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OPERATIONAL CONTROL BY PROCESS SIMULATION

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Abstract

Coal is the United States most available fuel. Coal use can cause environmental problems, due to ash, sulfur, or other pollutants from it's combustion. Reducing the problems, at an acceptable cost requires maximum energy recovery at maximum ash and sulfur rejection.

Mining directly impacts plant operation. Use of computer process simulation is common for plant design work. Process control on-line analyzers has been gaining increasing acceptance. A new approach is to combine all three of these well defined ideas into a new system which will react to what will happen, rather than to what did happen. This idea will achieve maximum plant performance at high ash and sulfur rejections and high Btu recovery. A smoother operation will results, without the built-in variations of feedback control systems. The inherent mining operation impact on preparation plant operation will be minimized and achieve a more stable plant operation.

Introduction

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 it may be the single biggest source of operating costs in power production. Reduction of these at an acceptable cost requires maximum energy recovery at maximum ash and sulfur rejection.

Many of these problems with coal begin with the mining operation. The mining methods used and the mine plan directly impact the coal preparation plant, both in design and operation. Variations in mining operations will cause direct variations in plant operations due to changes in dilution material from an increase or decrease in inclusion of out-of-seam material. Coal is not a homogeneous material, it is not even heterogeneous, but varies both horizontally and vertically across a mine. These variations will have an impact on the cleaning characteristics of the coal.

Feedback on-line control, which relies on the analysis of the cleaned product, will produce a consistent product but will not maximize recovery. Feedback process control strategy and systems allow for heuristic variations and may achieve an unstable plant operation. These variations arise from the lag time from the cleaning process to the downstream analyzer.

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

o The current circuit operation set points.
o The expected coal characteristics.
o The known response time for the circuit.

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

This is an interrelated intelligent supervisory system for automatic control of a preparation plant. It will achieve maximum plant performance and coal recovery at high ash and sulfur rejections and high Btu recovery.

The question is, can a computerized process simulator predict actual plant performance? The answer is yes. Let's begin by reviewing some basics, the background for this idea.

Impact of Mining on Coal Preparation

Process control actually begins during mine planning as the mining operation directly impacts plant operation. One major impact is the effect on size distribution depending on the method - surface or underground. Other impacts are the moisture content and reject material included with the coal. The choices of a mining method for a specific coal deposit depends on technical and economic needs and geological conditions -- what is desirable and what is possible. Selection of the mining method will have a significant impact on raw coal quality and hence coal preparation.

Coal preparation begins with the mining. Production of a quality product at an acceptable cost is a true interrelationship of mining methods and coal preparation processes. The method of mining has a strong impact on the design of a coal preparation plant. Trends in mining have been from low productivity highly selective methods towards high productivity less selective methods. This has generally increased the amount of out of seam material included with the raw coal. Increased emphasis on dust control has increased the moisture content of the coal.

Reports and studies have reported significant variation in plant feed characteristics depending on the mining method. The mines used in the papers were two Consol mines from Pennsylvania and WESTAR Mining's Balmer Operation in B.C.

At the time of the first paper, Balmer consisted of two underground mines, one continuous and one hydraulic, and a large surface pit. All were mining the same seam, but there was up to 20% variation in the minus 100 mesh plant feed.

To observe the variations, plot quality parameters (ash, sulfur, Btu/lb, etc.) as isopleth maps. Variations in the parameters over the range of the mine area (see figure 1) will be apparent. Depending on how and where mining is conducted this will vary the raw coal and clean coal quality. These are knowable variations and their impacts can help to optimize mine and plant operation.

Process Simulation

Applications for process simulation include; mine design and planning to maximize clean coal recovery and assure quality; process design; process development; and flowsheet design. Several alternative programs are available, with varying ease of use.

At its simplest, two pieces of information are required to simulate a cleaning circuit and to predict the clean coal yield and quality. The partition curves for the various gravity cleaning devices and washability or sink-float tests on the coal.

Table 1 gives a typical washability data. The data shows how one coal would separate at various specific gravities. The cumulative float at any 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 Figure 2. The term "partition" derives from the fact that the equipment separates or "partitions" the coal into two fractions, plus or minus the specific gravity of separation. This curve is often called a "Tromp" curve based on the work of K.F. Tromp in defining equipment performance. Work on defining the separation characteristics of processing equipment has been under investigation for over 60 years. A lot of work was done by the U.S. Bureau of Mines and then continued by Coal Preparation branch of the Department of Energy at Bruceton, PA. Trying to list the available information as published would take several pages and is beyond the scope of this paper. Any interested parties are referred to the DOE.

The matching of these two pieces of information is the heart of most process simulation routines. The use of computers to automate this process goes back over 25 years.

Use of Process Simulators

A primary use of computer based coal plant process simulation is to determine the minimum and maximum flows at various points in the circuit. This allows proper sizing of equipment, pipes, and chutes to handle the variation in flows without grossly over designing.

The general procedure is to prepare typical plant feed washabilities and then run them through the simulator to determine how the plant would perform. Expected variations due to the mine plan or known mining conditions are used to generate the minimum and maximum conditions.

Using this method you can determine the initial circuit set points. Table 2 shows a typical performance result based on mine plan variations. These were used to determine what performance would produce a 7.2 % ash.

From this point preliminary mass balances can be developed, either by the same routines are 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 quality figures for a specific cut point, which then must be put into a mass balance formula. This last part is simple and you can achieve excellent results using spreadsheet programs.

Use of process simulators for mine planning is doing the exact same as for plant design, but keeping the plant constant (same circuit) and varying the mine plan. Some mining companys, such as Consol, have doing this for over 10 years.

I have worked with several clients in defining the impact of alternative mining plans on the plant performance both during design, and during operations to maximize recovery at target ash levels. These studies have shown what changes in plant circuit are needed. They have also shown that how to achieve the same results by simply changing the mine plan, or mining direction.

Lets look at a typical mine plan (figure 3). This is from a project in Illinois, and shows the cleaned iso-ash contours (from figure 1) superimposed over an alternative mine plan. This mine plan can produce various products depending either on time or on the mine plan. Figure 4 shows the variation in raw and clean ash based on the mine plan. The large variation in product ash was due to keeping plant operation steady. It was a jig plant, and product ash was taken from the train loading samples. A tighter control could have improved the operation. The important point is to note the wide variation in feed and product quality, exhibited by a coal often considered fairly uniform (Illinois #6).

Process simulation is a useful tool that can do many things for the user. Several versions of process simulators are available, and they use different ways of calculating the results. Any will work. The main difference, noticeable to the user is the relative ease of use. The cost of these simulators is from "free" to $50,000(+). The variation in cost does not always reflect the capability of the program, but rather the amount of support you can expect. Selection should be made by each person or company in light of their needs.

The important part of any simulator is how well it can predict actual plant performance for a given feed. If a simulator cannot predict plant performance to within laboratory repeatability and reproducibility accuracy, all the best graphical interfaces and "bells and whistles" are not needed. Figure 5 shows the results of a process simulation versus actual plant performance. This was the first stage of the project summarized in figure 4.

Improvement in Computer Technology

Ten to fifteen years ago, the personal computer industry was in its infancy. To do good process and mine simulation required large, expensive computers. Most software (programs) were developed by the companies that used them. While these systems were significantly faster than doing the same work by hand, trying to use these for on-line control was difficult and expensive.

Today, high powered systems can be bought for a few hundred dollars. Mine planning and process simulation software is readily available from several sources.

The basic instrumentation system has also improved dramatically. Process control by use of on-line analyzers has been gaining increasing acceptance. The time is right for a new control idea.

Feed Forward versus Feedback Control

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. While the basic reasoning is sound, this is a reactive idea. You are always adjusting to what happened in the past. If you have a highly variable coal, coming from more that one seam, or two different areas in the mine you either have to have a wide tolerance band or constantly making changes. This will allow for heuristic variations and may achieve 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 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. This was a three circuit plant, with heavy medium on the coarse and water-only cyclones and flotation on the fines. Cut point adjustments were being made on the heavy medium circuit. It was noted that from the time an adjustment was started until stable circuit operation was re-established a significant part of the time until the next adjustment was made.

It can be argued that using on-line analyzers on the product, and using several hour averages, with emergency upset override, can achieve good results. I will not dispute this, because I believe any well run system will provide reliable and consistent results. My contention 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 prohibitively expensive and too slow to provide any better results.

Application

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

The process simulation program will tell how the plant circuitry would react to various feed conditions. The on-line analyzer, when placed on plant feed will tell how the feed is changing.

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 model of the uncleaned coal and the process and a rules base with logic used by an operator when supervising the plant. A process simulation module will tell how the plant circuitry would react to various feed conditions. An on-line analyzer, placed on plant feed will tell how the feed is changing.

A project to investigate the feasibility of a process simulation approach for on-line process control has been proposed to the Department of Energy. It was originally hoped when this paper was offered that detailed results would be available. Unfortunately, due to time constraints actual results are not ready for publication. This will hopefully be changed shortly. Parameters of such a system are known. The comparison of this approach to alternative methods of process control is currently being evaluated.

Conclusion

Process control begins during mine planning as the mining operation directly impacts plant operation. Combining this with an expert systems approach as applied to preparation plant operation with a structure based on a human operator model will be developed. It will consist of a knowledge base containing a model of the uncleaned coal and the process and a rules base with logic used by an operator when supervising the plant. A process simulation module will tell how the plant circuitry would react to various feed conditions. An on-line analyzer, placed on plant feed will tell how the feed is changing.

The use of computer based coal plant process simulation is common for plant design work. Process control by use of on-line analyzers has been gaining increasing acceptance. The novelty of this approach is to use a feed forward system with a process simulator to react to what will happen, rather than to what did happen. This idea will achieve maximum plant performance and coal recovery at high ash and sulfur rejections and high Btu recovery.

This system will allow maximum energy recovery at maximum ash and sulfur rejection 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.

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Table 1
TYPICAL WASHABILITY RESULTS

Job No. 88001
January 1987
+ 28 Mesh
Sample Wt.: 45.56 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
1.800	2.700	9.72	71.00	100.00	12.62	9.72	71.00

28 Mesh x 60 Mesh
Sample Wt.: 25.35 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	1.800	0.74	45.10	95.54	5.41	5.20	81.79
1.800	1.900	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

60 Mesh x 0
Sample Wt.: 29.09 Top size: 0.20 Bot. Size: 0.00 Ave. Size: 0.10

Float	Sink	%Wt	% Ash	%Wt	% Ash	%Wt	% Ash
1.200	1.500	87.83	7.50	87.83	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

Table 2
SUMMARY 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	7.07	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		2459.33	
8.0 % Ash	81.68	8.00	77.17	8.00	78.38	8.00	79.86	8.00	80.05	8.00	79.10	8.00
C/C Tonne	2569.12		2546.38		2525.88		2541.46		2559.71		2521.25	

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 Mesh	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	11.11	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	12.69	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	71.76	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

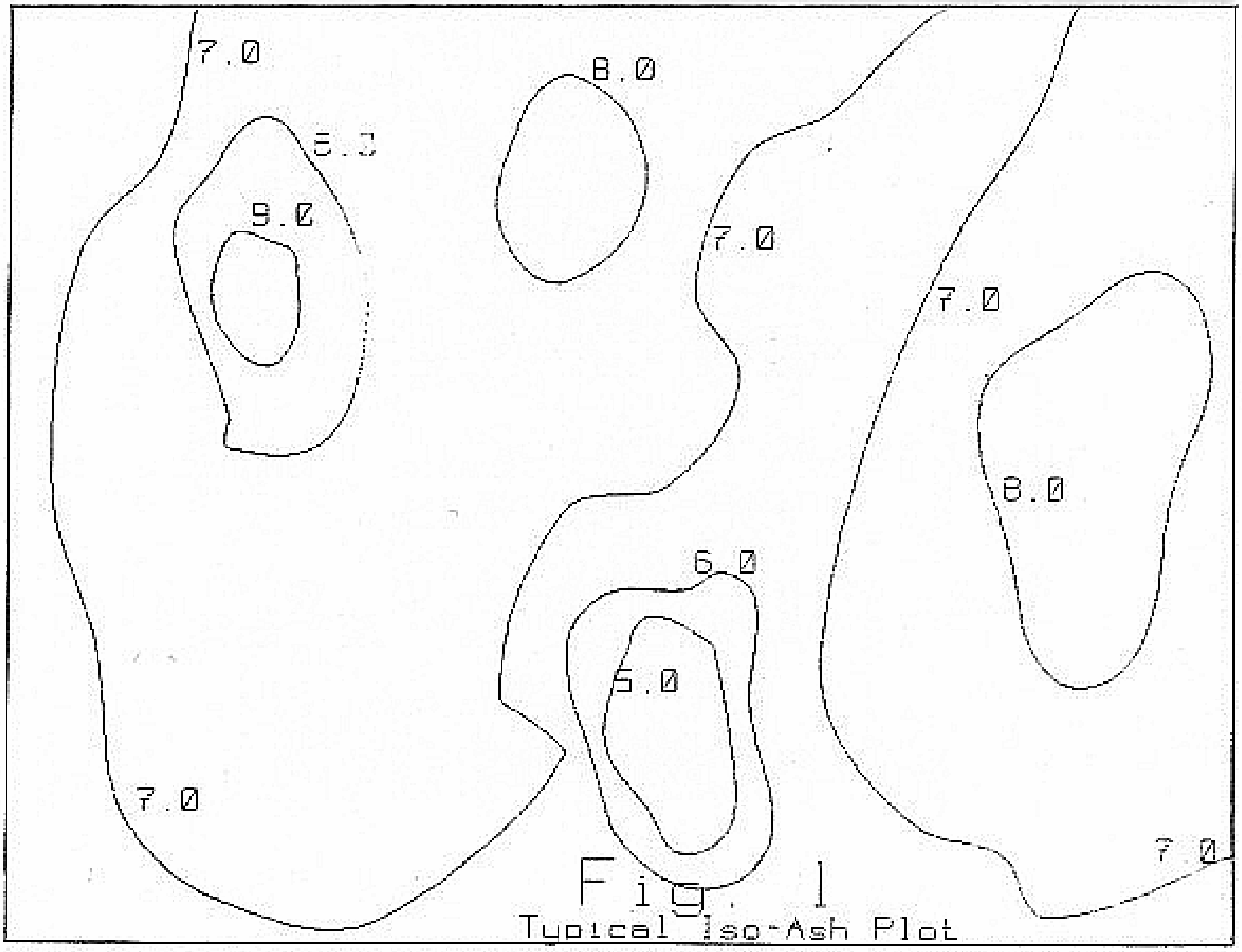

Fig. 1

Typical Iso-Ash Plot

Typical Partition Curve
Baum Jig

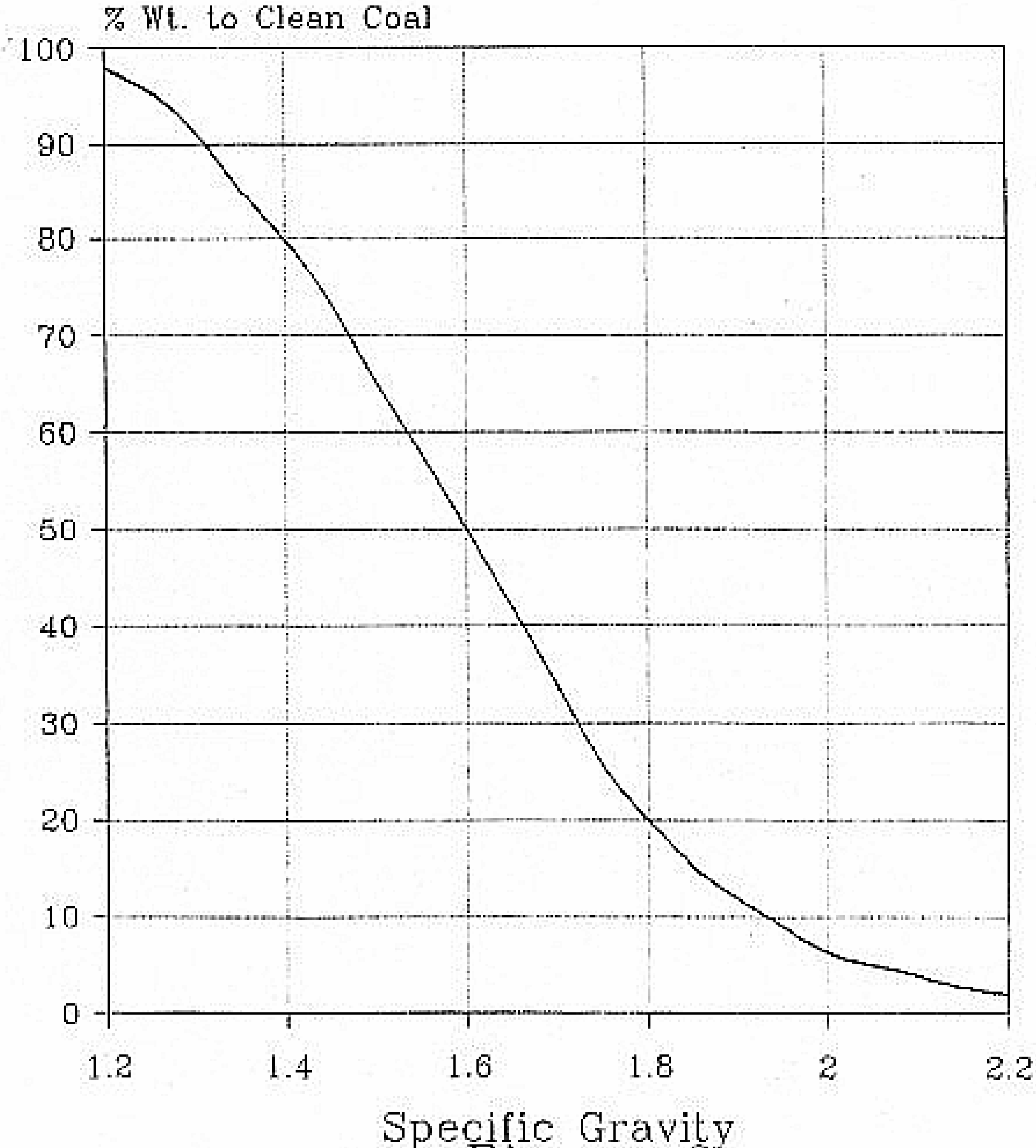

Figure 2

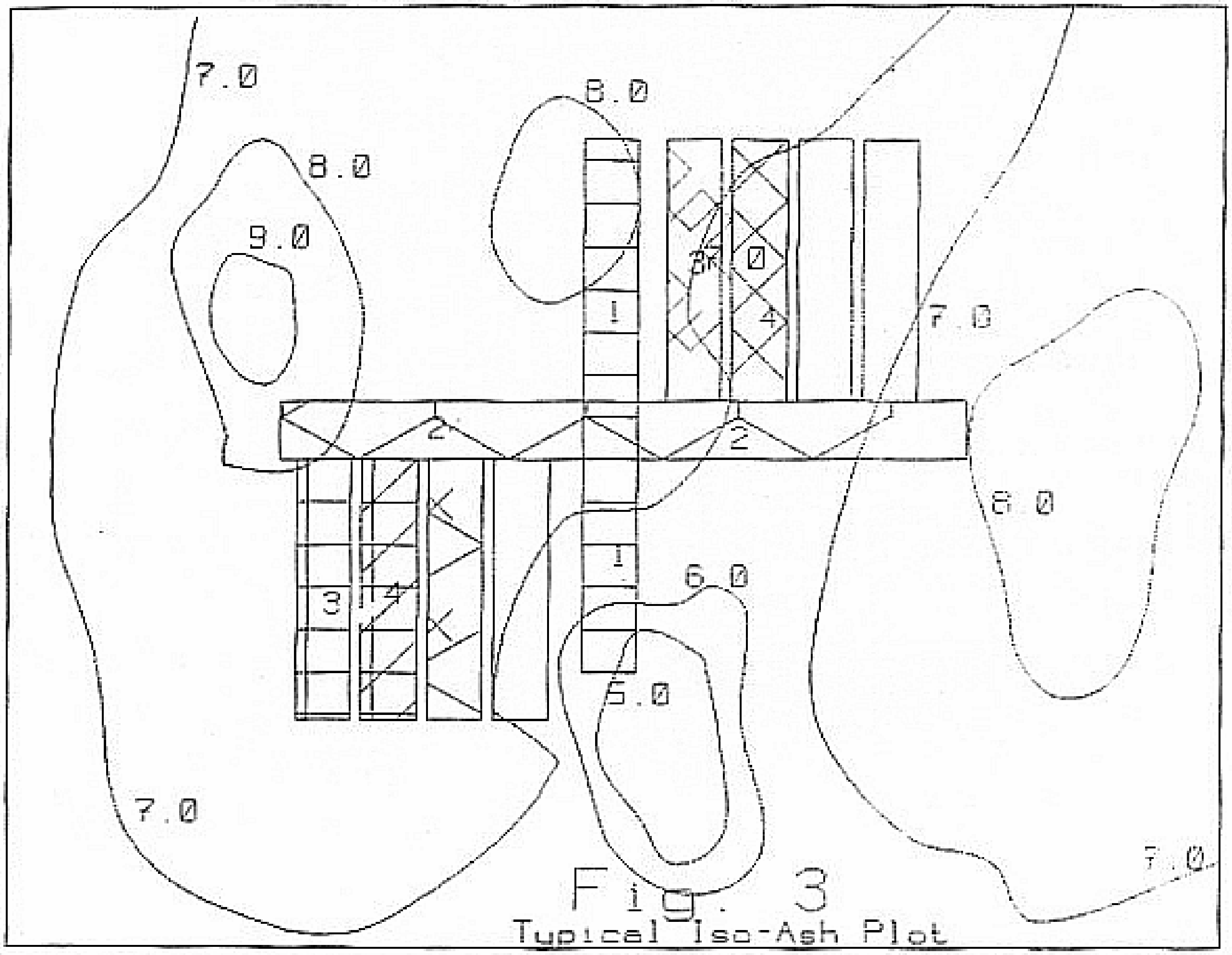

Fig. 3
Typical Iso-Ash Plot

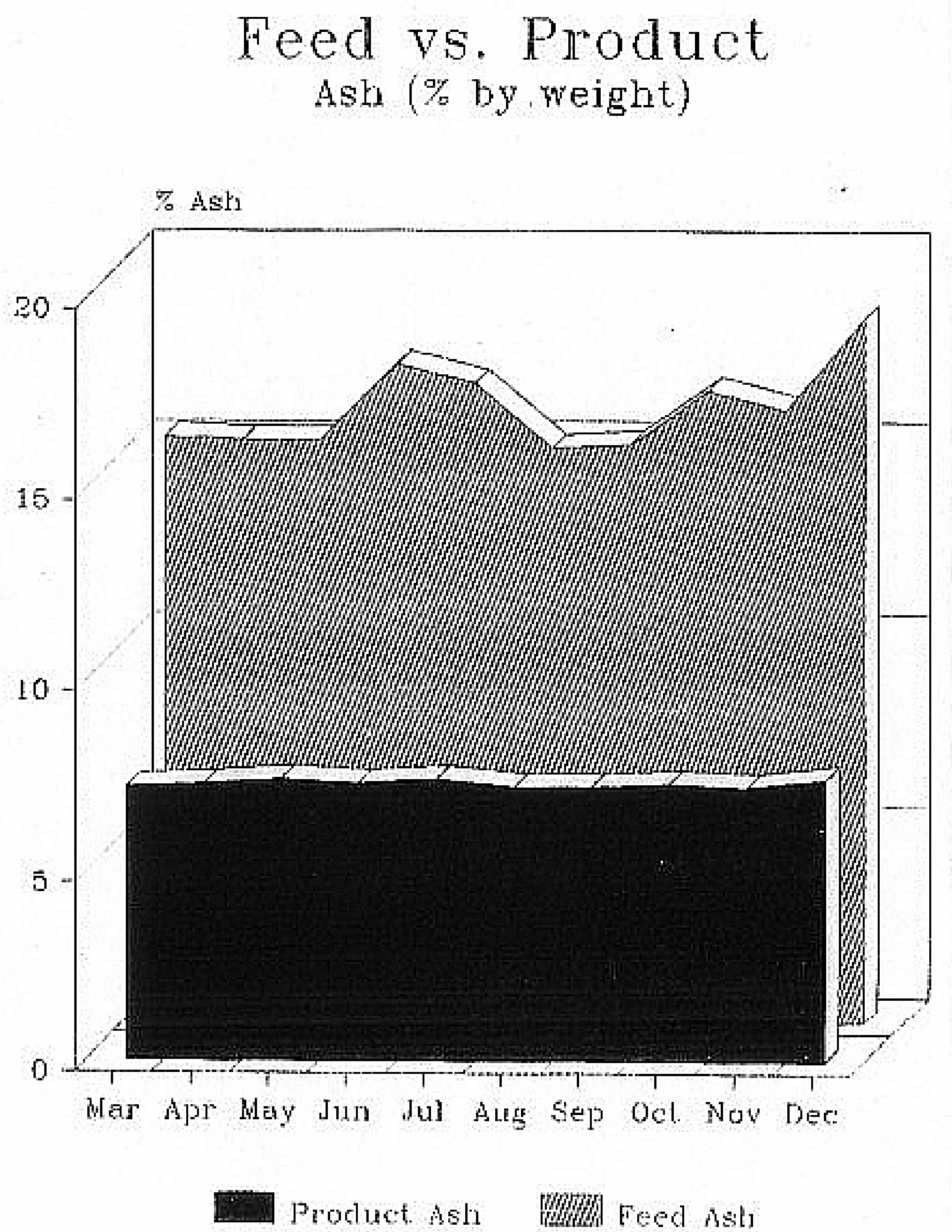
Feed vs. Product
Ash (% by weight)
% Ash
20
15
10
5
0
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Product Ash
Feed Ash

Figure 4

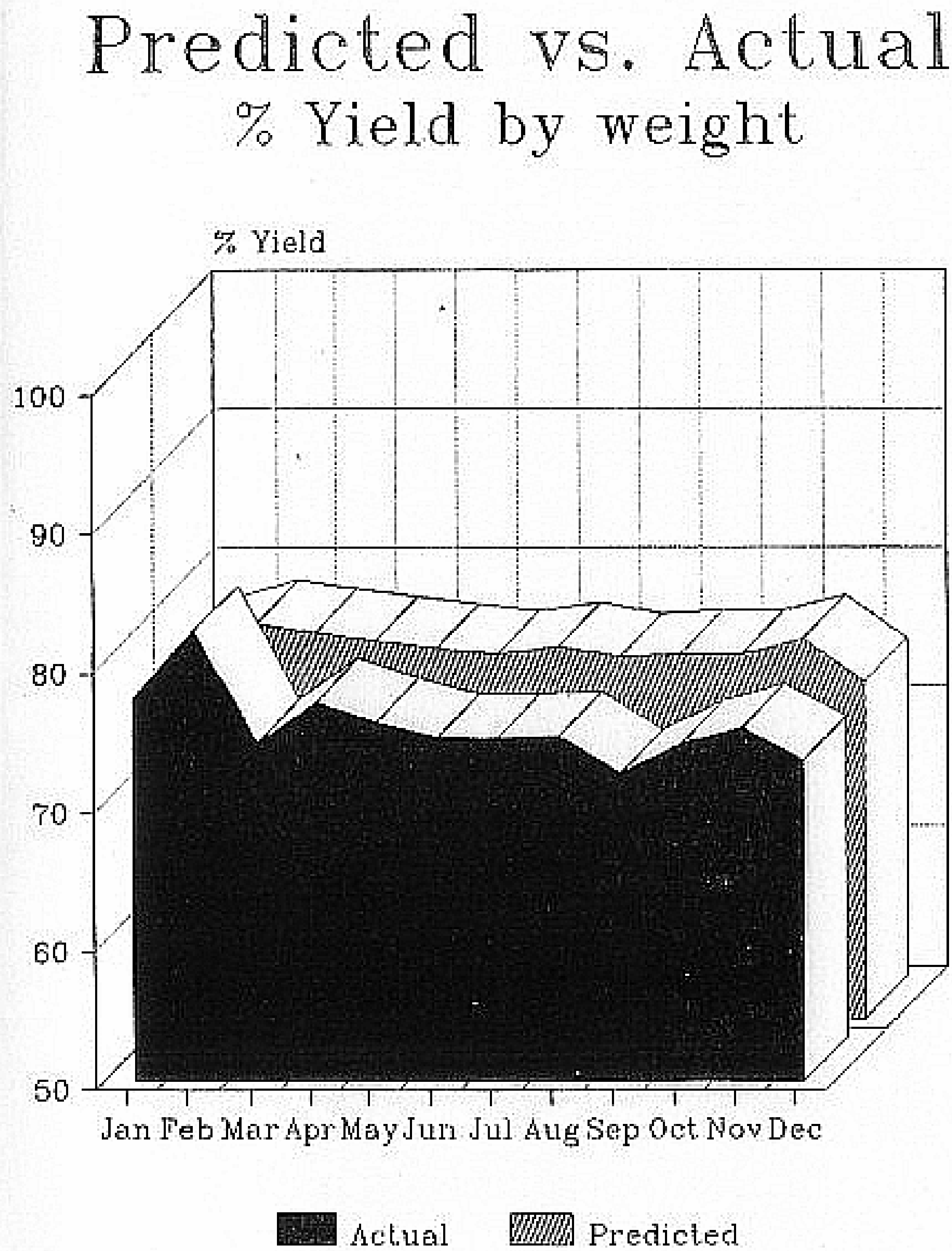
Predicted vs. Actual
% Yield by weight
% Yield
100
90
80
70
60
50
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Actual
Predicted

Figure 5