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ASSESSMENT OF VARIABLES CONCERNED WITH PARTIAL AGGLOMERATION OF COKE OVEN CHARGES

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by

J.T. Price*, W.R. Leeder*, and K.F. Hampel**

INTRODUCTION

The object of this preliminary investigation was to use small-scale methods to eliminate some of the variables involved with coke-oven charge partial agglomeration procedures prior to studies in the large technical-scale test. This study used twenty 3-in. diam by 12-in. long canisters filled with partially briquetted coal charges which were carbonized in the CANMET 12-inch technical-scale coke oven.

The partial agglomeration of coke oven charges has been used in several countries to improve coke quality and to extend the coking coal base to cheaper coals that are presently considered to be poor or non-coking. As early as 1950 Turchenko (1) at the Kuznetsk Integrated Iron and Steel Works experimented with the carbonization of charges containing coal briquettes in an attempt to improve coke quality. Experiments with various charges containing briquettes have been made in Canada (2), Australia (3), South Africa (4), Japan (5), USSR (1,6) and several European countries. Results indicated coke quality improved for briquetted coking coal charges and, more importantly, satisfactory metallurgical cokes could be made from blends containing poor and/or non-coking coals. Two basic methods are used. One technique puts poor or non-coking coal in briquettes that are then charged to the coke oven with a normal good coking-coal blend. The second technique blends the coking and non-coking coals and then briquettes only a portion of this mixture prior to charging to the coke ovens. In this case the total charge, both the loose coal blend and the briquettes contain poor or non-coking coal.

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A number of experimental variables may influence the quality of coke produced by either of the partial briquetting methods. These include: the choice and amounts of coal and binder to be used in briquette formation; the loose coal/briquette ratio; the size and shape of the briquettes; the degree of pulverization of the coal to be briquetted; the moisture content of the briquette; and briquetting pressures. However, no systematic study has been undertaken to assess the importance of all variables involved in the partial agglomeration procedures. The objective of this report is to present and discuss a study where a factorial experiment was designed to assess the effect of five of these variables on the resulting coke quality for partial briquetting tests where the poor or non-coking coal was only present in the briquette. The variables included: briquette size; size of coal briquetting; briquetting pressure; binder content; and additions of an oxidized coking (non-coking) coals to the briquettes. Thirty per cent briquette/coal mixtures were carbonized in 20 canisters within the 12-in. coke oven. Coke quality was assessed using the Red Devil Shatter Test (RDST) to obtain disintegration and hardness indices (7).

METHOD

In this study 20 cylindrical canisters (3-in. diam x 12-in. long) were charged with the 30 per cent briquette/coal mixtures and loaded into the side charge box for the CANMET 12-inch technical-scale coke oven as shown in Figure 1. The matrix area of the side charge box was filled with a good coking-coal blend and the entire charge coked in the conventional manner. The five variables involved in making the briquettes for this study are listed and detailed in Table 1. Each of these variables were studied at 2 basic levels and required 32 (2^5) tests to carry out the factorial study. As a result different briquette coal charges were loaded into each half of the canister and separated by a cardboard disc. Eight more half canister tests were made in the remaining canisters; four of these tests were carried out using no briquette additions to the half canister while 4 tests were made on coal/briquette mixtures containing 20 per cent oxidized Balmer in the briquettes. The basic coal blend selected for the tests was 12 per cent Itmann/88 per cent Devco-26 which was used for the matrix inside the canister as well as for the briquettes containing only coking coals. Other briquettes were also made from a blend containing 12 per cent Itmann/78 per cent Devco-26/10 per cent oxidized Balmer or from a blend containing 12 per cent Itmann/68 per cent Devco-26/20 per cent oxidized Balmer. Details of the 40 tests are listed in Tables 2, 3, and 4.

Coking conditions for the canister tests corresponded to standard 12-inch coke oven practice with the dry bulk density of the matrix coal set at 51 lb ft^{-3}. The carbonized contents of the canisters were carefully removed, sectioned, analyzed visually and photographed before testing in the RDST.

RESULTS

Previous work involving the RDST has suggested that the disintegration behaviour of 500 g samples of canister coke using this apparatus may be related to the ASTM strength and hardness values that would be obtained from the same coke in a full 12-inch oven test. The disintegration and hardness indices from the RDST and the predicted ASTM stability and hardness indices are given in Table 5. Also, the appearance of each piece of canister coke prior to testing is briefly described.

All coal/briquette charges for the 40 tests produced a fairly strong and uniform coke material. Figure 2a and 2b show the half canister coke from test sample 1 and the longitudinal section of this sample which originally contained ten-20 g briquettes. These photographs are typical of all the coke products; none of the products showed any evidence of where the briquettes had been placed.

Before detailed analysis of variance calculations are discussed, t-tests were used to determine if briquetting improved coke quality. The canister charges containing only loose coal (90 per cent -6 mesh, 88 per cent Devco-26/12 per cent Itmann) had an average RDST disintegration index of 75.48 (standard deviation of 2.24) and corresponded to an average ASTM stability index of 44.85. The 16 tests (actually only 15 as some of sample 16 was spilled during the RDST determination) using the same coal blend but with 30 per cent briquette additions had an average RDST disintegration index of 80.4 (S=4.52) which corresponded to an average calculated ASTM stability of 47.91. The canisters containing only loose coal gave an average RDST hardness of 61.20 (S=1.89) and corresponded to a calculated ASTM value of 63.95. The average RDST hardness value for briquetted samples made from the same coal was 63.23 (S=1.48) and corresponded to an average ASTM hardness of 65.20. A comparison of the means for RDST disintegrations of the non-briquetted and briquetted charges gave a t value of 2.25, slightly greater than the table value (2.11) for the 0.05 level of significance. A comparison of the means for the RDST hardnesses gave a t value of 2.33. Thus the hypotheses that the mean RDST index are equal for the briquetted and non-briquetted charges can be rejected with 95% confidence, and the increase in the RDST of the briquetted charge is greater than for non-briquetted charges. A similar result was obtained for the comparison of the calculated ASTM value.

Four test samples were also carbonized with 20% oxidized Balmer within the coal briquettes. A t test comparing the mean of these charges with the mean of charges containing no oxidized coals indicated there was no significant differences between the means (t=0.68 table=2.1), although such an hypothesis was rejected when comparing the 20% Balmer briquettes with loose coal (not-briquetted).

An analysis of variance was carried out on the factorial experiment for each of the 31 combinations of variables (i.e. 5 main effects, 10 first order, 10 second order, 5 third order, and 1 fourth order effect) for both RDST disintegration and hardness parameters.

Results suggest that the main effects in themselves do not cause a significant alteration in coke quality. However, some of the combinations of variables may have some significance. Table 6a, 6b lists the combinations of variables that have significant F ratios and may effect the RDST disintegration and hardness properties.

DISCUSSION

Results from the 40 partially briquetted test samples suggests that partial briquetting of the coal charge will increase the mean RDST from 75 to 80 units corresponding to an ASTM stability increase of about three units. Calculated ASTM hardness were found to be improved on the average by about four units. These results reinforce the findings of other researchers (1-6) who also concluded that partial briquetting of coke oven charges improved coke quality. Results from the canisters containing oxidized (non-coking) coal suggested that up to 20% and possibly more oxidized Balmer coal could be introduced into the briquettes (6 per cent of charge) without detrimentally affecting the resultant coke's quality. However, changes in the levels of all five of the major variables had no statistically significant effects upon the quality of coke produced. Single factors such as briquette weight, binder content, or coal size had little effect upon coke quality.

Analyses of variance on the RDST results do suggest that combinations of the major variables may have some significance. F ratios calculated from RDST disintegrations (coke strength) are summarized in Table 6a. Coal size with addition of non-coking coal (AC Table 6a), and briquetting pressure with briquette binder content (BE) appear to be the most significant first order effects. For example, stronger coke was made with finer coal size provided good coking coal was used and with coarser coal size if oxidized coals were used. Also, high briquetting pressures (15,000 psi) with the higher pitch level (or low briquetting pressure with the lower pitch level) resulted in stronger coke. A combination of these two first order effects (AC and BE Table 6a) would explain the high statistical effect of the third order effect ABCE. This combination of variables appeared to cause the largest alteration in coke strength by the partial briquetting of these coals and indicated the importance (and also complexity) in the interaction of variables used in the coking of partially briquetted charges. Briquette size appeared to have the least influence on coke strength as it (D) appears only once in the apparently significant combinations of variables listed in Table 5a.

Analysis of variance on the RDST hardnesses data suggests the first order interaction of grain size with oxidized (or non-oxidized) coal had the most influence on coke abrasion. Once again, better coke was produced with finer grain size if coking coal was used (and with coarser grain size if oxidized coal was used). Other first, second and even fourth order interaction appeared to be significant influences on coke hardness and once again indicates the complexities involved with partial briquetting practises. Coke hardnesses, unlike the disintegration results, appears to be influenced by briquette size (D - Table 6b) in combination with other variables.

The influence of using oxidized coking-coal in the briquettes on the coke RDST disintegration index is shown in Figure 3. This figure indicates: 1) an increase in the index when part of the charge is briquetted; and 2) suggests that incorporation of oxidized coking-coal in place of the hvb portion of the briquette, improved overall coke strength.

It was somewhat disappointing that the major variables did not allow any definite conclusions to be drawn from the different partial briquetting procedures. In this respect more confidence could have been placed in our data (and conclusions) if duplicate tests had been made. Possibly the initial test program was too ambitious and fewer variables should have been tested. However, the fact that briquetting of coal charges did improve coke quality does suggest that the results warrant extending the preliminary canister trials to another set of experiments. It is suggested that only four variables be tested (e.g. coal size, briquette size, addition of non-coking coal, and binder content) but with duplicate samples. The variation in the binder content should be set at new levels (i.e. 0 and 7 per cents) so that the effect of binder on coke quality can be more readily determined. The blends containing non-coking coals should be set at higher levels to better determine if these coals can be used to replace low-volatile coking coals with partial briquetting of the coal charge.

TABLE 1

Variable	Level	Reason
1. Coal Size	minus 6 mesh	Commercial sizing
	minus 14 mesh	Size suggested in NKK publication
2. Briquetting Pressure	6000	Determined experimentally
	15000	Higher density to briquette
3. Briquette Weight (shape)	10 g	Flat - similar to commercial pillow briquette
	20	Cylindrical - similar to commercial ovoid briquette
4. Binder Content	7	Corresponds to commercial range
	10	" " "
5. Addition of non-coking coal to briquettes	0	Standard coking blend
	10	Possible use of non-coking coal in coking blend

TABLE 2

Canister Loading and Placement

Canister Placement Number (see Figure 1 for position)	Canister Loading Test No. (see Table 3)	
	Top	Bottom
1	28	11
2	39	20
3	25	30
4	14	5
5	6	18
6	38	1
7	26	27
8	35	15
9	12	37
10	17	22
11	40	2
12	21	31
13	10	19
14	36	32
15	4	8
16	24	16
17	3	33
18	23	13
19	7	34
20	29	9

TABLE 3

		Size of Coal (minus mesh size)								
		14				6 (-1/8")				
		Briquetting Pressure (PSI)								
		6,000		15,000		6,000		15,000		
		Addition of Oxidized Balmer (10%)								
Weight of Briquette (g)	Binder Content (%)	Yes	No	Yes	No	Yes	No	Yes	No	
20	10	33* 10 1	34** 10 2	35* 10 3	36** 10 4	10 5	10 6	10 7	10 8	80
20	7	10 9	2 10 10	10 11	10 12	10 13	10 14	10 15	10 16	80
10	10	20 17	20 18	20 19	20 20	20 21	20 22	20 23	20 24	160
10	7	37* 20 25	38** 20 26	39* 20 27	40** 20 28	20 29	20 30	20 31	20 32	160
		60	60	60	60	60	60	60	60	480 Total Briquettes

*Additional briquettes to be prepared with 12:68:20 of Itmann:Devco-26: Balmer

**These tests contained only matrix coal (-6 mesh, 12:88 of Itmann:Devco-26)

TABLE 4 Materials in Canisters

MASTER CHART NUMBER	CANISTER NUMBER TOP/BOT.	POSITION IN OVEN	BRIQUETTE MOISTURE (%)	BRIQUETTE DRY B.D. (LB/CU.FT.)	SIZE OF COAL (MESH)	BRIQUETTE PRESSURE (PSI)	BRIQUETTE WEIGHT (GRAM)	ADDITION 10% OXIDIZED BALMER	BINDER CONTENT (%)
1	6-B	6	2·81	67·9	-14	6,000	20	YES	10
2	11-B	11	1·60	69·1	-14	6,000	20	NO	10
3	17-T	17	0·76	73·4	-14	15,000	20	YES	10
4	15-T	15	0·82	72·7	-14	15,000	20	NO	10
5	4-B	4	2·12	70·2	-6	6,000	20	YES	10
6	5-T	5	1·50	70·0	-6	6,000	20	NO	10
7	19-T	19	1·07	73·1	-6	15,000	20	YES	10
8	15-B	15	0·85	71·7	-6	15,000	20	NO	10
9	20-B	20	2·77	66·8	-14	6,000	20	YES	10
10	13-T	13	4·15	66·9	-14	6,000	20	NO	10
11	1-B	1	0·90	70·2	-14	15,000	20	YES	7
12	9-T	9	0·92	71·8	-14	15,000	20	NO	7
13	18-B	18	0·84	68·8	-6	6,000	20	YES	7
14	4-T	4	4·96	69·4	-6	6,000	20	NO	7
15	8-B	8	1·45	71·5	-6	15,000	20	YES	7
16	16-B	16	2·72	71·3	-6	15,000	20	NO	7
17	10-T	10	1·91	68·1	-14	6,000	10	YES	10
18	5-B	5	1·63	67·8	-14	6,000	10	NO	10
19	13-B	13	0·89	72·2	-14	15,000	10	YES	10
20	2-B	2	0·98	71·7	-14	15,000	10	NO	10
21	12-T	12	1·27	69·6	-6	6,000	10	YES	10
22	10-B	10	1·47	68·8	-6	6,000	10	NO	10
23	18-T	18	1·05	72·2	-6	15,000	10	YES	10
24	16-T	16	1·14	72·9	-6	15,000	10	NO	10
25	3-T	3	1·88	68·8	-14	6,000	10	YES	7
26	7-T	7	2·82	66·2	-14	6,000	10	NO	7
27	7-B	7	0·86	71·6	-14	15,000	10	YES	7
28	1-T	1	1·07	69·1	-14	15,000	10	NO	7
29	20-T	20	2·57	68·8	-6	6,000	10	YES	7
30	3-B	3	2·88	69·6	-6	6,000	10	NO	7
31	12-B	12	1·80	71·0	-6	15,000	10	YES	7
32	14-B	14	2·06	71·6	-6	15,000	10	NO	7
33	17-B	17	3·29	71·9	-14	6,000	20	YES	10
34	19-B	19	0·93	51·0	-6	—	—	—	—
35	8-T	8	2·01	73·7	-14	15,000	20	YES	10
36	14-T	14	0·93	51·0	-6	—	—	—	—
37	9-B	9	2·98	70·5	-14	6,000	10	YES	7
38	6-T	6	0·76	51·0	-6	—	—	—	—
39	2-T	2	2·26	71·9	-14	15,000	10	YES	7
40	11-T	11	0·76	51·0	-6	—	—	—	—

TABLE 5

Canister Test Results

MASTER CHART NUMBER	RDST % DEGRADATION	RDST HARDNESS	ASTM STABILITY	ASTM HARDNESS	APPEARANCE OF COKE		
					PIECES 1,3,5,5+	SCALE % OF SURFACE	OTHER
1	71·5	61·1	42·7	63·9	1	30	—
2	87·6	63·8	52·1	65·6	3	50	—
3	82·6	58·3	49·0	62·2	3	50	—
4	82·0	65·7	48·6	66·7	1	70	—
5	77·0	61·9	45·7	64·4	3	50	SC.
6	77·2	61·3	45·8	64·0	5+	50	—
7	85·3	65·3	50·7	66·5	3	60	—
8	77·9	60·3	46·2	63·4	5+	70	—
9	81·1	57·3	48·1	61·6	5+	10	—
10	83·7	63·0	49·7	65·1	3	50	—
11	70·9	64·7	42·4	66·1	3	50	CR.
12	77·6	64·1	46·0	65·7	5+	50	—
13	80·0	64·4	47·4	65·9	3	50	—
14	80·8	63·1	47·9	65·1	3	70	CR.
15	87·7	64·3	52·2	65·9	1	40	—
16	74·8	62·1	44·5	64·5	3	20	—
17	79·4	63·7	47·0	65·5	3	60	—
18	80·3	64·7	47·6	66·0	5	30	—
19	84·0	62·5	49·9	64·8	3	10	—
20	76·9	63·7	45·6	65·5	5	30	CR.
21	86·2	63·2	51·2	65·2	3	50	—
22	79·9	61·4	47·4	64·1	3	10	—
23	83·8	63·2	49·7	65·2	3	60	—
24	79·8	63·5	47·3	65·4	5	80	SC.
25	87·5	64·2	52·1	65·8	5+	10	—
26	85·0	64·1	50·5	65·7	3	60	—
27	76·4	58·0	45·4	62·0	3	20	—
28	87·3	63·5	51·7	65·4	5+	50	CR.
29	77·8	61·4	46·2	64·1	3	70	—
30	84·6	64·6	50·2	66·0	3	5	—
31	78·1	61·2	46·3	64·0	3	40	—
32	70·5	61·7	42·1	64·3	3	50	—
33	77·9	60·1	46·2	63·3	3	50	—
34	75·3	58·6	44·7	62·4	1	10	—
35	87·8	67·2	52·3	67·6	5	40	—
36	73·8	63·1	43·9	65·1	1	60	SC.
37	81·1	63·9	48·1	65·6	1	60	—
38	74·1	61·5	44·1	64·1	3	60	SC.
39	82·8	65·8	49·1	66·8	5+	40	CR.
40	78·7	61·6	46·6	64·2	3	60	—

SC. - DEEP SCALES
CR. - DEEP CRACKS

TABLE 6a*

Analysis of Variance of RDST Disintegration Data

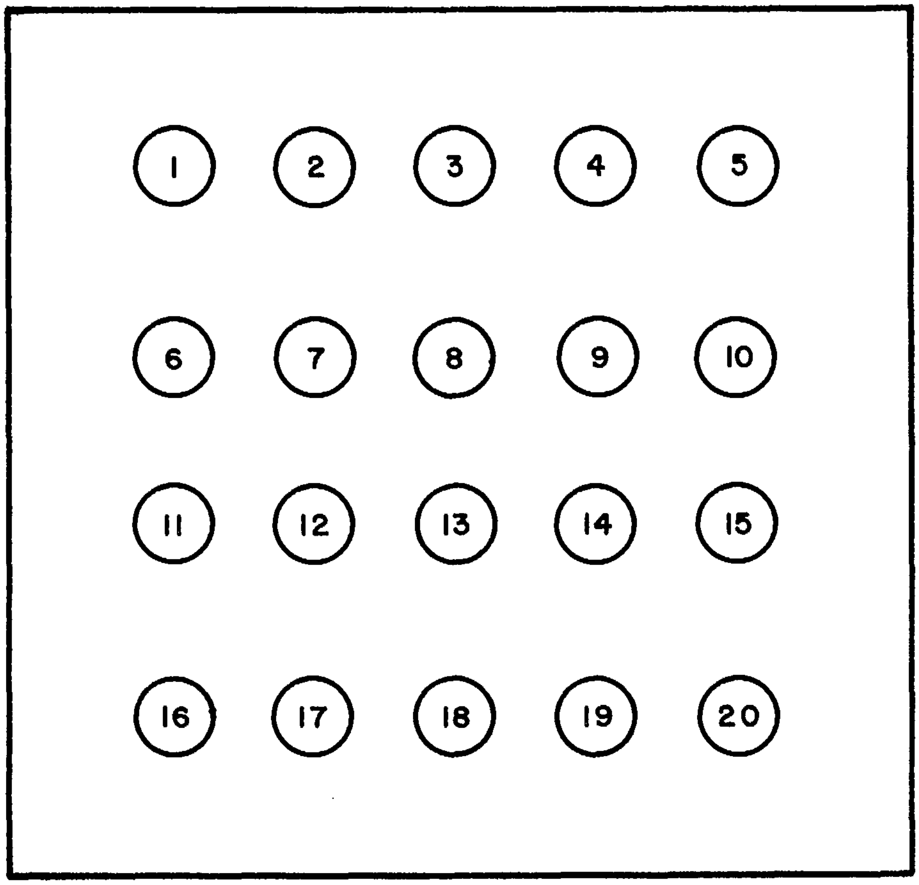
Variable Interaction	Sums of Squares	Degrees of Freedom	F Ratio
ABCE	131.63	30	6.71
AC	103.32	29	6.17
BE	88.45	28	6.24
ADE	80.33	27	6.85
BC	51.76	26	5.08

TABLE 6b*

Analysis of Variance of RDST Hardnesses Data

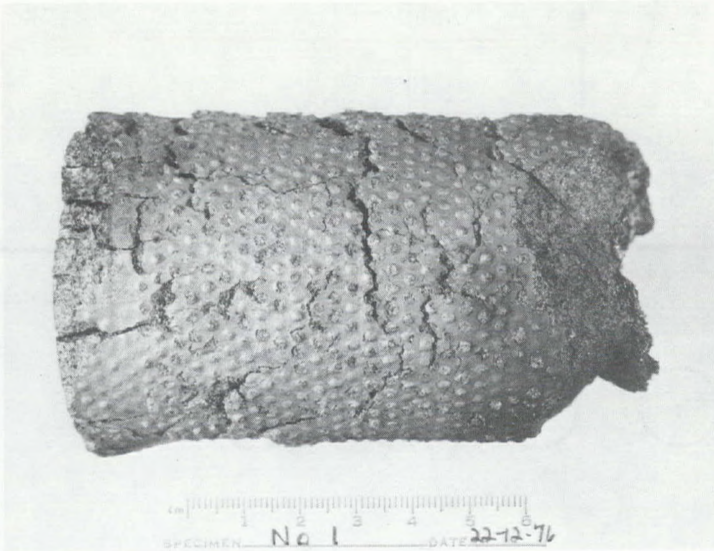
Variable Interaction	Sums of Squares	Degrees of Freedom	F ratio
AC	27.57	30	7.88
ABCDE	19.07	29	6.42
BD	11.28	28	4.23
BCD	11.28	27	4.80
ACD	11.16	26	5.55

* A = coal size; B = Briquetting Pressure;
C = Addition of non-coking coals; D = Briquette size;
E = Binder content.



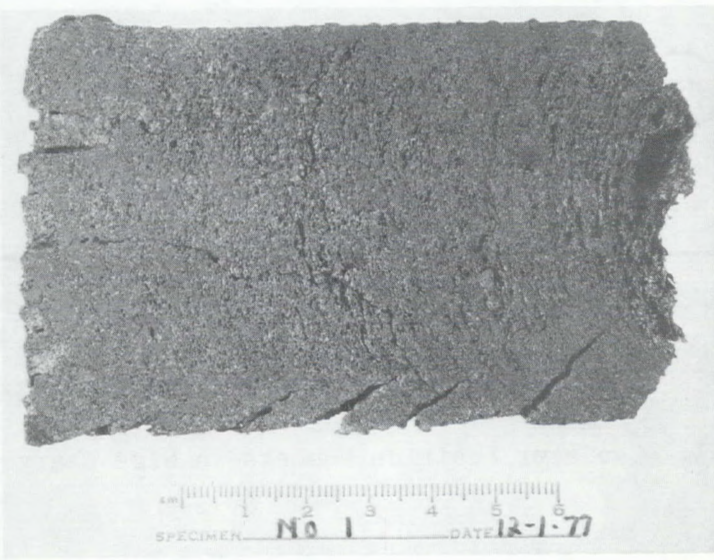
Side View

Figure 1. Canister Position Numbers in Side Charge Box.



(a)

Photograph of Half Canister Coke of test sample 1



(b)

Photograph of the Longitudinal Section of coke from test #1

FIGURE 2

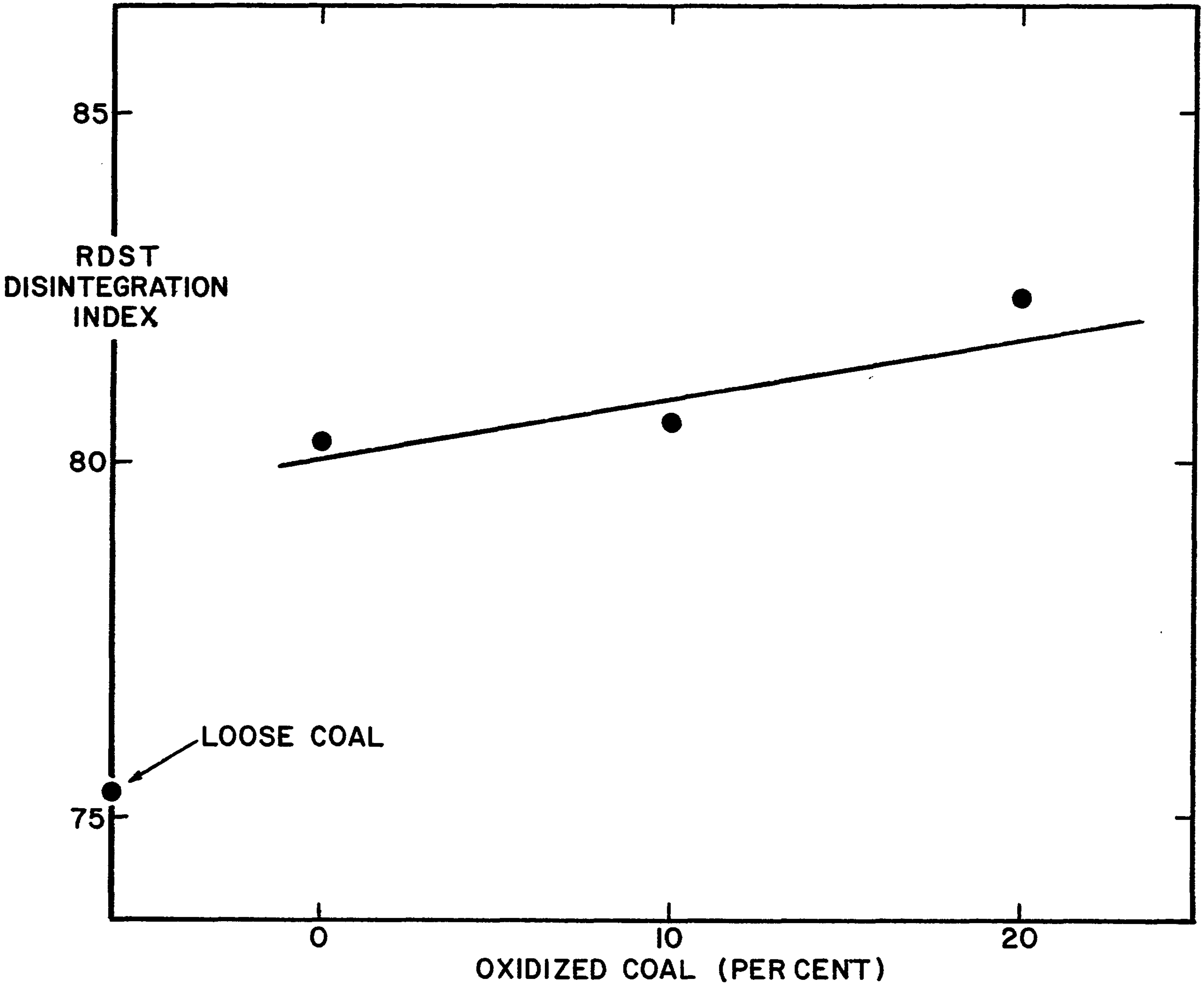


Figure 3. RDST Disintegration versus amount of oxidized coal in the briquettes.

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