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A REVIEW OF PARTIAL AGGLOMERATION OF COKE OVEN CHARGES

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by

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ABSTRACT

The partial agglomeration of conventional coke oven charges has gained increased attention recently in several industrialized countries because studies have shown that this method can improve coke quality and extend the normal range of coals used in coke oven charges to include less expensive non-coking coals. This report surveys investigations made in several countries into the influences on coke quality: of briquette preparation; of methods of mixing briquettes and loose coal; of bulk density as affected by shape, size, and percentage of briquettes in the coke oven charge. Development of various technologies from several countries are described along with processes that are now used indestrially in Japan. Several investigations are suggested for Coal Resource and Processing Laboratory (CRPL) using blends made with non-coking Canadian coals to determine how partial briquetting of coke oven charges may alter coke quality.

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INTRODUCTION

This report describes some of the investigations that have been conducted in several countries concerning the production of high quality cokes using partially agglomerated coke oven charges. It is reported that this method can improve coke quality and be used in conjunction with coal blending technology to extend the range of coals that can be used to produce high quality coke.

As early as 1950 Turchenko[1] at the Kuznetsk Integrated Iron and Steels (USSR) 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 countries including Canada[2], Australia[3], South Africa[4], Japan[5], USSR[6] and several European countries. Results from these tests indicated that partial agglomeration of conventional coke oven charges improved the resulting coke's properties. Using this technique, good metallurgical coke can also be produced by using non-coking coals in the coal blends. Two techniques have been employed to add the non-coking coal. The first technique puts all the non-coking coal into the blend to be used for the briquettes. The briquettes are then blended in the oven with good matrix coking coal that fills the voids between briquettes. The second technique blends the coking and non-coking coals together and briquettes a portion of this material prior to charging into the coke ovens.

Variables that must be considered for partial briquetting practices 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 briquettes, the degree of pulverization of the coal to be briquetted, the moisture content of the briquette, and the briquette bulk density.

Industrial coke oven trials of partially briquetted charges have been made in England, South Africa, Hungary, Japan and Germany with successful results. In West Germany, the addition of briquetted coals to coke oven charges is now being practised commercially at Volklingen by Firma Carl Still and in the Saar by the Roechling Iron and Steel Works. The plant at Volklingen has a daily capacity of 2,000 tonnes from a battery of 40 ovens.

Partial briquetting techniques are also being practised on a commercial scale in Japan(5) at Nippon Kokan, Keihin Corporation (NKK), Nippon Steel Corporation (NSC), Kobe Steel Corporation and Sumitomo Metal Industries (SMI). NSC will soon have facilities to produce 7,600 tonnes of coke per day at their Tobato Steel Works. NKK has a 1,000 tonne per day facility at the Keihin works and a 3,000 tonne per day facility at the Fukuyama works. The NSC and NKK methods are similar with 30 percent of the coke oven charge consisting of briquettes made from the same coal blend as the matrix coal. Kawasaki and the Kobe Steel Company have also decided to adopt this process. The Sumitomo Corporation operate two lines that produce 6,000 tonnes of coke per day from their partial briquetting process. This process differs from the NSC and NKK process since their briquettes are made from different coals (poor and non-coking) than the matrix blend. The total daily coke production in Japan from various partial agglomerating techniques is 20,900 tonnes.

This paper describes some of the more interesting results of work done in several countries resulting in the evolution of the technology of partial agglomeration of coke oven charges to its current state of development.

SOVIET STUDIES

Laboratory investigations in the Soviet Union(1,6-10) have shown that the bulk density of partially briquetted charges is a function of briquette density, briquette size, and the proportion of briquettes in the coal charge. Figure 1 shows the bulk densities obtained from various coal-briquette ratios as a function of briquette size. In general, coal charges using larger briquettes tended to result in higher bulk densities of the overall charge. For example, the highest bulk density was attained using 50 percent briquette addition and briquettes of 50 mm diameter. However

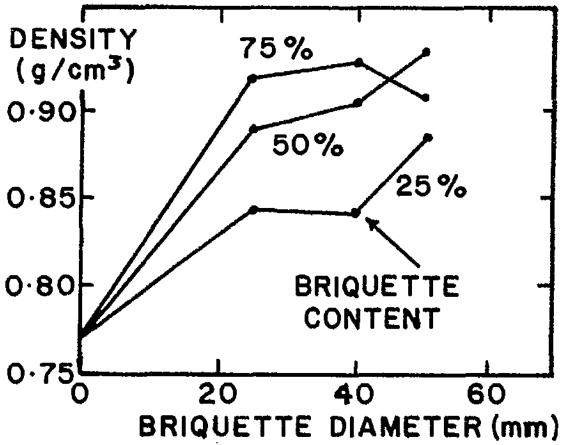

Fig. 1 Relationship between bulk density and briquette content.

coke quality did not necessarily improve with increased bulk density of the charge. A strength test, measured as material >2.5 mm after crushing 20 g of coke (9-13 mm), indicated that coke strength decreased when briquetting some coals having high cakability (17 mm plastic layer) but increased for coals of poorer cakability[6,7], (12-13 mm plastic layer). The reduced coke strength obtained from good coking coals briquetted with binder was attributed to an increased shrinkage within the briquette which promoted fissuring.

The inclusion of binders in briquettes brings about a marked improvement in coke strength when the coal blends include a majority of high volatile (hv) and poorly coking coals[7,8,9]. Binders generally investigated were petroleum bitumens. During carbonization, weak briquettes made without binders or from unsuitable coal blends had their surfaces agglomerate with the matrix coal promoting fissuring within the briquette. Since more volatile products were evolved from the briquettes* than from the matrix coal,

* In the example cited the VM of the hv coals used for briquetting was 35-40% and 26% for the loose charge.

the briquettes shrank at a faster rate than the matrix and fissures formed within the briquette at temperatures of maximum shrinkage (400-500^{o}C)[6]. Stronger briquettes were made from coal and binder compositions that produced less fissuring within the briquette during carbonization. These briquettes pulled semi-coke away from the loose charge during shrinkage, and the breakage of semi-coke occurred between adjacent briquettes (Fig. 2). The addition of binder reduced the compacting pressures required to form briquettes. Thus, the briquette composition (coal and binder) can be related to the nature and number of fissures in the resultant coke. Since the size of coke lumps is dependent upon fissure formation it may be possible to control coke size by briquette addition. Optimum coke size for the blast

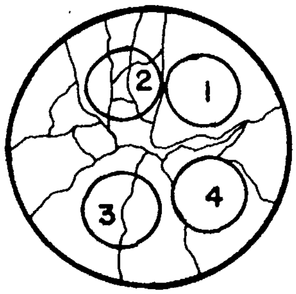

Fig. 2: Coke obtained from a coal charge containing four briquettes.

Briquette Composition:
1. 95% SS + 5% bitumen
2. 95% G_{17} + 5% bitumen
3. 95% G + 5% bitumen
4. 22.5% G_{17} + 22.5% G_6 + 50% SS + 5% bitumen

furnace is suggested to be 60-80 mm. Large briquettes (d=60 mm, wt=120 g) when coked with a coal charge in a box test (Moscow Coke and Gas Works) produced more +60 mm coke fractions than a similar charge without briquettes. Controlling briquette size when using partial agglomeration techniques may be a means of controlling the size distribution of the resulting coke.

Briquettes for a semi-commercial oven test (400 x 705 x 840 mm)[7] were made on a commercial roll press, were pillow shaped (50 x 40 x 35 mm) and weighed 70 g (bd=1.2 g/cm^3). The coal blends for the briquettes were not always the same as the matrix coal. The oven was charged at a wall temperature of 1040°C. Carbonization was considered complete when the centre temperature reached 950°C. Carbonizing times were 15h for ordinary charges, 17h for charges having briquettes made with binders, and 18h for charges containing briquettes made without binders (briquettes in this case containing up to 11 percent moisture). The charges that were 60 percent partially briquetted produced stronger coke than the charges that were not briquetted. Addition of binder to the briquette further improved coke strength (M40 index); the optimum amount of binder (1 or 6%) depended upon the material briquetted (Table 1). The improvement in coke strength is thought to be the result of changes in pore size and pore wall thickness. Briquetting caused the pore walls of the resulting coke to be thicker than normal.

TABLE 1

Results of carbonization of charges

Test No.	Charge					Coke									
	unbriquetted portion		briquetted portion		binders	Size analysis by mm fractions after 3-fall shatter test, %							Micum indices,		
	No.	%	No.	%	%*	>80	80-60	60-40	40-25	25-10	10-0	>60 mm	M40	M25	M10
1	II	100	-	-	-	29.6	31.3	26.7	5.1	0.9	6.4	60.9	72.4	86.5	10.9
2	II	40	II	60	1	34.9	28.4	27.6	5.7	1.4	2.0	65.5	78.6	92.3	5.1
3	II	40	II	60	-	36.2	24.0	25.7	8.2	1.8	4.1	60.2	73.0	89.0	9.5
5	III	100	-	-	-	22.8	20.7	31.5	8.4	2.5	14.1	43.5	52.0	74.6	19.8
6	II	40	-	-	-	25.5	24.9	29.5	7.0	1.8	11.3	50.4	60.1	79.3	16.0
	III	60													
7	II	40	III	60	1	50.4	19.2	17.7	6.4	2.3	4.0	69.6	71.2	86.4	11.1
8	II	40	III	60	6	44.6	17.8	22.4	9.0	1.8	4.4	62.4	68.5	87.2	8.5
9	XII	100	-	-	-	34.6	23.0	20.7	5.8	2.1	13.8	57.6	63.8	75.6	22.1
10	II	40	-	-	-	45.6	23.8	18.6	5.5	1.2	5.3	69.4	66.1	79.1	17.1
	XII	60													
12	II	40	XII	60	6	40.4	21.0	22.6	9.1	2.5	4.4	61.4	70.0	87.6	7.7
13	II	60	XII	40	1	51.5	17.1	19.2	6.2	1.7	3.6	68.6	76.6	90.8	7.6
14	I	100	-	-	-	37.5	21.4	21.8	9.0	0.8	3.2	58.9	79.7	90.1	7.2
15	V	100	-	-	-	42.9	24.0	19.1	6.2	1.8	6.0	66.9	78.0	87.9	10.4
16	V	40	V	60	1	43.5	23.0	24.5	6.2	0.9	1.9	68.5	83.5	93.5	5.0
18	XIII	100	-	-	-	46.0	19.5	15.9	5.1	1.8	11.7	65.5	57.6	77.2	20.3
19	I	40	-	-	-	45.4	22.3	20.0	5.1	1.9	5.3	67.7	73.0	85.0	12.9
	XIII	60													
20	I	40	XIII	60	1	50.9	21.9	16.3	4.6	1.3	5.0	72.8	77.0	89.3	8.6
21	I	40	XIII	60	6	38.0	25.4	25.1	7.5	1.7	2.3	63.4	80.8	92.8	5.2

* by weight of briquettes

Other tests[9] have been made in 200 kg coke ovens at the Zhilevskaya Pilot-Commercial Cleaning Plant. The carbonization time for the 180-210 kg charges was 15.7 -17.7 h with the final centre temperature being 1050 - 1100°C. A simple roll press, using roll pressures of 400-500 kg/cm^2, was used to make briquettes having dimensions 97x33x17 or 122x55x22 mm. Finer crushing of the blend (97 percent <3 mm) used to make briquettes resulted in unusually strong coke considering the high proportion of poor coals. Blends for briquettes contained small amounts of fuel oil and 7-9 percent moisture. The partial briquetting procedure increased coke oven capacity by 16.7 percent and allowed up to 35 percent hv coals to be charged to the coke ovens without detrimentally affecting coke quality. These workers predicted a saving of 1.25-1.57 million roubles per million tonnes of saleable coke by installing partial briquetting facilities.

EUROPEAN INVESTIGATIONS

Several investigations in European countries have indicated that partial briquetting procedures enhanced coke oven bulk densities[11-19]. For example, Czechoslovakian researchers[11,12] found bulk densities of coke oven charges could be increased from 4-8 percent by pelletizing coal and wash-plant flotation concentrates (90 percent <3 mm). Tumbler tests indicated coke quality had improved. More detailed investigations[13,14] have been made in Germany in a model coke chamber to determine the relationships between moisture content, briquette ratio, and oven bulk density. Maximum density was attained at 60-70 percent briquette addition for the three types of briquettes studied. The moisture content of the charge decreased linearly with increased briquette addition. However, the bulk density and briquette distribution within the chamber depended upon how the chamber was charged. By dividing the height of the model chamber into ten equal portions, it was found that a hand charged briquette/coal mixture (46.5:53.5) had the highest bulk density in the bottom section and lowest bulk density at the top. Briquette distribution depended on particle size, moisture content and how the chamber was charged, but generally more briquettes were found at the top and bottom of the chamber. By using a bin divided into two compartments, each containing coal or briquettes, and by selecting a suitable moisture content and coal particle size, a simultaneous discharge and uniform distribution of coal and briquettes was achieved. The effect of the moisture content on the time of coal discharge is more important than the particle size of the matrix coal.

Other West German researchers[15] at Firma Carl Still, Stahlwerke Roechling/Burbach, and Eschweiler Bergswerksverein have developed a process which increased coke oven bulk density and throughput while maintaining coke quality by briquetting wet fine coals of inferior coking capacity.

Processes to produce metallurgical cokes by briquetting non-coking coals prior to mixing with coking coals are described in Belgium[16] and German patents[17]. The latter (from Stahlwerke Roechling-Burbach) described the process in which non-coking coals were blended, transported, crushed and briquetted. The briquettes were then mixed with 30-35 percent coking coal and coked. Particle size of the loose coal was ≤3 mm. Briquettes had a density of 1.0-1.2 g/cm^3 and were 4-6 mm thick with a 10 mm diameter.

Charbonnages de France described[18] a partial briquetting process for making foundry cokes of high density and low reactivity. For example, the process briquetted low volatile coal (International Classification 211), coking coal (International Classification 434) and coal tar (65:30:5) and mixed 64 parts briquettes with 36 parts loose coal (low volatile to coking coal ratio- 40:60). Thus, the mixture charged to the oven was 56 percent low volatile, 41 percent coking coal and 3 percent coal tar pitch. The oven charge mixture was subjected to vibrations by rods vibrating at 6000 periods/min which raised the density of the load to 1.07 g/cm^3. The mixture was coked for 30 h at a wall temperature of 950°C and produced high density coke (1.276 g/cm^3) of low reactivity, with good strength characteristics.

British investigations[19] have studied (10 tonne oven tests) the carbonization of a charge made from an agglomerated poor coking coal mixed (40:60) with a good coking matrix coal and compared the results with a test made by briquetting the whole blend (100 percent). With weak briquettes used in this investigation the charges made from 100 percent briquetted material had a slightly higher impact strength. The micum M_{40} results for cokes made by briquetting part or all of charges using fine (90 percent <0.63 cm) or coarse (75 percent <0.63 cm) coals indicated stronger cokes were produced using briquettes made with finer coals. Other results indicated bulk density, carbonizing time, and dry coal throughput increased with increased briquette addition.

The majority of European research describing the development of partial briquetting technology has been published by the Hungarian Mining Research Institute. As early as 1957 coke oven charges containing 15 percent briquettes made from brown coals were studied as means of extending the coking coal base[20]. Continuations of this work[21,22,23] have studied charges containing from 30-70% coal briquettes made from coals of low coking potential. A summary of the early Hungarian research[24] indicated that the correct briquette/coal mixture resulted in the cavities between the briquettes being filled by the matrix coal which should be smaller than the briquettes by about one order of magnitude. Binding material within the briquettes improved the coking ability of the entire briquette/coal charge. The moisture content of the mixture can be significantly reduced without dust problems by using dried briquettes or those with a small moisture content. These technical steps improved the production of their coke-ovens and extended the coal base to include low-rank coals and coal sludges. The best homogeneous coke was produced by eliminating briquette and bed-coal segregation and ensuring low moisture content of the mixture while avoiding high expansion pressure usually associated with high charge densities. These technical difficulties were all overcome by using low mass (10 g) flat briquettes (lamella shape) having dimensions of 9 x 30 x 34 mm. These briquettes are not easily separated from the bed-coal ensuring an adequate space distribution in the coke oven which results in the simultaneous homogeneous coking of matrix coal and briquettes. No high swelling pressures arose in the oven using the flat briquette. This was attributed to the briquette swelling component being taken up by the looser bed-coal over a greater surface area. The lamella shape also facilitated in removing moisture from the briquette.

During their investigation, 200 box tests, 70 small chamber tests, 12 large chamber tests and two industrial (ten chamber tests) were made. The results of the large chamber and industrial tests are given in Table 2. In these tests, the poor-coking fine-grained components of the coal blend (e.g. lean coal, gas coal, and flotation products) were added to the briquettes as well as pitch or bitumen binder. The briquettes made up from 40-52 percent of the charge. Carbonization tests were performed at flue temperatures of 1400°C corresponding to a 15 h coking time used at the Danubian Iron Works.

TABLE 2: Main data of large scale industrial chamber tests mixed with briquettes

Series No.	1	2	3	4	5	6	7	8	9	10	11	12	Ten chambers I	Ten chambers II
Mixture composition related to dry material (%)**														
Washed coal														
from Dunaujvaros...	56.4	55.1	59.2	59.1	51.3	51.5	44.1	44.4	50.2	49.9	49.7	34.7	49.8	52.0
from Pecs..........	–	–	–	–	–	–	–	–	–	–	–	14.9	–	–
Czech gas coal......	20.0	20.7	18.8	18.7	–	–	–	–	–	–	–	–	–	–
Czech coal coke.....	–	–	–	–	–	20.4	16.6	16.5	–	–	–	–	–	–
Flotate............	20.1	20.6	18.8	18.7	42.7	20.4	25.5	25.4	44.7	44.9	35.1	30.1	34.0	42.0
Anthracite..........	–	–	–	–	–	3.9	8.9	8.8	–	–	–	–	–	–
Lean coal..........	–	–	–	–	–	–	–	–	–	–	10.0	15.1	10.0	–
Gas oil............	–	–	–	0.3	0.3	0.3	0.5	0.5	0.2	0.2	0.2	0.2	0.2	0.2
Black pitch.........	3.5	3.6	3.2	3.2	3.7	3.5	4.4	4.4	4.9	2.5	3.0	3.0	4.0	3.7
Bitumen............	–	–	–	–	–	–	–	–	–	2.5	2.0	2.0	2.0	1.9
Additive Roga number of basic coals.....	46.9	54.3	54.0	54.0	55.0	51.8	48.7	64.5	65.8	54.9	51.8	51.8	51.8	59.1
Briquette proportion %............	43.6	44.9	41.8	40.6	46.4	44.3	55.5	55.1	50.0	50.0	50.1	50.2	50.0	52.2
Mixture moisture, %.	9.6	8.0	7.0	5.8	6.5	4.1	4.8	5.8	7.8	8.0	5.85	5.05	7.2	11.8
Experimental data:														
Charged dry coal t/chamber..........	16.88	16.75	16.85	17.69	16.93	18.28	17.88	17.68	16.30	17.53	17.160	17.750	18.000	16.05
Dry volume weight, kg/m^3.............	805	805	810	850	815	880	860	850	810	845	825	865	870	772
Volume weight excess, %...........	9.7	10.0	10.6	16.4	11.4	20.3	17.6	16.4	16.5	15.3	13.1	17.5	19.2	5.8
Standing time, min..	890	1070	1012	930	930	926	1085	935	945	1020	858	910	921	916
Increase in standing time, %...........	–	11.5	13.6	4.5	4.5	5.0	14.8	6.0	4.8	13.3	-4.7	1.1	2.3	1.8
Capacity surplus, %.	9.7	-1.5	-3.0	11.9	6.9	16.3	2.8	10.4	5.7	2.0	17.8	16.7	16.4	4.0
Metallurgical coke investigation data														
M_{+40}..............	67.2	74.8	69.7	70.5	77.7	71.3	74.9	73.3	75.4	75.0	80.4	78.2	78.2	73.1
M_{-10}..............	3.4	4.2	5.4	7.8	6.8	8.3	9.9	12.1	5.6	5.5	5.8	8.3	6.8	7.1
Ash %..............	13.7	13.7	14.4	13.1	14.8	15.0	13.6	15.7	15.2	15.0	14.32	13.63	14.58	16.21
Volatile matters, %.			2.4	4.7	2.8	1.7	1.5	1.5	2.0	1.8	2.18	2.76	1.96	1.96
S %................			1.50	1.85	1.90	1.61	1.42	1.48	1.65	1.8	1.52	1.65	1.71	1.76
Metallurgical coke, part above 80 mm grain size, %......	22.0	20.7	14.6	14.9	16.6	44.2		63.5	15.5	27.8	23.6	28.9	32.8	29.7

* Test performed in the operation period of lower temperature.

** The washed coals of Dunaujvaros or Pecs and the gas oil applied as bed-coal and the other components as briquette.

Results indicated that the Roga number of a coal blend could be reduced by using partial briquetting technology without decreasing coke friability (M_{10}) or strength (M_{40} - Tables 2, 3 and 4).

TABLE 3

	Average value Danubian Iron Works for first half of 1965	Average value of plant tests 1-8 of VA
Summarized Roga number of components	64.2	51.8
Coke strength		
M_{+40}	72.5	72.4
M_{-10}	8.0	7.2

TABLE 4

Test No	2+3	9+10
	DV mixture + + gas coal	DV mixture + + flotate
Summarized Roga number of components	54.3	65.0
Coke strength		
M_{+40}	72.5	75.2
M_{-10}	4.8	5.5

In large-scale industrial trials the charge bulk density was increased from 730 kg/m^3 (dry coal basis) for normal coal charges to 810-860 kg/m^3 for charges with 50 percent briquette additions (i.e. from 45.6 to 50.6 - 53.7 lb/ft^3). Simultaneously, the coking time increased approximately 4 percent, however, with 6-7% moisture an average increase of 15 percent in output was achieved. Total moisture was reduced to 5-6 percent (3-5 percent for briquette, 8-10 percent for coal matrix) without substantial dusting or burning during oven charging. Three to six percent (black) pitch or pitch-bitumen was used as binder for the briquettes.

Recent publications by the same workers[25,26] point out the value of briquetting coals having an exceptionally high proportion of fine material. Coal fines and flotation concentrate from coal washeries were briquetted and charged with coking coal to the coke ovens. Pillow shaped briquettes (15 g) having dimensions 36 x 30 x 18 mm were used in this study and did not segregate from the coal matrix during transportation or oven charging. The coal to be briquetted was heated by steam (95-100°C) and mixed with the binder at 200-250°C. The heat from the binder vapourized a portion of the moisture in the coal causing a bituminous froth to appear. This froth having a low viscosity mixed easily with the coal at a temperature of 100°C.

Another study[27] concerned with the bulk density of coke oven charges indicated that an increase of 17 percent in bulk density could be achieved by simultaneously oiling and partially briquetting of the oven charge.

JAPANESE INVESTIGATIONS

Japanese research[28,29,30] concerning partial briquetting of coke oven charges has indicated that maximum bulk density is achieved when the briquettes (51 x 51 x 31 mm) make up 50 to 60 percent of the charge.

Although coke strength (JIS DI_{15}^{150}) appears to improve linearly with increased briquette addition[30] (Fig. 3) it is stated[28,29] that in most coal blends the amount of improvement in coke strength diminishes when the briquette ratio exceeds 30 percent. In a Koppers oven test, wall pressure increased with increasing briquette addition and reached a value of 0.12 kg/cm^2 with 40 percent briquette addition[30] (oven b.d. 825 kg/m^3). The pushing current in the commercial oven test also increased with briquette loading. As a result most Japanese coke producers consider that 30 percent briquette loading should be used as a safe limit to avoid excessive coke oven wall pressures.

Using the 30 percent briquetting procedure, the amount of coal in the coke-oven charges could be increased by 8.1 percent but coking time also increased 7.1 percent so that only a small increase in productivity was achieved. Table 5 shows the increases in productivity in commercial oven tests[30] (Kukioka #2 oven).

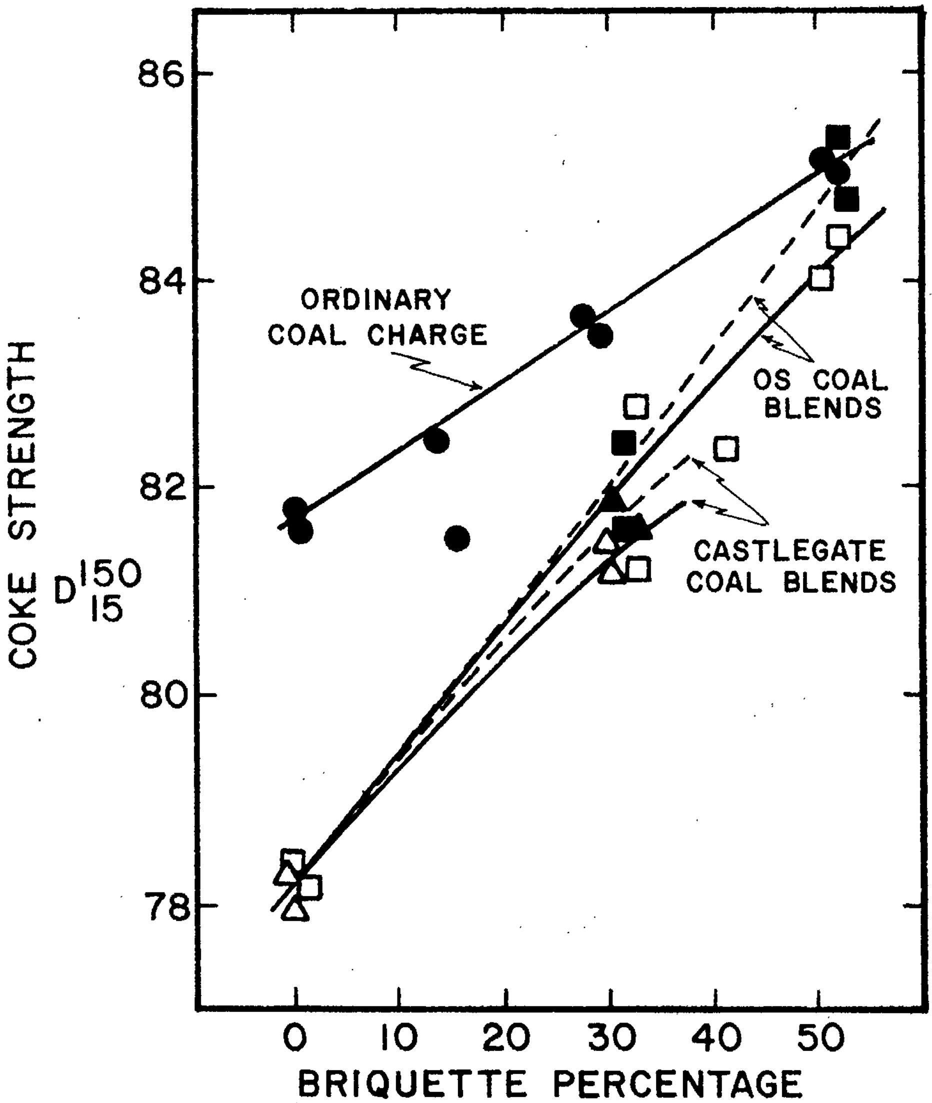

Fig. 3 Strength of coke from a commercial oven as a function of briquette percentage.

TABLE 5

Briquettes blended (%)	Weight of charge (t/ch, dry)	Carbonizing time (end of coking + 1°45)	Increase in productivity (%) (I)	(II)
0	11.160 (0%)	14°18' (0%)	0	0
10	11.427 (2.4)	14°34' (1.9)	+0.50	+0.21
20	11.694 (4.8)	14°50' (3.7)	+1.04	+0.47
30	11.961 (7.2)	15°06' (5.6)	+1.50	+0.64
40	12.228 (9.6)	15°23' (7.6)	+1.88	+0.73
50	12.495 (12.0)	15°39' (9.4)	+2.30	+0.87

Notes: 1) Numbers in brackets in 'weight of charge' and 'carbonizing time' columns show percent increases

2) When no correction for volatile matter in binder is included in the increase in productivity (I),

$$y_1 = \frac{X_1}{X_0} \cdot \frac{T_0}{T_1} = 1 \quad x\ 100$$

X_0= wt of charge without briquettes
X_1= " " " with "
T_0= carbonizing time without
T_1= " " with

When correction for volatile matter in binder is included in the increase in productivity (II),

$$y_2 = \frac{X_1}{X_0} \cdot \frac{T_0}{T_1} \cdot \frac{V_1}{V_0} = 1 \ x\ 100$$

V_0= coke yield when 0% blended
V_1= coke yield when briquetted

An investigation[30] into the variance in coke strength of partially briquetted charges according to its position in the oven (coke side, center or pusher side) indicated no significant difference from the variance found for conventional coke.

Metallurgical cokes of high quality have been produced[29,30] by briquetting 30 percent of the total coal blend even when the amounts of good coking coal and U.S. medium volatile and low volatile coals had been reduced. In one test period at the Tobata works of NSC, three percent U.S. medium volatile coal was used (no low volatile) with 65 percent good coking coal; the remainder of the charge contained weakly coking coals. The resulting coke was of good quality (JIS DI^{150}_{15} = 82.3 percent). Sufficient studies of this nature have been completed so that the JIS DI^{150}_{15} can be predicted from the caking index* and volatile matter of their coal blends. For coke made

Note: Caking index: One gram of coal crushed to below 65-mesh size and 9 grams of coke breeze controlled to 48-65 mesh size are put into a crucible. After the crucible is heated in an electric furnace at 950 plus or minus 20°C for 7 minutes, the carbonated content is screened by 48-mesh screen. The percentage of the coke remaining on the screen is called the caking index. This index is closely related to caking property of coal.

from conventional coking procedures[31]:

$$\text{JIS DI}^{150}_{15} = 0.67\ x - 0.155\ \text{VM} + 26.45$$

where x is the caking index, and VM is the volatile matter of the coal blend. For coke made using 30 percent briquette blending[29]:

$$\text{JIS DI}^{150}_{15} = 0.197\ x - 0.405\ \text{VM} + 76.84$$

Plots of these equations indicated that satisfactory metallurgical coke can be made from coal blends having much lower caking capacity. Figures 3[29] and 4[32] indicate how the range of coals can be extended from conventional practices. Coal blends having a mean volatile matter content of 27% can have a caking index as low as 82 to produce acceptable metallurgical coke using a 30 percent briquetting procedure. A blend of this type would have a Gieseler fluidity of 30 ddpm compared to 90-100 ddpm that is considered minimum for conventional coke making.

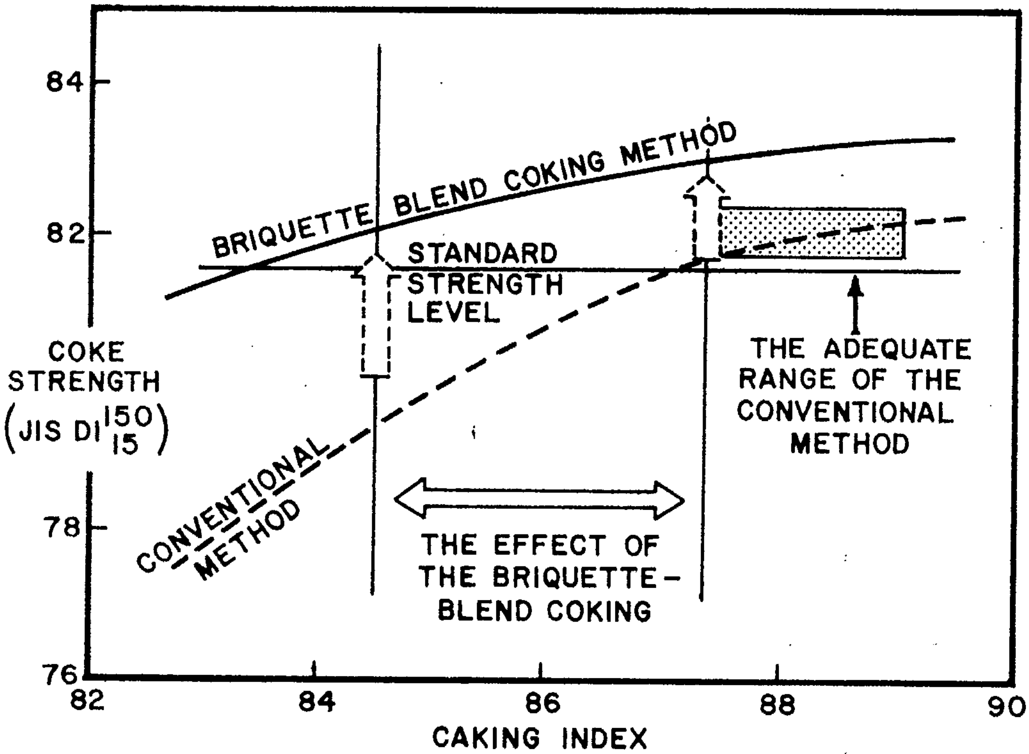

Fig. 4 Effect of Caking Index of blend on coke strength.

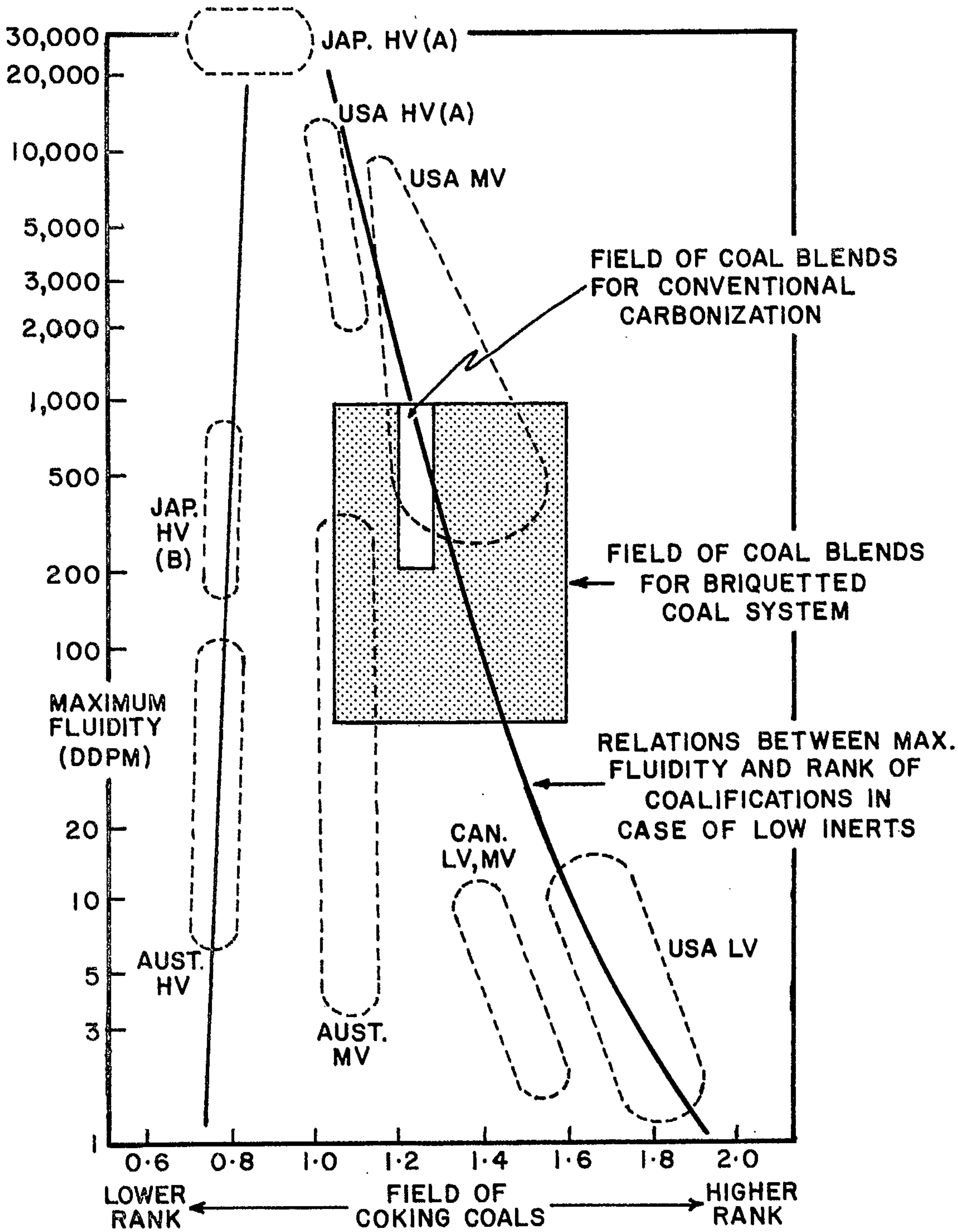

Fig. 5 Comparison of Acceptable Range of Charging Coal of 30% Briquette Addition with Conventional Process.

Increased oven bulk density caused by partially agglomerating the charge was found[32] to alter the temperature and gas pressures during carbonization (Fig. 6) as well as increasing the apparent density of the coke. Thus, the dense coke made by the partial briquetting procedure pyrolyzed at higher temperatures, had higher gas pressures, and a longer coking time than coke made by the conventional procedures.

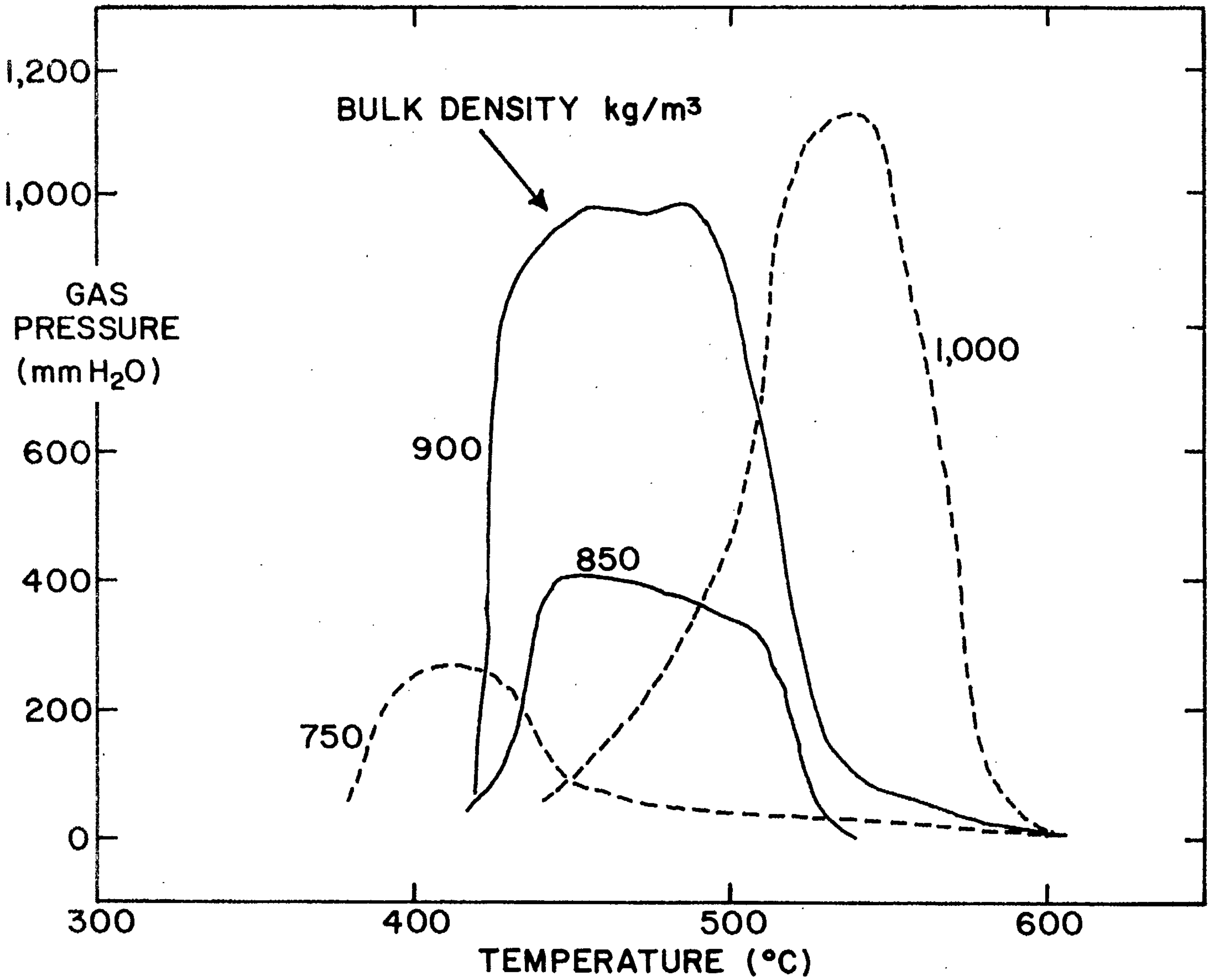

Fig. 6 Effect of Bulk Density on Gas Pressure and Pyrolysis Temperature.

Increased coke strength is most probably the result of compaction of the coal particles. Petrography indicated[30] the voids between the coal particles in briquetted charges were smaller; upon carbonization the semi-coke was much denser and had a better continuity of cell walls than semi-coke made by conventional means. The increased apparent density of coke resulting from partial briquetting is probably the cause of the decrease in reactivity to CO_2 of cokes made from economy blends (containing small amounts of lv coal) at the Yawata Steel Works[30]. Table 6 shows cokes made from economy blends containing 20-25 percent Canadian coals using 30 percent briquetting procedures had decreased reactivity and increased coke strength (before and after reacting with CO_2) when compared with coke made conventionally from the basic blend. The decline in coke reactivity as a result of briquette blending has been confirmed by other workers[29].

TABLE 6

Properties of Coke with Economy in American L and M'

	Blending conditions / Brand	Base mixture	Briquetted Charges		
			No. 1	No. 2	No. 3
Charge coal mixture (%)	American L	9			
	" M'	17	5		
	Canadian heavy No. 1	10	10	10	10
	" No. 2	13	10	15	15
	Russian		7	7	7
	Australian heavy	7	20	20	20
	B/W	9			
	Australian semi	8	10	13	10
	" light caking	15			18
	S. African		10	10	10
	Miike	12			15
	OS				5
	Heavy caking ratio	73	62	65	62
coke properties (%)	Ash	10.6	10.6	10.9	10.8
	Microstrength	27	29.4	29.4	29.8
	JIS Reactivity	49.0	46.2	45.2	46.0
	Cell Space	25.0	22.0	26.0	26.4
	DI^{150}_{15} after CO_2 Rxn.	82.8	83.1	84.2	84.5
	DI^{150}_{15} cold Strength	78.6	80.3	80.7	81.0

Blast furnace trials at the Tobata Works[29], using cokes made by partially briquetting coal blends having reduced amounts of coking coals, indicated their blast furnaces could be operated for extended periods at the same level of productivity without any deterioration in fuel rate, bed permeability, etc. from conventional operation.

The partial briquetting process[32] at the Fukayama and Keihin works of NKK involves the screening and crushing (80 percent -3mm) of the individual coals prior to blending and storing in bunkers. Thirty percent of this mixture is taken to another hopper from which amounts of the blend are weighed, crushed (90 percent -1mm), mixed with pitch (~6 percent), and passed to a distribution hopper. The mixture is passed through a constant feed weigher, heated with steam and kneaded. It is then passed through a double roll briquetting press at a temperature of 110°C. The briquettes which measure 44 x 44 x 27 mm are cooled during conveyance to a briquette hopper before being blended with the matrix blend.

A similar operation[29,33] exists at the Tobata Coke Plant of NSC. Briquettes (44 x 44 x 26 mm, d=1.16 -1.17 g/cc) have 6-8 percent binder and 6.9 percent moisture compared to the matrix coal which averages 7.6 percent moisture[32]. Figure 7 shows diagrammatically the Tobata briquette facility.

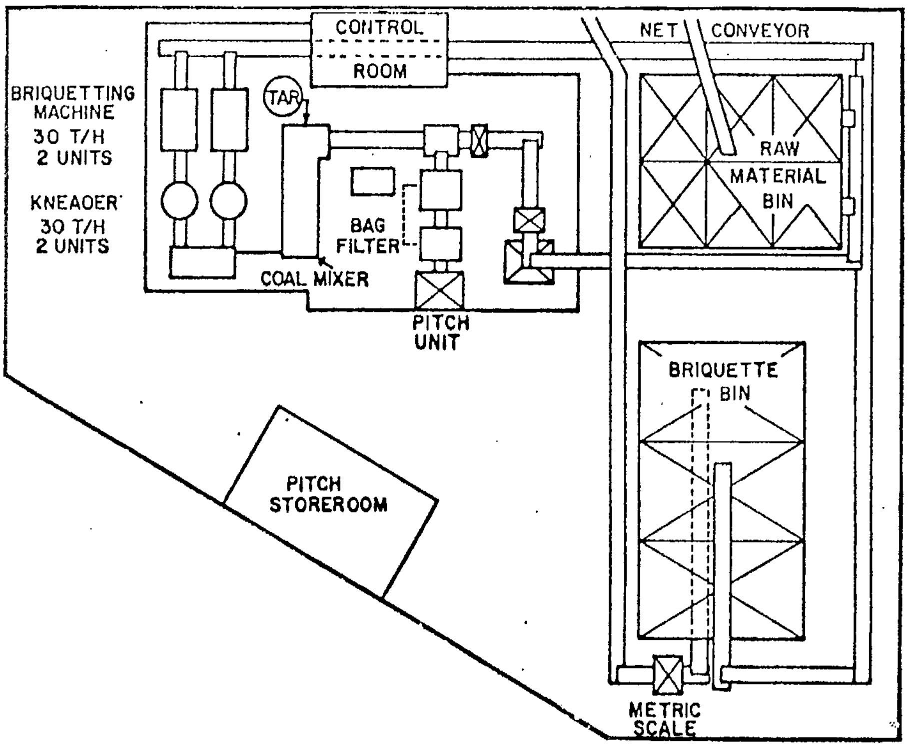

Fig. 7 Plant layout of Tobata briquette facility

Segregation of briquette and matrix coal in the coke oven must be avoided to produce good metallurgical coke. NSC[31] has found it extremely difficult to control segregation unless the loose coal and briquettes are blended directly into the charging car. The briquettes and coal are stored in separate coal bunkers prior to blending in the charge car. Figure 8 shows the belt feeder equipment installed beneath the coal bunkers at the Tobata coke facility. This equipment provides uniform blending (±2 percent variance) having operated smoothly for two years without serious problems. The method avoids serious briquette segregation when the charging car loads the coke oven.

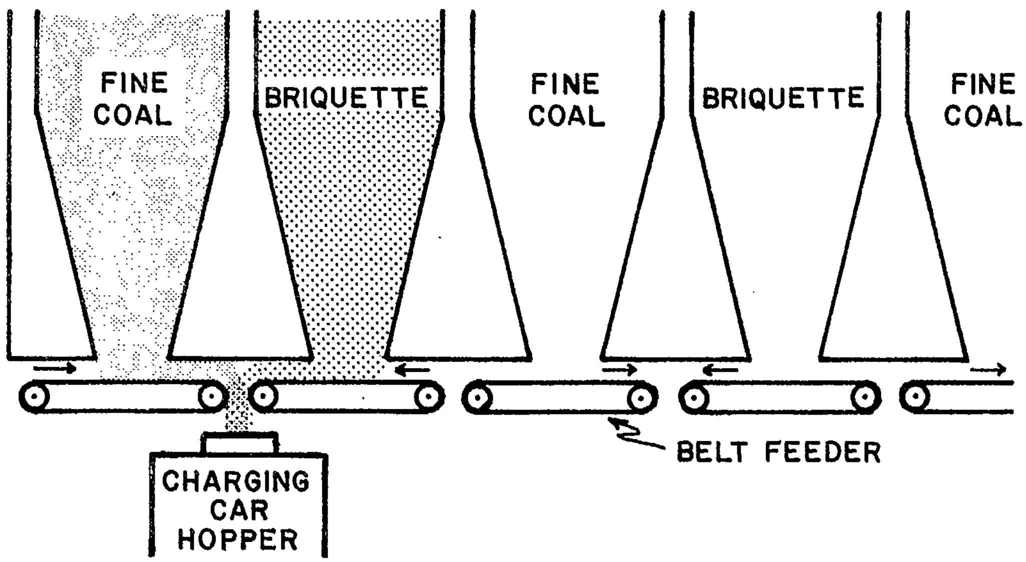

Fig. 8 Belt feeder equipment beneath coal bunkers at the Tobata coke facility

Sumitomo Metal Industries have also developed a briquette charging process (Sumi-Coal System)[34,35] that will improve (or maintain) coke quality while increasing the quantities of non-coking coals that can be used. Like the NSC and NKK method, the process briquettes 30 percent of the charge; the basic difference, however, is that all the non-coking coals are used in the briquettes. A flow diagram of their system is shown in Fig. 9.

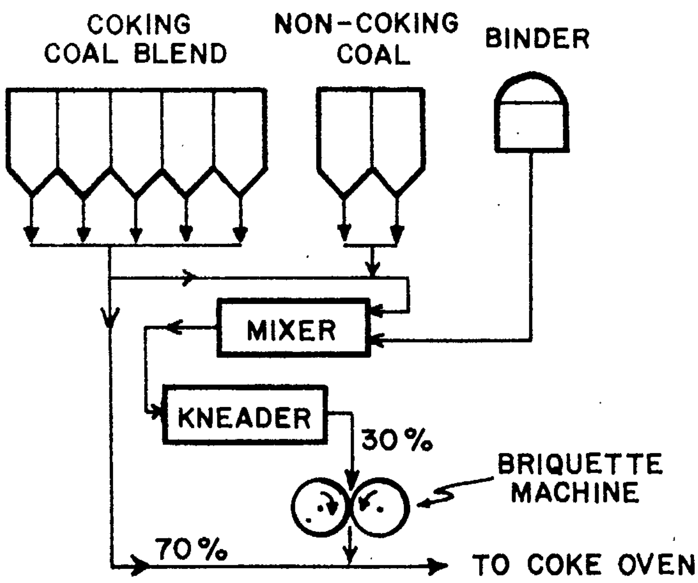

Fig. 9: Briquette charging method of Sumitomo Metal Industries.

Important facets incorporated into the "Sumi" Coal System for the manufacturing of briquettes include the degree of coal pulverization, the selection and amount of binder, the mixing of coal and binder, the use of a double roll briquetting machine, the size of briquettes, and the ratio of non-coking to coking coal used in the briquette. The system has the same features as other partial briquetting processes giving increased oven bulk density and increased coke production per unit oven volume while prolonging coking times. The fluctuations of coke quality and oven temperatures were found to be less using the "Sumi" process than when using conventional procedures.

The Sumi-coal process also envelopes a method of making a special caking substance (binder)[34-35] which when added to non coking coals in an appropriate amount will cause the coal to behave like a coking coal[36,37]. This material is made (at 500^{o}C) from asphalt in contact with super heated steam which strips and removes the volatile products. At the same time the special caking substance is formed as polycondensation products of the aromatic components. This material is said to have all the properties associated with the caking components of coking coals but can be stored in the open air.

This special caking substance when added to non-coking coals in the appropriate amounts (depending upon the coals classification) can produce suitable metallurgical coke. Figure 10 shows the JIS DI^{30}_{15} for conventional cokes obtained from 4 coal types as a function of the amount of special caking component added:

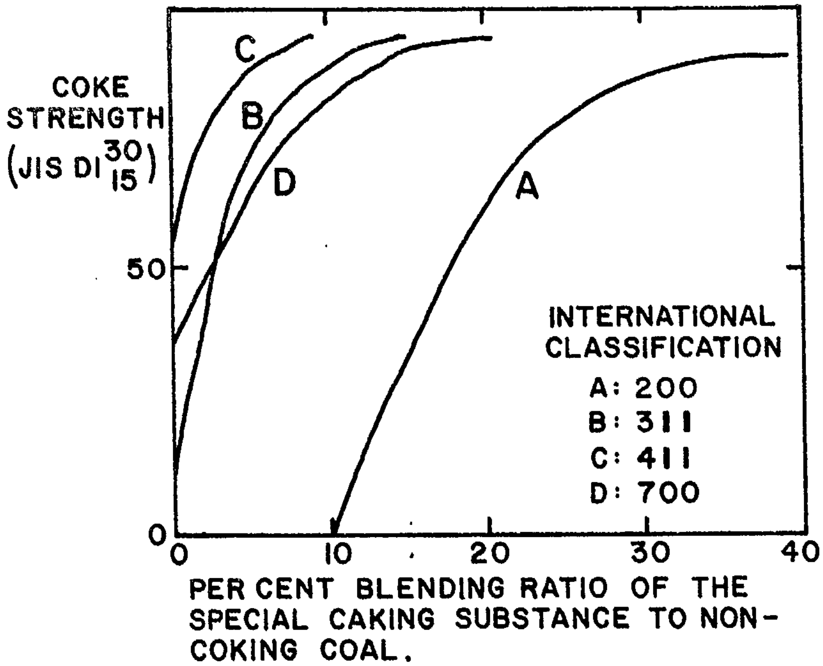

Fig. 10 Effect of blending of the special caking substance to the non-coking coal.

The special coking substance can be combined with coal tar (mutually soluble) and used as binder for the preparation of briquettes. The effect of the special caking substance on the increased briquette blending of non-coking coals is shown in Table 7[(34)]. Using the special caking material as much as 28 percent non-coking coal can be used in their oven charges. A flow chart of the system required to convert asphalt to the special caking substance is shown in Fig. 11.

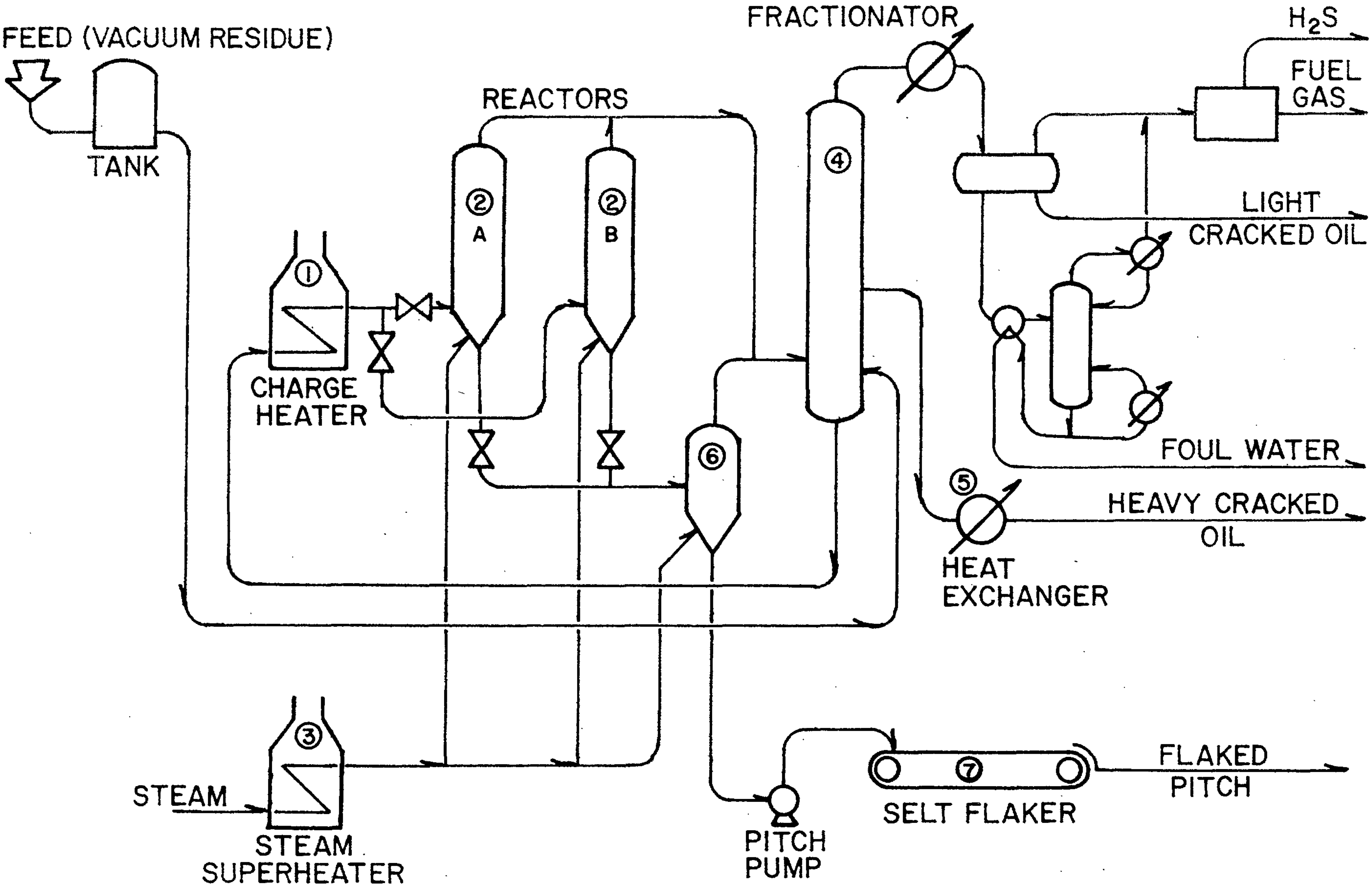

Fig. 11 Schematic Diagram of Residual Oil Cracking Process

TABLE 7

The effect of the special caking substance on the increase of blending of non-coking coal

Kind of binder	Special caking substance			Coal tar pitch	
Content of binder in briquette (%)	5	10	10	5	10
Content of non-coking coal in briquette (%)	40	60	70	40	60
Mixing ratio of briquette (%)	30	30	40	30	30
Amount of non-coking coal in the charging coal into the coke oven (%)	12	18	28	12	18
Coke strength (JIS DI^{30}_{15})	93.2	93.0	92.5	92.8	91.5
Maximum blending amount of non-coking coal (calculated) (%)	19	23	28	16	16

For metallurgical coke preparation by conventional methods coals whose free-swelling indices (FSI) are greater than 3 are generally used. It is claimed(34,35) that the Sumi-Coal Process allows the range of coals to be extended to coals (FSI<3) whose volatile matters (d.a.f.) are within the range 14-45 per cent. Figures 12 and 13 show the amounts of non-coking coals, and the range of coals that have been used by Sumitomo Metal Industries at their Wakayama and Kashima Works.

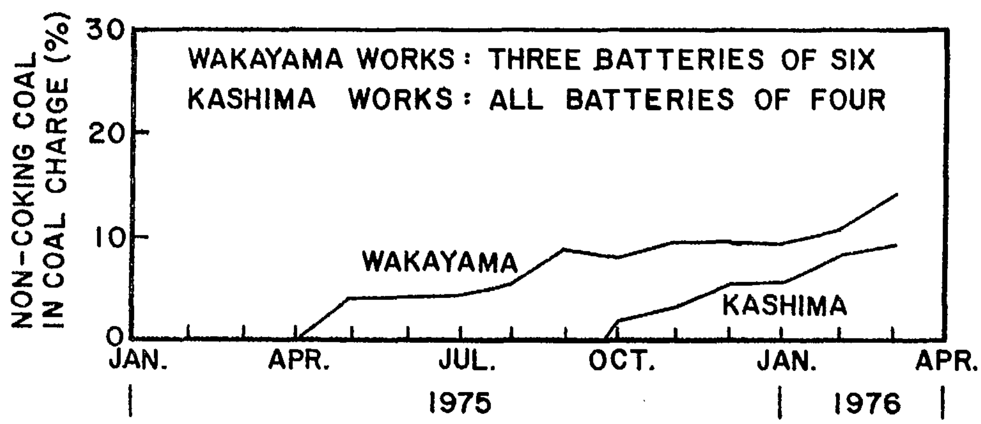

Fig. 12 Amount of non-coking coals used by Sumitomo Metals Industries.

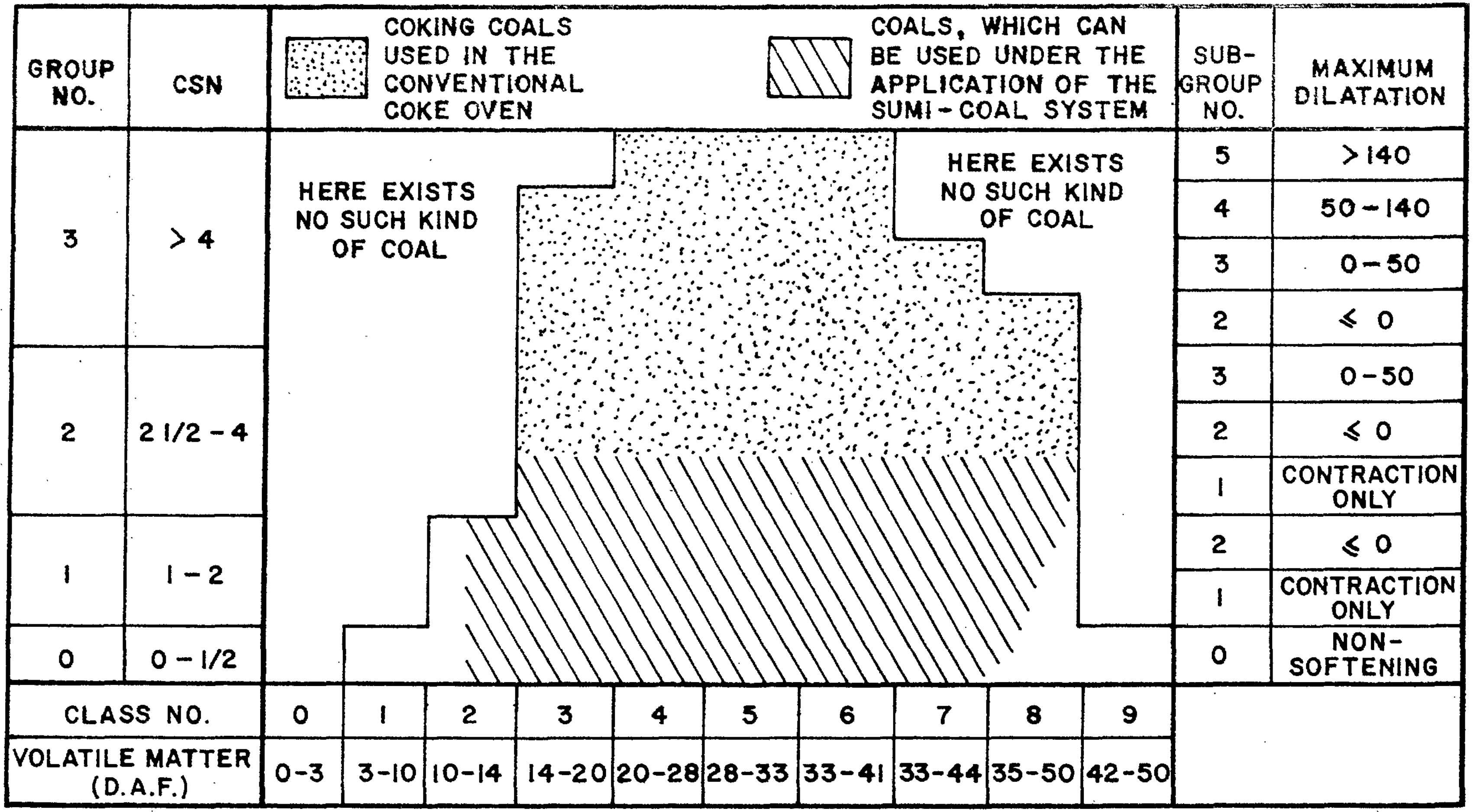

Fig. 13 Region where coals can be useful by the application of the Sumi-coal system.

Sumitomo Metal Industries have also experimented with the third Japanese procedure of partially agglomerating coke oven charges[38,39]. The method requires that the briquettes be charged to the coke ovens on top of the conventional charge. The briquettes contain a 60:30:10 mixture of poor caking (or non-coking) coal, petroleum coke, and coal tar pitch. The raw materials are pulverized to less than 3 mm, kneaded and mixed with pitch melted by steam, and the mixture briquetted at 950 kg/cm (line pressure) to produce 10 g briquettes (28 x 28 x 19 mm). The briquettes (6-30 percent of the charge) are placed in the oven on top of the conventional charge and carbonized during normal coke oven operation. In one example, a charge of 230 kg coked for 15 h and 45 min at 1160^{o} produced coke briquettes that had a JIS DI^{30}_{15} of 94.6 and an ASTM stability of 64.4. This method which uses virtually no coking coals in the agglomerates enables 20 percent of the oven charge to be poor coking or non-coking coals.

DISCUSSION AND CONCLUSIONS

Increased bulk density of the coal charge to coke ovens has been associated with improved coke quality but most methods (e.g. stamp charging) that produced large increases in bulk density were found to cause high coke-oven wall pressures. Studies on the partial agglomeration of coke oven charges have indicated that this method of increasing the oven bulk density improved coke quality and extended the coking coal base. Maximum bulk density was achieved when 50-70 percent of the charge was briquetted. Japanese studies indicated that 30 percent of a charge could be briquetted safely without adversely affecting coke oven-wall pressures.

Two partial agglomeration methods have been used to expand the coking coal base. In one method, the poor and non-coking coals were added to the basic blend and a portion of this blend was briquetted before charging of the coke oven. The second method involved selectively briquetting a blend made from non-coking coals and mixing the briquettes with a normal coking coal blend before charging of the coke oven. The first method is favoured by most Japanese companies (NKK and NSC) while the latter method appears to be favoured in Europe, and the Soviet Union. Adding all the poor and non-coking coals to the briquettes may be the preferred method to obtain the maximum coking power from the increased bulk density since this method appears to increase the amounts of non-coking coals that can be used.

However, briquetting a portion of the total charge may be less costly and easier to put into industrial practise.

Producing satisfactory coke by partial briquetting procedures requires that the briquettes and matrix coal be evenly distributed in the coke oven. The shape of the briquettes is important for avoiding segregation of the briquette from the matrix coal. Briquettes that are flat would appear to be preferable while spherical briquettes or pellets should be avoided because they can roll together and become segregated. The Japanese have devised a conveyor system which homogeneously loads the coke oven charging car with briquettes and matrix coal. German studies indicate that segregation of the charge can be avoided by quickly charging the coke ovens with the gate of the charging car completely open so that the charge drops quickly into the oven.

Soviet work has suggested that coke-oven bulk density depends on the briquette size and that larger briquettes generally produced coke of a larger mean coke size. Thus briquette size may be important in controlling the coke size distribution.

Briquette preparation is probably more important than briquette size and shape for assuring good coke quality. Coal pulverization, blending, and the moisture and pitch content of the briquette must be controlled. Hungarian, British, and Japanese workers used finer coal in the briquettes than in the matrix blend (NSC 90%<1 mm for briquettes, 80%<3 mm for the matrix coal). Most investigations held the moisture content of the coal blend to be briquetted between 7 and 10 percent. The NSC and NKK process maintains the moisture content of the briquetted coal at 6.9 percent with the matrix coal at 7.6 percent. Hungarian investigations allowed the briquettes to dry prior to charging into the coke oven to increase oven productivity. According to Soviet studies, the amount of pitch added to the blend to be briquetted depends upon the blends constituent coals. Their blends required from one to six percent pitch additions; Hungarian workers used from three to six percent pitch, while the NKK and NSC process requires from six to eight percent pitch. The bulk densities of the briquetted coal materials were between 1.1 and 1.25 g/cm^3 for the studies reviewed here but briquetting pressures varied from 400-500 kg/cm^2 in a Soviet study to 1000 kg/cm^2 in a German investigation.

Research should be initiated with several non-coking Canadian coals to determine if they can be used to make good metallurgical coke using partial briquetting practices. Laboratory and pilot plant studies would determine the quality of cokes that could be produced if these non-coking coals were included solely in the briquettes or in a total blend which were partially briquetted. Oven wall pressures should be measured as a function of the percentage of briquettes in the charge. The amount and type of binder for the briquettes should be examined according to the coal blends used. Larger agglomerates should be carbonized to determine if the mean coke size could be increased using this technique. Preliminary carbonization tests could be made in the laboratory and stopped periodically so that the coke could be examined microscopically to determine how carbonization and fissuring proceeds in the briquettes and in the coal matrix.

Partial briquetting techniques could be tried in conjunction with other techniques such as preheating, antifissurant addition, and oiling of the charges to determine how the properties of the resultant cokes have been altered.

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