TABLE I. COMPARATIVE SURFACE MOISTURE BY MINING METHOD

Type of Mining	Raw Coal Surface Moisture (% by Weight)
Surface	6.0
Continuous	8.0
Hydraulic	12.0

TABLE II. COMPARATIVE COAL QUALITY BY MINING METHOD

	Feed		Product	
Type of Mining	Weight	Ash	Yield	Ash
Surface	100.0	18.0	75.0	8.7
Continuous	100.0	19.6	74.0	8.5
Hydraulic	100.0	20.0	73.0	8.5

PROCESS SIMULATION

A key to unlocking the problems of process control

A typical conversation that might be heard between a coal miner and a plant man may involve the miner expressing his dissatisfaction about a large amount of his mined coal being discarded. The same conversation probably would consist of the plant manager telling the miner to mine more coal and less rock.

Unfortunately, both coal miners and plant managers may be hearing those refrains too often, and it is easy to see from this hypothetical conversation that the mining of coal and the cleaning of coal are viewed by many as two separate processes. Not so.

Author information
Michael C. Albrecht is president of Pacific Coal Energy.

Mining and cleaning should be considered integral parts of one complete process. What happens in the mine will always affect what happens in the preparation plant, and vice versa. Furthermore, because coal preparation begins with mining, the production of a quality product at an acceptable cost becomes the true interrelationship between mining and coal preparation.

As with coal preparation, process control of the preparation plant also begins during mining. Process control, however, is more than selection of instruments: Good process control must look at the entire operation as an integrated whole.

Given the above, it is safe to assume that anything affecting the process—and anything the process does that affects the mining—will affect process control.

Several studies of two Consolidation Coal Co. mines in Pennsylvania and of Westar Mining's Balmer operation in British Columbia have shown that feed characteristics vary significantly depending on the mining method used.[1,2] At the time of the first study, Balmer consisted of two underground mines—one using continuous miners and one utilizing hydraulic—and a large surface pit. All three mines were mining the same seam, but there was up to a 20% variation in the minus 100 mesh plant feed (Fig. 1, Tables I and II).

There are several factors that may limit the methods used to mine coal.

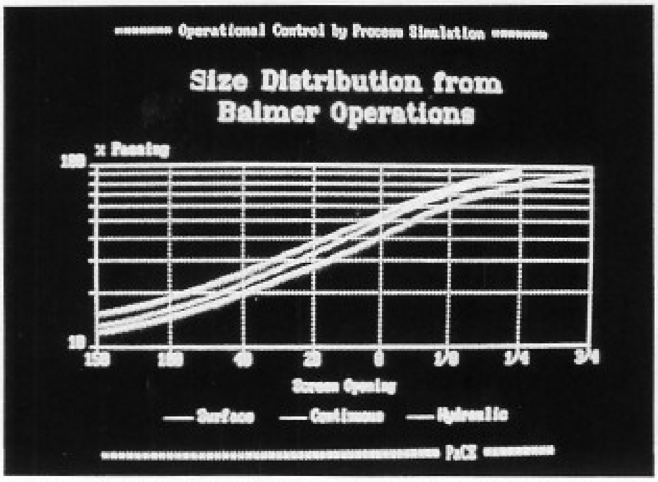

Fig. 1. Although mining the same seam, the three mines had a 20% variation in the minus 100 mesh plant feed.

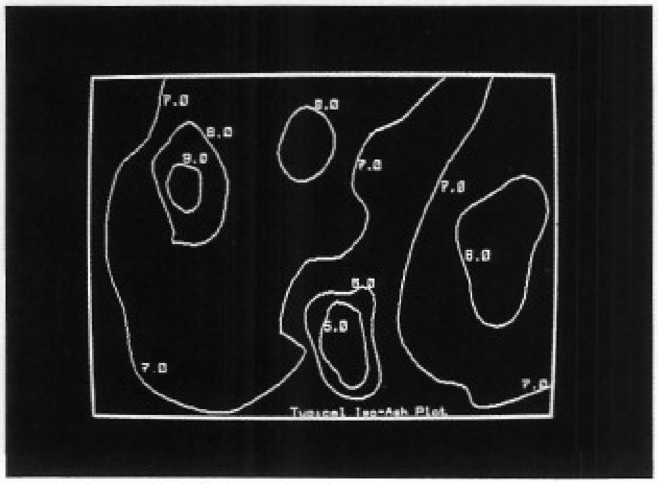

Fig. 2. Variations in the coal can be seen by plotting quality parameters as isopeth maps.

In one of the above studies, for instance, variations in the coal are observed by plotting quality parameters (ash, sulfur, Btu, etc.) as isopleth maps (Fig. 2), and are dependent on how and where mining is conducted. Predicting variations in new coal and its impact on clean coal will help optimize mine and plant operation.

The preparation plant also has limits that should be considered: If circuit control problems or equipment breakdown lowers the yield, more raw coal must be mined to obtain the same amount of clean coal. More raw coal mined means less maintenance and more production hours, which are not always easy to find. In addition, if the plant is having many mechanical problems, raw coal storage may fill up and cause a reduction in mine operations, which is never cheap.

Another factor that may limit the mining options is the design of a plant and its components. Bottlenecks may occur that require a coarser or finer feed. Also, the ability to handle large swings in refuse content may limit mining of certain areas or establish the mine cut-off height.

Predicting the above situations, then, involves knowing how the mine impacts the plant and how the plant impacts the mine. This is the first step to good process control, and the key to this is the ability to simulate the plant in order to handle changing mining conditions. This is accomplished using process simulation.

PROCESS SIMULATION

Process simulation is a model of a plant, existing either on paper or in a computer. With this model, one can see the impact of feed changes caused by mining. One can also determine potential plant bottlenecks. Other possible applications for process simulation include: mine design and planning to maximize clean coal recovery and assure quality; process design; process development; and flowsheet design. The main use of process simulation, however, is its use by plant designers.

Fifteen years ago, the personal computer industry was in its infancy, and doing good process and mine simulation required large, expensive computers. Most mine simulation programs were developed by the companies that used them. But, while these systems were significantly faster than doing the same work by hand, trying to use them for on-line control was difficult and expensive. Today, however, many high-powered systems can be bought for a few hundred dollars, with program prices ranging from free to over $50,000.

The variation in cost, however, does not always reflect the capability of the program, but rather the amount of support you can expect. The instrumentation system has also improved dramatically, and process control by use of on-line analyzers has been gaining increasing acceptance. Each process simulation program uses a different way of calculating the results. The main difference, noticeable to the user, is the relative ease of use. Selection should be made by each person or company in light of their needs.

Two pieces of information are required to simulate a cleaning circuit and to predict the clean coal yield and quality. These are: 1) partition curves for the various gravity cleaning devices, and 2) washability and sink-float tests on the coal.

Table III gives typical washability data. The data shows how one coal would separate at various specific gravities. The cumulative float at any

TABLE III. TYPICAL WASHABILITY RESULTS

		Top size: 50.00		Bot. size: 0.50		Ave. size: 25.25	
Float	Sink	%Wt	%Ash	%Wt	%Ash	%Wt	%Ash
1.200	1.300	56.76	2.60	56.76	2.60	100.00	12.62
1.300	1.350	13.40	7.10	70.16	3.46	43.24	37.34
1.350	1.400	9.14	10.00	79.30	4.21	29.84	49.24
1.400	1.450	3.78	14.40	83.08	4.68	20.70	54.83
1.450	1.500	2.50	17.50	85.58	5.05	16.92	60.56
1.500	1.550	1.17	21.50	86.75	5.27	14.42	62.61
1.550	1.600	1.41	27.50	88.16	5.63	13.25	67.94
1.600	1.700	1.17	29.40	89.33	5.94	11.84	71.76
1.700	1.800	0.95	43.30	90.28	6.33	10.67	75.23

+ 28 Mesh Sample Wt: 45.46

		Top size: 0.50		Bot. size: 0.20		Ave. size: 0.35	
Float	Sink	%Wt	%Ash	%Wt	%Ash	%Wt	%Ash
1.200	1.300	25.55	1.30	25.55	1.30	100.00	8.48
1.300	1.350	8.68	2.10	34.23	1.50	74.45	12.39
1.350	1.400	11.91	3.20	46.14	1.94	65.77	14.80
1.400	1.450	17.86	3.90	64.00	2.49	53.86	21.08
1.450	1.500	20.34	6.20	84.34	3.38	36.00	44.01
1.500	1.550	6.70	13.80	91.04	4.15	15.66	62.84
1.550	1.600	2.27	24.30	93.31	4.64	8.96	70.34
1.600	1.700	1.49	34.00	94.80	5.10	6.69	79.89
1.700	1.900	0.74	45.10	95.54	5.41	5.20	81.79
1.800	2.700	0.50	54.60	96.04	5.67	4.46	83.68
1.900	2.000	0.25	61.80	96.29	5.81	3.96	81.96
2.000	2.700	3.71	77.80	100.00	8.48	3.71	77.80

28 Mesh x 60 Mesh Sample Wt: 25.35

		Top size: 0.20		Bot. size: 0.00		Ave. size: 0.10	
Float	Sink	%Wt	%Ash	%Wt	%Ash	%Wt	%Ash
1.200	1.500	87.73	7.50	87.73	7.50	100.00	9.38
1.500	1.550	6.12	13.00	93.95	7.86	12.17	46.12
1.550	1.700	2.39	17.60	96.34	8.10	6.05	54.49
1.700	2.700	3.66	43.00	100.00	9.38	3.66	43.00

60 Mesh x 0 Sample Wt: 29.09

float specific gravity is what a perfect separation would produce in the way of clean coal yield and quality, with the cumulative sink being the refuse from the perfect separation.

Each type of washing equipment has its own characteristic performance curve, commonly called a partition (distribution) curve. A typical curve is shown in Fig. 3. The term partition is derived from the process whereby the equipment separates or partitions the coal into two fractions, plus or minus the specific gravity of separation.

The matching of these two pieces of information is the heart of most process simulation routines. Computers have been used to automate this process for the last 25 years.[3,4]

MINE PLANNING

The use of process simulators for mine planning means the same circuit will be used in the preparation plant, but the mine plan will be varied. Some mining companies, such as Consol, have been doing this for more than 10 years.[5]

A key use of computer process simulation in this manner is to determine the minimum and maximum flows at various points in the circuit. Sizing of equipment, pipes and chutes can thus be adjusted, without over-designing, in oder to handle flow variations.

The general procedure is designed to prepare typical plant feed washabilities and run them through the simulator to determine how the plant

TABLE IV. PLANT PERFORMANCE RESULTS

Overall Plant Performance—Existing Plant

	1989		1990		1991		1992		1993		1994	
Separating Gravity	% Wt	% Ash	% Wt	% Ash	% Wt	% Ash	% Wt	% Ash	% Wt	% Ash	% Wt	% Ash
1.50	78.02	6.93	74.62	7.35	74.94	7.03	76.12	6.82	76.16	6.68	75.40	6.78
1.55	79.20	7.15	75.92.	7.63	76.30	7.32	77.33	7.70	77.32	6.92	76.57	7.03
1.60	79.98	7.35	76.80	7.87	77.20	7.56	78.16	7.30	78.09	7.14	77.37	7.26
1.65	80.57	7.53	77.47	8.11	77.88	7.79	78.77	7.50	78.66	7.33	77.94	7.46
1.70	81.07	7.71	78.05	8.36	78.46	8.03	79.27	7.71	79.13	7.53	78.44	7.67
1.75	81.54	7.93	78.62	8.63	79.04	8.31	79.76	7.95	79.61	7.76	78.94	7.91
1.80	82.05	8.19	79.23	8.94	79.65	8.63	80.30	8.23	80.14	8.05	79.49	8.21
1.85	82.55	8.46	79.81	9.27	80.24	8.97	80.81	8.53	80.66	8.35	80.04	8.53
7.2% Ash	79.41	7.20	73.90	7.20	75.74	7.20	77.82	7.20	78.28	7.20	77.16	7.20
C/C Tonne	2497.83		2438.37		2440.83		2476.38		2503.07		2459.32	

Plant Performance by Circuit—Existing Plant, 7.2% Ash

	1989		1990		1991		1992		1993		1994	
	% Wt	% Ash	% Wt	% Ash	% Wt	% Ash	% Wt	% Ash	% Wt	% Ash	% Wt	% Ash
Total												
Feed	100.00	17.35	100.00	18.59	100.00	18.58	100.00	17.02	100.00	17.14	100.00	17.86
Product	79.41	7.20	73.90	7.20	75.74	7.20	77.82	7.20	78.28	7.20	77.16	7.20
Tails	20.59	56.48	26.10	50.84	24.26	54.09	22.18	51.49	21.72	52.97	22.84	53.87
+28 Mesh	60.88		60.73		63.85		60.45		62.29		63.05	
Feed	100.00	19.27	100.00	21.16	100.00	21.28	100.00	19.31	100.00	19.32	100.00	20.09
Product	76.99	5.97	70.42	5.72	73.47	6.29	77.10	6.28	78.03	6.38	76.30	6.29
Tails	23.01	63.78	29.58	57.90	26.53	62.77	22.90	63.18	21.97	65.28	23.70	64.52
28 Mesh x 60	17.23		16.36		15.34		16.24		15.48		15.32	
Feed	99.98	16.60	100.02	17.05	99.99	15.69	99.98	15.73	100.00	15.66	99.99	16.30
Product	88.48	10.85	88.27	11.24	89.07	10.30	88.99	10.27	88.89	10.08	88.32	10.43
Tails	11.50	60.87	11.75	60.73	10.92	59.68	10.99	59.94	111.11	60.27	11.67	60.70
60 Mesh x 0	21.89		22.91		20.81		23.31		22.23		21.63	
Feed	100.01	12.58	100.01	12.89	100.00	12.41	99.98	11.99	100.02	12.06	99.98	12.46
Product	79.00	7.32	72.84	7.49	72.89	7.22	71.89	7.10	71.60	7.20	71.16	7.20
Tails	21.01	32.37	27.17	27.36	27.11	26.37	28.09	24.50	28.42	24.30	28.22	25.85

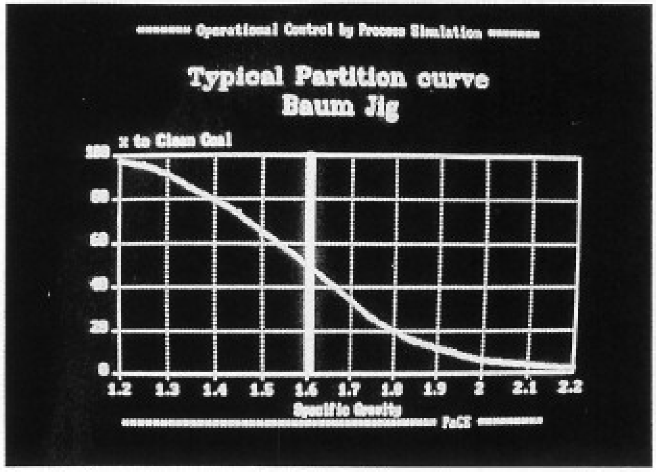

Fig. 3. A partition curve is derived from the process whereby the equipment separates the coal, plus or minus the specific gravity of separation.

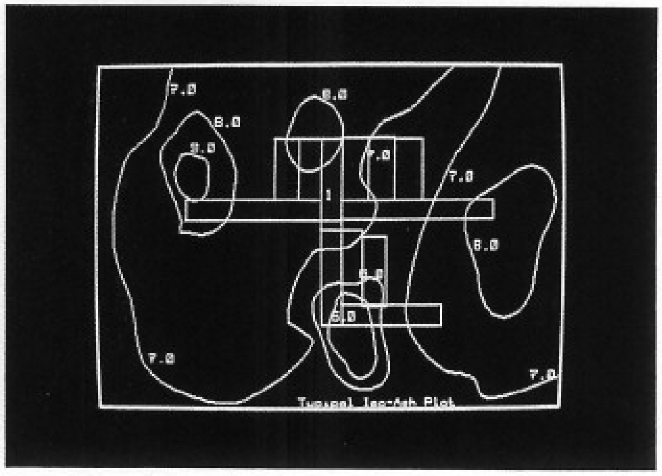

Fig. 4. Cleaned iso-ash contours are superimposed over an alternative mine plan.

would perform under those hypothetical conditions. Expected variations due to the mine plan or to known mining conditions are used to generate the best- and worst-case conditions.

Using this method, the initial circuit set points can be determined. Table IV shows a typical performance result based on mine plan variations. In this case, the set points were used to determine what performance would produce a 7.2% ash.

After this stage, preliminary mass balances can be developed, either by the same routines or by separate routines. The larger process simulation packages often do the complete balance system to include graphical representations of flowsheets. The simpler programs provide only the yield and the quality figures for a specific cut point, which then must be put into a mass balance formula. This can be achieved, with excellent results, using spreadsheet programs.

Pacific Coal Energy has worked with several clients to define the impact of alternative mining plans (both during design and during operations) on the plant performance in an effort to maximize recovery at target ash levels. These studies showed the changes that needed to be made in the plant circuit, as well as how to achieve the same results by changing either the mine plan or the direction of mining.

For instance, Fig. 4 shows a typical mine plan. This is from a project in Illinois, and shows the cleaned iso-ash contours (from Fig. 2) superimposed over an alternative mine plan. The mine can produce various products, which are dependent on time or on the mine plan. Fig. 5 shows the variation in feed and product ash based on the mine plan.

The plant was a jig plant, and product ash was taken from the train loading samples. The large variation in product ash was the result of nothing more than steady plant operation. The important point is that coal that was often considered uniform (such as Illinois #6 coal), produced a wide variation in feed and product quality. Some method of tighter control was needed to improve the operation.

The important part of any simulator is how well it can predict actual plant performance for a given feed. But, if a simulator cannot predict plant performance to within laboratory repeatability and reproducibility accuracy, all the best graphical interfaces are not needed. Could process simulation have been used in the above case to predict actual plant performance? Fig. 6 shows the results of a process simulation (predicted) versus actual plant performance.

The important point is that simulation-thinking is needed to allow one

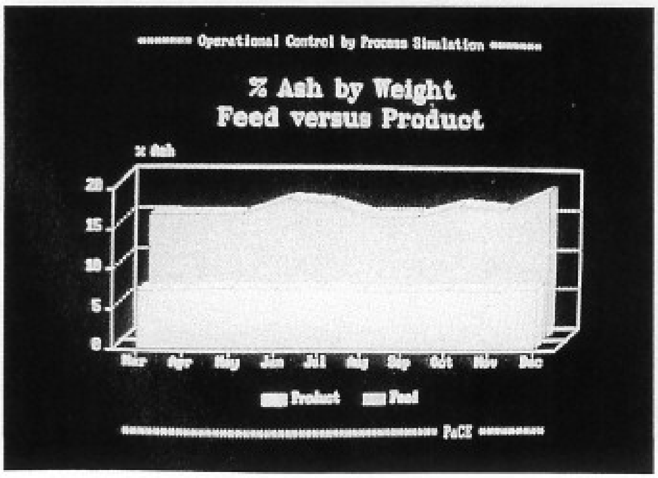

Fig. 5. The mine can produce various products dependent on time or on the mine plan.

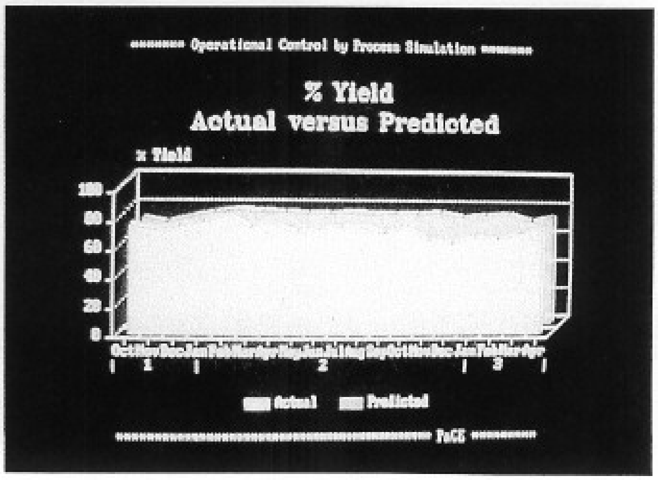

Fig. 6. Results of a process simulation can be plotted against actual plant performance.

to adopt a new control concept. Feedback on-line control, which relies on the analysis of the cleaned product, will probably produce a consistent product. This method, however, will not maximize recovery. Feedback process control strategy and systems allow for heuristic variations and may achieve an unstable plant operation, but these variations arise from lag time during the interim between the cleaning process and the downstream analyzer. In other words, this process does not take into account the history of the plant.

THE SIMULATION SYSTEM

The idea presented here is a system that would use a data base of expected coal quality over time. The data base would be used to predict the mine plan and would be updated as mining changes. This data base, along with a model of the plant circuitry, can simulate the cleaning of the coal. An on-line analyzer would monitor the raw coal characteristics and then update the expected raw coal quality. The process simulation module would then determine the optimal set points from:

- the current circuit operation set points
- the expected coal characteristics
- the known response time for the plant circuit.

The optimal adjustments would then be made to achieve the maximum results in energy recovery and in ash and sulfur rejection.

The proposed system is an interrelated, intelligent supervisory system for automatic control of a preparation plant. The novelty of this approach is the use of a feed-forward system, which contains a process simulator that would react to what *will happen*, rather than to what did happen. This would facilitate maximum plant performance and coal recovery, and would provide high ash and sulfur rejections with high Btu recovery.

Reducing the problems of coal use at an acceptable cost requires maximum energy recovery at maximum ash and sulfur rejection. Conventional process control works by analyzing the product of the plant. If the ash is increasing, the cut point decreases; if the ash decreases, the cut point is raised. But while the basic reasoning is sound, this is a reactive idea. The plant is always adjusting to what happened in the past. If you have a highly variable coal, coming from more than one seam, or two different areas in the mine, you either have to have a wide tolerance band or constantly make changes. This will produce heuristic variations and may cause an unstable plant operation.

A study several years ago showed that by lengthening the time between making process adjustments, the yield was increased at the same ash level. This was achieved by using a four-hour moving average for determining the cut point adjustment. It was concluded that the original idea, using a one-hour fast ash analysis, and adjusting from there, caused a constant change, which meant that the plant was always reacting.

It can be argued that using on-line analyzers on the output product only, and using the averages of several 3-hour testing periods, can achieve good results. I will not dispute this, because I believe any well-run system will provide reliable and consistent results. My contention, however, is that any reactive system will provide a lower yield then a proactive system. And until recently, with the improvement and lowered cost of computer systems, a proactive system was expensive and too slow to provide any better results.

The components of the proposed system will consist of 1) an on-line analyzer on the plant feed, far enough away from the cleaning circuit to allow reaction time, 2) a data base of the current mine plan, and 3) a process simulation routine.

This idea is combined with an expert systems approach to preparation plant operation. The expert system will have a structure based on a human operator model. The expert system will consist of a knowledge base containing a data base describing the uncleaned coal and the preparation process, and a rules base with logic used by an operator when supervising the plant. The process simulation module will tell how the plant circuitry would react to various feed conditions; and the on-line analyzer, placed on plant feed, will tell how the feed is changing.

This system will allow maximum energy recovery at maximum ash and sulfur rejection and at an economically viable cost. It will smooth out the heuristic variations in conventional on-line process control systems, and achieve a more stable plant operation. The inherent mining operation impact on preparation plant operation will be minimized.

Can we safely say whether process simulation can predict actual plant performance? Coal is the United States' most available fuel, but its use is constrained by environmental disadvantages. These disadvantages relate to the coal itself: Nitrogen and sulfur are precursors to acid rain. The non-combustible matter (ash) must be disposed of at the combustion site, or may end up as suspended particles in the air. Ash also causes maintenance problems in the combustion system. Some studies have shown that it may be the single biggest source of operating costs in power production.[6]

Thus we cannot hope to change the content of the coal itself. We can, however, use a computerized process simulator to predict actual plant performance, thus reducing the inherent problems of elemental coal to a minimum, while obtaining efficient, maximum energy recovery. □

REFERENCES

1. Albrecht, M.C., D.A. Olsen, "Mining Methods Impact on Coal Preparation Plant Design," First International Symposium on Mine Planning and Development, Beijing/Beidaihe, China, September, 1980

2. Stefank, R., I.K. Chopra, R.V. Ramani, "Mining Influence on Size Consist and Washability Characteristics of Coal," Society of Mining Engineers Fall Meeting, September, 1974

3. Absil, J.H., Keuning, W., Meerman, P.G., "Prediction of Washery Plant Performance by Data Processing," 5th International Coal Preparation Conference, October, 1966

4. Brookes, G.F., R.L. Whitmore, "An Application of the Digital Computer to Coal Preparation," Coal preparationaration, May/June, 1966

5. Eyer, David, "Forecasting Coal Quality from Exploration Data as a Tool for Mine Planning," First International Symposium on Mine Planning and Development, Beijing/Beidaihe, China, September, 1980

6. Holt, E.C. Jr.,"Effect of Coal Quality on Maintenance Costs at Utility Plants," Mining Congress Journal, pp.48-54, May, 1982