CAMADA BONITO - A RESERVE OF ENERGY COAL IN SANTA CATARINA

Dr. Eckart Hoffmann*

1. Introduction

Up to now the Bonito seam was considered marginal due to extremely high intercalation conditions. With a possible utilization of coal with 35% ash for substitution of oil in the cement industry and for gasification as well as of coal with 45% ash for power generation, the seam with its potential remarkable for Santa Catarina could move into the foreground.

2. Previous investigations

In 1974 the CPRM took a channel sample in the C.N.M.C. Barro Branco concession near Lauro Muller. The basic investigations carried out by Lavador de Capivari on the coal crushed to - 25 mm arrived at a yield of 32,0% for a 35% ash product. The yield drops to 29,0%, related to the raw coal.
Three years later the FINEP took another channel sample near Lauro Muller and charged Paulo Abib S.A. with the execution of the washability tests, which resulted in a yield of 27,5 (26,2) % for a 35 % ash coal with the sample crushed to - 100 mm.
The C.N.M.C. Barro Branco executed new investigations in cooperation with Lavador de Capivari in 1980. The coal was crushed to - 3,15 mm; the yield was 45,5 (31,6) % for a coal with 35 % ash.
The Carbonífera Criciuma did sink and float analysis on drill hole samples 3,15 - 0,074 mm with a yield of 37,5 (34,0) %.
Another sample of unknown origin was analyzed in Germany by Bergbauforschung. In this case only the lower part of the seam, the so-called Banco, was sampled. The coal was crushed to - 10 mm and resulted in a yield of 69,5 (55,6) %.
All results indicate an overall yield of $\pm$ 30 %, depending on the degree of comminution. The sulfur content fluctuates between 2 and 3 %.

3. Objectives

The investigations aimed to describe systematically the Bonito coal in regard to its raw material characteristics and preparation behaviour and so to give basic data to the interested industry, concerning quantities and qualities to be expected. In particular, the investigations aimed to

* Engenheiro - Cooperação Técnica Brasil/Alemanha (GTZ/DNPM/CETEM)

establish the

- size-ash-sulfur distribution
- amount of pure rock material in the coarse fractions
- density-ash-sulfur distribution
- floatability.

The work was part of the CETEM/DITCAR project "Tecnologia dos Carvões e das Turfas" and was financed by PME/DNPM. It was executed in close cooperation with Carbonífera Criciúma.

4. Sampling

The Bonito seam outcrops within the concession area of Carbonífera Criciúma near Lauro Muller. At the moment of sampling the seam was opened and worked at a 100 m wide face. The coal already mined was stockpiled near the outcrop. The pile with some 100 t capacity was to feed the Santa Rosa plant for some preliminary test runs at a later period. Preference was given to the bulk sampling from the pile instead of channel sampling from the seam, since most probably a bigger seam volume was covered representatively by sampling from the pile. Some bigger lumps were crushed manually on the spot. The sample, approximately 5000 kg, was collected in oil drums and shipped without water protection to the CETEM.
Sampling and shipping were carried out by Carbonífera Criciúma.

5. Test material

The Bonito bulk sample can be described macroscopically as follows:

- coarse-grained, often cubic forms in the ROM, but with the tendency to generate difficult-to-clean "fishes"
- high ash content, but little in-seam and out-of-seam dilution
- apparently highly intercalated
- little clean coal, only smallest layers in the millimetric range.

The sample has a top size of 400 mm. The ash content is 56,7 % (d.b.) and the sulfur content 4,37 % (d.b.). Table 1 shows ash and sulfur contents in comparison with the other investigations. The volatile matters amount to 38,8 % (d.a.b.), analyzed with clean coal - 1,40 kg/dm^3. Table 2 gives the ash composition of a washed coal with 40,4 % ash (private information by Dr. C. Otto & Co.).

6. Test program

First the head sample was air-dried and then homogenized. The first increment of the material was used to establish the size-ash-sulfur distribution. The resultant coarse fractions + 37,5 mm were submitted to an one-stage sink and

float analysis at 1,92 kg/dm^3 to determine the percentage of pure rock to be removed, if necessary, prior to the comminution.
Another increment of the material was crushed to - 25 mm, once again homogenized and divided into four sub-samples A to D, 300 kg each. After removal of the fines - 0,6 mm the sub-sample A was subjected to a complete sink and float analysis. The sub-samples B to D were crushed to - 12,5 mm, - 6,3 mm and - 3,4 mm, respectively. After adequate mass reduction and removal of the fines, they were submitted to the sink and float analysis, too.
A remaining part of the sample was archived for additional tests.

7. Investigation results

In the following the results are given in form of tables and figures.

7.1. Size-ash-sulfur distribution

Table 3 gives the size-ash-sulfur distribution of the sample as received. The material is relatively coarse-grained which is an indication for the same physical properties as already known from the Barro Branco seam. The size distribution follows somehow the Rosin-Rammler-Bennett distribution with the fine fractions - 1 mm slightly underrepresented. The ash content increases with decreasing size which is considered to be normal. The sulfur content shows more or less the inverse tendency. Most of the sulfur is pyritic (80 %).
The size distributions of the sub-samples A to D after comminution are presented in Table 4.

7.2. Amount of pure rock in the fractions + 37,5 mm

Table 5 shows the percentage of pure rock in the coarse fractions + 37,5 mm. The amount of the sink material + 1,92 kg/dm^3 is surprisingly small, in comparison with the Barro Branco conditions. This could be caused by absent dilution. The percentage of pure rock + 1,92 kg/dm^3 in the + 37,5 mm fractions is only 14 %, corresponding to 8 % of the total ash, with an ash content of 75 % assumed of the rock. Therefore the initial intention to remove the coarse rock and its pyrite prior to crushing was abandoned.

7.3. Density-ash-sulfur distribution

The results of the sink and float analysis are given as washability curves according to Henry-Reinhardt in Figures 1 to 4, particularly Figure 1 showing the coal 25 - 0,6 mm, Figure 2 the coal 12,5 - 0,6 mm, Figure 3 the coal 6,3 - 0,6 mm and Figure 4 the coal 3,4 - 0,6 mm.

The Henry-Reinhardt diagram is the graphical presentation of the ash layers resulting from the density-ash analysis. The elements for the construction of the Henry-Reinhardt diagram are included in the German Standard Vornorm DIN 23011.
The diagram contains four curves:

- elementary or instantaneous ash curve
- cumulative float or clean coal curve
- cumulative sink or rejects curve
- density curve.

The elementary ash curve gives for every fraction which floats or sinks the ash content of the highest-in-ash or lowest-in-ash layer, respectively. The cumulative float curve gives for every float fraction the average ash content, the same with the cumulative sink curve for every sink fraction. The density curve gives the density for every yield and vice versa.

7.4. Floatability

The flotation investigations were executed with the fines - 0,6 mm of the sub-samples C and D, whose comminution produced a bigger quantity of fines, 23,9 and 43,5 %. The fines have a high ash content and show the quality of flotation tailings. But it seemed that good and liberated coal was enriched in this fraction, thus justifying the hopes to gain a metallurgical coal by skimming off the cream.
The fines were processed by rougher-cleaner flotation in two parallel series, the first one executed carefully with flotation oil deficiency, the second one with oil surplus. The results of representative tests are given in Table 6. The ash contents falsify, of course, the FSI used for cokification characteristic.
Generally spoken, it can be noted that the floatability of the Bonito coal is poor. It must be assumed that the sample was oxidyzed (petrographic research by Z. Correa da Silva, outcrop coal, stockpiling). In reality, a better product was expected since the sink and float analysis of the fraction 0,6 - 0,074 mm of the CPRM/Capivari campaign resulted in a yield of 30 % with 18,5 % ash. With the FINEP/Paulo Abib investigations the yield was even better. Additional investigations have to be carried out since the FSI values as a matter of fact indicate coking coal properties, and the author feels that the flotation of the Bonito coal has not yet been dealt with.

8. Evaluation

Table 7 gives the results of the interpretation of the Henry-Reinhardt diagrams. The interpretation aimed at ash contents of 35 % and 45 % of the coal, in accordance with the demands of the industry.

The combined product, the sink and float coal and the flotation concentrate, results in the coal described in Table 8, with a flotation concentrate assumed of 10 % yield and 28 % ash added to the samples A and B and with a flotation concentrate measured of 18 % yield and 28 % ash added to the samples C and D.
By mixing the sink and float coal with the lower-in-ash flotation coal, the overall ash content drops below 35,0 % and 45,0 %, respectively, so that the cut point of the density separation can be shifted to a higher density. These circumstances are considered in Table 9, which demonstrates the final theoretical products to be reached at maximum.
A third alternative - production of coal for the cement industry and steam coal - was checked out as well. But with the potential of 35 % ash coal used, no additional product with 45 % ash can be attained.

9. Conclusions

Since the lab scale cleaning of the fines - 0,6 mm failed and especially under consideration of the water content of the product coal, it is suggested to crush the Bonito coal with a minimum generation of - 0,6 mm material and to discard the fines uncleaned and leave it to local contractors to wash some low-in-ash, perhaps metallurgical coal from the tailings pond.
If an ash content of 35,0 % is aimed at, then the Bonito coal must be crushed to - 12,5 mm with 86 % + 0,6 mm and 14 % - 0,6 mm. A coarser comminution leads to worse results; a finer one up to now not to significantly better ones. Based on the sink and float analysis, the + 0,6 mm fraction yields 34,6 % coal with 35,0 % ash at a density cut of 1,73 kg/dm^3. The coarse rejects are 50,9 % with 64,5 % ash and the fine rejects 14,5 % with 77,9 % ash. The sulfur content is approximately 2,40 %.
If the aim is an ash content of 45,0 %, the + 0,6 mm fraction delivers with the same conditions of comminution a coal with 65,4 % yield. The coarse rejects amount to 20,1 % with 75,5 % ash and the fine rejects to 14,5 % with 77,9 % ash. The sulfur content can be estimated below 3,0 %.
But the picture developed above changes considerably if the results of the analysis of the fines made by CPRM/Capivari are implicated.
Anyhow, the investigations have demonstrated that the Bonito coal does not reach the qualities and quantities of the Barro Branco seam, but that on the other hand the coal can be converted in a satisfactory grade energy coal by means of proper preparation.

10. Tables and figures

Sample	Ash%	S%
Criciuma bulk	56,7	4,37
CPRM/Capivari	58,0	3,90
Criciuma sondagem	58,1	3,89
FINEP/Paulo Abib	52,0	4,30
BB/Capivari	59,8	1,65
BBE/Banco	42,0	3,18

Table 1: Ash and sulfur contents of the Bonito seam

Oxide	%
SiO_2	62,5
Al_2O_3	23,8
Fe_2O_3	6,9
TiO_2	0,6
CaO	0,7
MgO	0,8
Na_2O	0,4
K_2O	2,7
SO_3	1,1

Table 2: Ash composition of the Bonito seam

Sample	Head	A	B	C	D
Topsize mm	400	25,0	12,5	6,3	3,4
Size mm					
+6,3	70,20	57,78			
+0,6	20,74	35,18	85,47	76,10	56,50
-0,6	9,06	12,04	14,53	23,90	43,50
	100,0	100,0	100,0	100,0	100,0

Table 4: Size distributions of the crushed Bonito samples

Size mm	Yield%	Ash%	S%
+200	3,26	48,4	4,15
200 -100	13,80	50,4	4,12
100 - 50	19,65	49,6	4,47
50 - 37,5	6,30	51,2	6,69
37,5- 25	7,64	51,2	5,93
25 - 12,5	10,01	52,7	6,27
12,5- 6,3	9,54	60,5	4,73
6,3- 3,4	7,32	65,2	3,51
3,4- 1,2	8,87	67,2	2,93
1,2- 0,6	4,55	67,0	2,55
0,6- 0,2	4,70	69,4	2,16
0,2- 0,074	2,45	72,3	2,10
- 0,074	1,91	73,5	2,44
	100,00	56,7	4,37

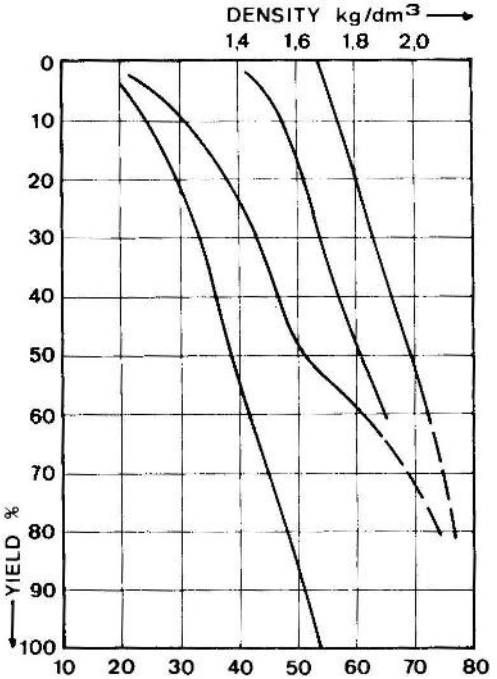
Table 3: Size-ash-sulfur distribution of the Bonito seam

Size mm	Sink%
+200	-
200-100	12,40
100- 50	14,70
50- 37,5	22,90

Table 5: Percentage of pure rock + 1,92 kg/dm^3 in the course fractions + 37,5 mm

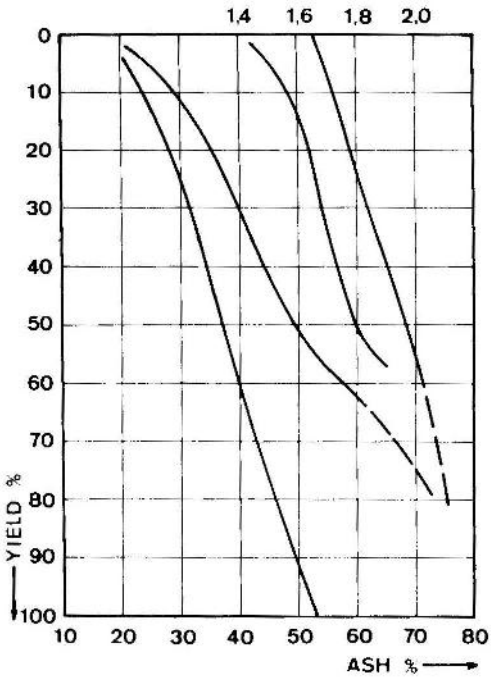
D	Yield%	Ash%	S%
-1,3	0,36	7,2	1,70
-1,4	1,24	19,7	1,89
-1,5	3,67	22,4	1,88
-1,6	11,38	31,4	2,05
-1,7	18,80	40,6	2,24
-1,8	13,38	47,3	2,28
-1,9	12,28	56,1	2,45
+1,9	38,89	72,8	7,38
	100,00	53,8	4,22

Figure 1: Results of the sink and float analysis and Henry-Reinhardt diagram of the Bonito coal A 25 - 0,6 mm



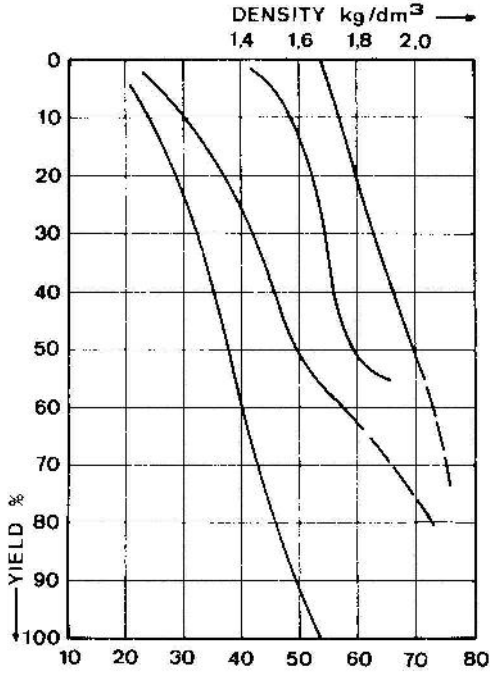
D	Yield%	Ash%	S%
-1,3	0,23	10,7	1,78
-1,4	1,24	19,3	1,99
-1,5	2,57	21,6	1,94
-1,6	8,48	27,9	2,12
-1,7	21,21	37,6	2,30
-1,8	16,97	46,0	2,46
-1,9	5,82	52,6	2,43
+1,9	43,48	71,4	8,57
	100,00	53,1	5,03

Figure 2: Results of the sink and float analysis and Henry-Reinhardt diagram of the Bonito coal B 12,5 - 0,6 mm



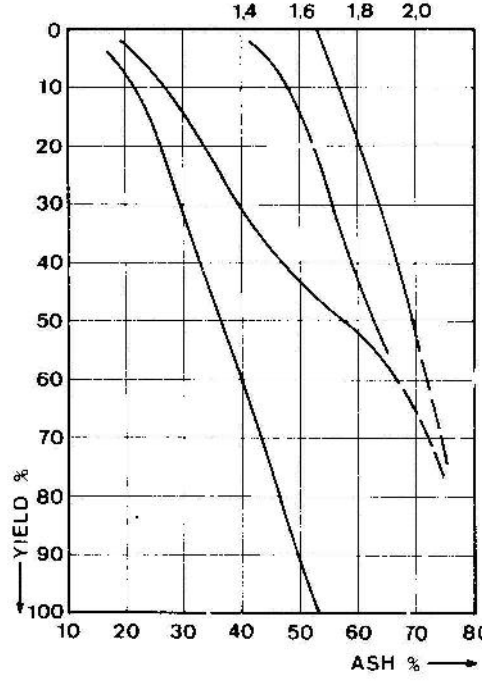
D	Yield%	Ash%	S%
-1,3	0,34	10,1	2,59
-1,4	1,77	18,6	2,91
-1,5	2,42	23,7	2,38
-1,6	8,76	28,6	2,12
-1,7	23,53	39,1	2,32
-1,8	14,66	47,1	2,35
-1,9	3,45	50,4	2,58
+1,9	45,07	71,3	9,17
	100,00	53,4	5,44

Figure 3: Results of the sink and float analysis and Henry-Reinhardt diagram of the Bonito coal C 6,3 - 0,6 mm



D	Yield%	Ash%	S%
-1,3	0,50	7,7	1,72
-1,4	1,94	16,1	1,97
-1,5	3,23	19,9	1,89
-1,6	8,62	26,5	1,89
-1,7	6,09	34,0	1,92
-1,8	15,45	44,6	2,00
-1,9	9,56	58,9	1,77
+1,9	44,61	70,3	9,36
	100,00	52,6	5,25

Figure 4: Results of the sink and float analysis and Henry-Reinhardt diagram of the Bonito coal D 3,4 - 0,6 mm



Sample	Size mm	%	Feed Ash%	Product Ash%	Yld%	Yld%	S%	FSI
C	-0,6	23,9	67,7	21,5	9,1	2,2	2,57	4 1/2
D	-0,6	43,5	62,4	22,9	10,0	4,4	2,41	3 1/2
C	-0,6	23,9	67,9	29,5	18,3	4,4	2,74	2 1/2
D	-0,6	43,5	62,0	28,6	18,6	8,1	2,98	2 1/2

Table 6: Results of the flotation analysis of the Bonito fines - 0,6 mm

Sample	Size mm	%	Feed Ash%	Product Ash%	Yld%	Yld%	Product Ash%	Yld%	Yld%
A	25,0-0,6	87,9	53,8	35,0	37,0	32,5	45,0	70,0	61,5
B	12,5-0,6	85,5	53,1	35,0	40,5	34,6	45,0	76,5	65,4
C	6,3-0,6	76,1	53,4	35,0	40,0	30,4	45,0	77,5	59,0
D	3,4-0,6	56,5	52,6	35,0	48,0	27,1	45,0	76,0	42,9

Table 7: Ash contents and yields from the Henry-Reinhardt diagrams

Sample	Ash%	Yld%	Ash%	Yld%
A	34,8	33,7	44,7	62,7
B	34,7	36,0	44,6	66,8
C	34,1	34,7	43,8	63,3
D	33,4	34,9	42,4	50,7

Table 8: Ash contents and yields of the combined products

Sample	Ash%	Yld%	Ash%	Yld%
A	35,0	34,6	45,0	63,2
B	35,0	36,9	45,0	67,4
C	35,0	37,4	45,0	66,3
D	35,0	37,3	45,0	56,4

Table 9: Ash contents and maximum yields of the Bonito coal