CHAPTER 4
ALTERNATIVE METHODS

4.1 Introduction

As a result of the comparison of the three release analysis procedures presented in
Chapter 3, it is now possible to determine which procedure produces the best yield-vs.-
ash curve. However, it is still unclear whether a new procedure can be devised which
can produce a better curve, or whether any of these procedures come near to achieving
the ideal flotation separation. Clearly, each of the common procedures has its
advantages. For example, the timed release analysis technique seems to produce the best
overall curve, but it is somewhat deficient at the elbow. The simplified release analysis
curve is good at locating the elbow, but it is not able to accurately represent the low-ash,
low-yield portion of the curve. The tree analysis technique is capable of representing the
low-ash, low-yield portion of the curve, but it is deficient at the elbow and it requires an
inordinate amount of tests.

The purpose of this chapter is to present a new method for improving the release
analysis curve based on a modification of the simplified release analysis procedure. In
addition, a concept for producing an ideal separation curve is presented.

4.2 Reverse Release Analysis

4.2.1 Introduction

As discussed previously, the simplified release analysis technique is good at
locating the elbow of the yield-vs.-ash curve; however, it is not good in the low-ash, low-
yield region. This is primarily a result of inherent problems in the second stage of the
simplified release analysis procedure. In the second stage of the procedure, where the
sample is separated into fractions of increasing ash content, the fractionation procedure is
begun by using low aeration rates and low impeller speeds in the flotation cell. The
aeration rate and impeller speed are then increased in each subsequent float. The idea is
to generate a very low ash fraction in the first stage, and fractions of increasing ash
content in subsequent stages. Unfortunately, even with low aeration rates and low
impeller speeds, a high ash particle still has a finite probability of reporting to the
flotation concentrate. Since these misplaced particles have no subsequent chance of
being redistributed, they end up contaminating the low-ash product. Thus, the simplified
release analysis procedure can never generate a good result in the low-ash, low-yield
region. On the other hand, the separation of floatable material from non-floatable
material in the first stage of the process is a good means of locating the elbow of the
yield-vs.-ash curve.

Thus, a better way of performing the second stage of the simplified release
analysis procedure is to use intense flotation conditions in the first float, save the tailings
for analysis, and refloat the concentrate under less intense conditions. This procedure
can be repeated for as many floats as is necessary, just as in the present simplified release
analysis procedure. The final concentrate then becomes the low-ash product, and the tailings from each of the previous floats can be added back to this product to generate the cumulative yield-vs.-ash curve. The advantage of this procedure is that high-ash particle have several opportunities to be removed before they can end up in the low-ash product. Furthermore, the low-ash product is produced from a much lower-ash feed material than is the case with the current procedure. Finally, the low-ash, low-yield end of the release curve can simply be extended by adding more floats to the second stage of the test. Because the second stage is carried out in reverse order, this procedure is being called reverse release analysis and is illustrated schematically in Figure 31.

Figure 31. Schematic diagram of the reverse release analysis procedure.

4.2.2 Simulation

Simulations of the reverse release analysis procedure were conducted using the same procedural model as described previously for simplified release analysis; however, the order of the floats in the second stage was reversed. These simulations are shown in Figures 32-35.

As shown in Figure 32, the yield-vs.-ash curves are now extended farther into the low-ash, low-yield region than was the case with the traditional simplified release analysis approach (Figure 9). However, the elbow of the curve is still just as good. Once
again, a first-stage flotation time of 15 minutes appears to be most appropriate. Figure 33 appears to indicate that additional first-stage floats can improve the curve, but the improvement is relatively small, as was noted for the traditional simplified release analysis technique (Figure 10).

Figure 32. Simulated result showing the effect of first stage flotation time on the yield-vs.-ash curve obtained using reverse release analysis on a simulated Stockton seam coal.
Figure 33. Simulated result showing the effect of number of first stage floats on the yield-vs.-ash curve obtained using reverse release analysis on a simulated Stockton seam coal.
Similar results were observed for the Beckley seam (Figures 34-35) as were found for the Stockton seam; however, as was the case with the simplified release analysis technique, the number of first stage floats was much more significant for the well-liberated Beckley seam coal than for the Stockton seam coal. Overall, it appears that factors which affect the first stage of the reverse release analysis procedure, have much less impact on the second stage than is the case for the simplified release analysis procedure.

Figure 34. Simulated result showing the effect of first stage flotation time on the yield-vs.-ash curve obtained using reverse release analysis on a simulated Beckley seam coal.
Figure 35. Simulated result showing the effect of number of first stage floats on the yield-vs.-ash curve obtained using reverse release analysis on a simulated Beckley seam coal.
Comparisons of the simulated results for all four techniques are shown in Figures 36 and 37. In both cases, the advantages of the reverse release analysis procedure are very clear. The new procedure is able to locate the elbow of the yield-vs.-ash curve just as well as the simplified release analysis procedure; however, it is also able to extend the curve into the low-ash, low-yield region of the scale in a manner similar to the timed release analysis procedure. At the same time, the new procedure offers the experimental simplicity of the simplified release analysis procedure.

Figure 36. 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), tree analysis (4 levels, 2 minute flotation time), and reverse release analysis (3 floats, 15 minute flotation time) on a simulated Stockton seam coal.
Figure 37. 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), tree analysis (4 levels, 2 minute flotation time), and reverse release analysis (3 floats, 15 minute flotation time) on a simulated Beckley seam coal.
4.2.3 Experimental

Experimental testing of the reverse release analysis procedure was carried out using a 200-gram sample in a 4-liter batch flotation cell. Water was added to produce a slurry of approximately 5 percent solids. The slurry was then conditioned for five minutes at 1700 rpm with 5 drops of MIBC frother. Next, the first phase of the simplified release analysis procedure was followed to separate the floatable material from the non-floatable material. The tails from the first phase were saved for analysis while the concentrate was reconditioned in order to begin the second phase of the test. A concentrate was then collected until the froth was barren at an impeller speed of 1700 rpm and an aeration rate of 100%. The tails were saved for analysis and the concentrate was refloated at 1500 rpm and 75% air. This procedure was repeated two additional times, each time at a lower aeration rate and impeller speed, to produce five tailings fractions (including tails from the first phase) and one concentrate fraction. These fractions were then filtered, dried, weighed, and assayed to produce a release curve.

The experimental results for the Stockton seam sample are shown in Figure 38. As shown, the reverse release analysis procedure is very reproducible, although there appears to be some scatter due to variations in the feed ash content. Also, there seems to be a concentration of data points at the elbow of the curve. In many cases, this is a good feature since the elbow is an important operating point. However, if a better definition of the low-ash, low-yield end is desired, additional floats could be carried out in the second stage of the procedure. When the reverse release analysis result is compared to the results obtained from the other procedures (Figure 39), the conclusion is the same as that found by simulation. In other words, reverse release analysis is able to locate the elbow of the yield-vs.-ash curve just as well as simplified release analysis, plus it is able to extend the curve into the low-ash, low-yield region in a manner comparable to timed release analysis or tree analysis. This conclusion can be seen more clearly if lines are used to plot the experimental results for four tests having nearly identical feed ash contents (Figure 40). In this case, both reverse release analysis and timed release analysis seem to provide superior yield-vs.-ash curves to tree analysis and simplified release analysis.

Similar results can be seen for the Beckley seam sample (Figure 41), although there appears to be considerably more data scatter. Since this coal is well liberated, it is possible that the scatter in the yield-vs.-ash curve is due to variations in the separation of floatable material from non-floatable material in the first stage of the procedure. In fact, test 3 almost seems to be on a different curve than the other four tests. It appears that more work may be needed to refine the experimental procedure for the reverse release analysis technique. As it turns out, test 3 is the only test that has a similar ash content to the simulated Beckley seam data. Thus, if the results are compared on the basis of test 3 (Figures 42 and 43), reverse release analysis shows the same advantage as discussed for the Stockton seam sample. In fact, in this case it appears to be superior to the other three techniques.
Figure 38. Yield-vs.-ash curve produced from reverse release analysis of Stockton seam coal.
Figure 39. Comparison of yield-vs.-ash curves obtained using timed release analysis, simplified release analysis, tree analysis, and reverse release analysis on Stockton seam coal.
Figure 40. Comparison of yield-vs.-ash curves obtained using timed release analysis, simplified release analysis, tree analysis, and reverse release analysis on Stockton seam coal (experimental data points removed).
Figure 41. Yield-vs.-ash curve produced from reverse release analysis of Beckley seam coal.
Figure 42. Comparison of yield-vs.-ash curves obtained using timed release analysis, simplified release analysis, tree analysis, and reverse release analysis on Beckley seam coal.
Figure 43. Comparison of yield-vs.-ash curves obtained using timed release analysis, simplified release analysis, tree analysis, and reverse release analysis on Beckley seam coal (experimental data points removed).
4.2.4 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 44 and 45. Once again, 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. In addition to the conclusions summarized previously for the other release analysis procedures (Section 3.4), it appears that reverse release analysis is the best method of all existing techniques. It has the advantage of simplified release analysis in locating the elbow of the yield-vs.-ash curve. It also is able to extend into the low-ash, low-yield region of the curve in a manner similar to timed release analysis or tree analysis. Furthermore, it is experimentally much simpler than either timed release analysis or tree analysis. Data scatter problems in some of the experimental tests, however, would seem to indicate that the experimental procedure may need further refinement.
Figure 44. Comparison of simulated and experimental release analysis procedures, including reverse release analysis, for Stockton seam coal.
Figure 45. Comparison of simulated and experimental release analysis procedures, including reverse release analysis, for Beckley seam coal.
4.3 Rougher-Cleaner-Scavenger Circuits

Meloy has shown from circuit analysis that a rougher-cleaner-scavenger (RCS) circuit, with recycle flows, as shown in Figure 46, produces the most efficient separation possible. Furthermore, the efficiency of separation improves exponentially as the number of cleaner and scavenger stages on each leg is increased. This is largely due to the fact that the recycle streams allow many opportunities for misplaced particles to be refloated and rearranged until they appear in the appropriate concentrate (Meloy, 1983).

Based on this concept, locked-cycle simulations were conducted using the semi-batch flotation model to represent each cell in the circuit. The number of stages along each leg was varied from 1 to 5 and the results of these simulations are shown in Figures 47 and 48. The ideal flotation response was determined by taking the original feed material and assuming that all free carbonaceous material floats before the 10% ash material, which floats before the 20% ash material, etc. As shown, in excess of one cleaner and scavenger stage is required in order to approach the ideal separation curve. In fact, a one-stage RCS circuit produces a yield-vs.-ash curve comparable to existing techniques such as timed release analysis and reverse release analysis. A three-stage RCS circuit is probably adequate and a five-stage RCS circuit is very near the ideal separation curve. Furthermore, it appears that the RCS circuit comes closer to matching the ideal curve when the material is well liberated, as is the case with the simulated Beckley seam material, as compared to the simulated Stockton seam sample. In either case, a three- to five-stage RCS circuit comes very near to producing the ideal separation curve.
Figure 46. Schematic diagram showing a two-stage ideal RCS circuit with recycle.
Figure 47. Yield-vs.-ash curves produced from the simulation of various locked-cycle RCS circuits processing a simulated Stockton seam coal.
Figure 48. Yield-vs.-ash curves produced from the simulation of various locked-cycle RCS circuits processing a simulated Beckley seam coal.

4.4 Comparison of Techniques

Based on all the simulated results obtained in this investigation, a comparison of the various release analysis techniques and conceptual methods is shown in Figures 49 and 50. The conclusions from this comparison can be summarized as follows:
1. Reverse release analysis appears to be the best of all existing techniques tested, both from simulation results and experimental results.

2. The simulation trends seem to mirror experimental trends very well.

3. A technique based on the ideal RCS circuit with recycle would provide the best means of performing release analysis. A one-stage RCS circuit is comparable to the existing release analysis methods. A three-stage RCS circuit should be adequate in most cases. A five-stage RCS circuit very nearly approaches an ideal separation.

4. The RCS circuit seems to approach the ideal separation with fewer stages for the well-liberated Beckley seam material.

5. None of the existing release analysis procedures is adequate for representing the ideal flotation behavior.

Based on these results, it is clear that an effort should be made to develop a release analysis test or device that can duplicate the behavior of a three-stage RCS circuit.
Figure 49. Comparison of all simulated release analysis procedures and conceptual methods for a simulated Stockton seam coal.
Figure 50. Comparison of all simulated release analysis procedures and conceptual methods for a simulated Beckley seam coal.