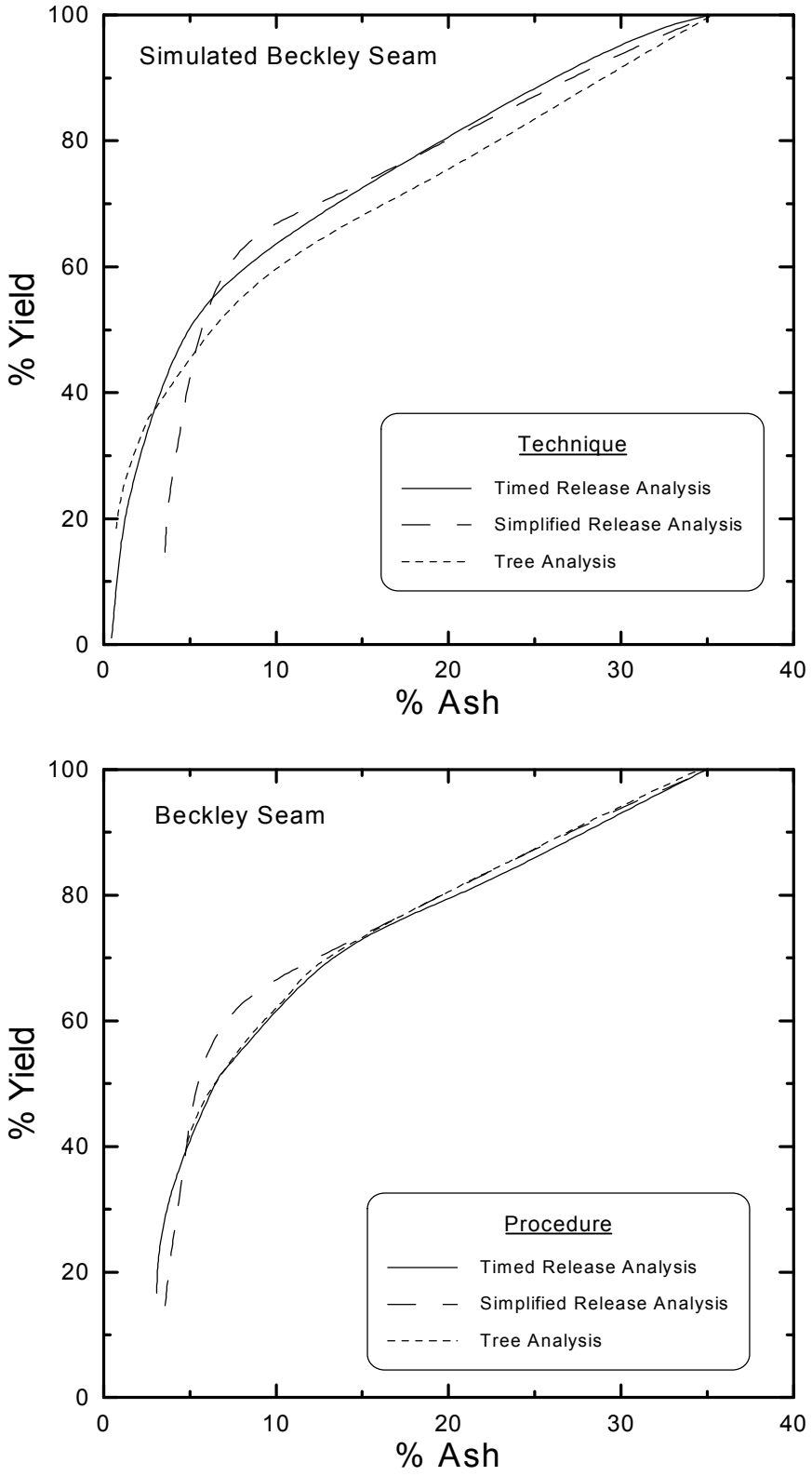

Figure 30. Comparison of simulated and experimental release analysis procedures for Beckley seam coal.