PREPARATION AND COKING RESEARCHES AT BHP CENTRAL RESEARCH LABORATORIES

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INTRODUCTION

The Permian coals of the Newcastle district of N.S.W. yield weak coke, but those mined in the Southern N.S.W. coalfield yield quite reasonable metallurgical cokes. Our problem has been to establish methods whereby stronger cokes can be made from these coals, particularly those from the Newcastle area. Certain aspects of the work concerned with this problem form the subject matter of this paper. A related aspect is dealt with in the paper by J. Gregory to this Symposium.

There are four major phases to the production of metallurgical coke, firstly, the mining and transportation of coals, usually to washeries; secondly, the washing, blending, grinding and delivery of the ground coal to the coke ovens' bunkers; thirdly, charging the ovens, coking and quenching the coke; and, finally, delivery of the coke, perhaps screened and crushed, to the blast furnace. Factors pertinent to the quality of blast furnace coke arise at each stage, and modification of the processing operations at an earlier stage may introduce changes that eventually affect the quality of the blast furnace coke.

Research work can be invalidated by a lack of knowledge of such effects at the production scale or by a failure to reproduce on the smaller research scale, conditions leading to nearly similar materials and processing for the four stages in coke production. In our case, the second (preparation) stage has presented the most immediate possibilities for plant developments. Our research has thus been concerned with this stage to a greater extent than the others.

2. COALS AND PROPERTIES

A summary of the analytical and carbonisation characteristics of the Newcastle coals is given in Table 1. Although Brown, Callcott and Kirov[1] have shown that Seyler's Chart 47B is applicable to Australian coals, the use of Parr's basis to express results is not sound. The commonly used dry-ash-free basis is even less sound, and, so, N.A. Brown and the writer have studied the direct determination of mineral matter and of its water of constitution after modifying the C.S.I.R.O. slow combustion method[2]. In Table 1, the d.a.f.; Parr and direct dmmf ultimate analyses of "float" and "sinks" fractions of Victoria Tunnel coal are compared. The laboratory carbonisation tests refer to 10% ash washed coal samples. The penetration plastometer is similar to that described by Nadziekiewicz[3].

Some or all of the parameters of the laboratory coking tests of the Newcastle coals have been found to depend on the mean particle size and the size distribution, on the proportion of mineral matter and on the extent of oxidation[4]. At present, it seems that the rate of oxidation is one of the few characteristics of these coals that may vary appreciably between the coals[5].

Results such as those of Table 1 suggest that the bright coals of the Newcastle coalfield are unlikely to yield good blast furnace cokes after conventional preparation. The common coke strength indices of a steelworks blend of these coals, and the better ones made at Port Kembla, are given in Table 2.

The predominant coal minerals[6] are interlayered montmorillonite-illite, kaolinite, and quartz. The proportions of these minerals depend on the seam and ply; but, for some plies of the seams, they are consistent. The water of constitution of the mineral matter in coal samples varies from 3% to 13%. Much of the mineral matter is finely disseminated in the coals.

The possibility of "selective" breakage, of one or another form[7], has been examined. In shatter, no significant selectivity could be detected. Swing hammer mill tests have not so far substantiated any major "selectivity" in breakage; but it seems possible that some differentiation between the minerals and coal may develop. The differentiation was however, never more than slight for feed samples with less than 20% ash and most probably, arose from the differences in density affecting the size classification efficiency of the mill rather than from appreciable differences between the natures of the disintegration patterns for mineral and coal particles or differences in their respective strengths.

3. HAMMER MILL STUDIES

The beneficial effect on coke strength indices of charging finely ground Newcastle coals to coke ovens has long been known. This effect was quantitatively established by subsequent pilot scale and plant scale trials[8]. It was found, however, that plant hammer mills could not attain the required levels of fineness without serious loss in output rates.

The writer has reported[9] on the early stages of a mathematical analysis of the grinding mechanism of swing hammer mills and experimental studies using high speed cine photography. The breakage in a 5 tph test mill due to the impact of 3¼ lb. hammers at 11000 ft./min. was very mild: for example, a 50% +1 in. product on feeding 100% -2 +1 in. coal. The passage of the hammers past a breaker bar was shown to be equivalent to closed circuit grinding; and the probability of breakage was approximately proportional to the square root of size for sizes smaller than ½ in.; constant at 0.6 for larger sizes. The proportion retained above the breaker bar, for further breakage, varied as the fourth root of particle size. This work suggested that the region above breaker bars (i.e. above the point of narrowest gap between hammer and bar) acts essentially as a means of redirecting particles into this zone. The efficiency of removal of particles which are already sufficiently small, is particularly poor and considerable attention to the design of the recesses above breaker bars may be needed before it is improved.

Work on this aspect and on the design of more suitable screens (grids), after the breaker bars, is in hand. Results to date suggest that a considerable reduction in the proportion of very fine particles in the mill output may be achieved.

Fig. 1 shows a typical path for the discharge of a 1mm particle from a model of a hammer mill fitted with grids. The heater tip speed was much slower than normal hammer tip speeds. These photographic studies showed that the classification efficiency will remain low so long as the particles must change substantially their direction of flight. This feature also lowers mill capacity; and increases the percentage of fines by undesirable further breakage of particles already sufficiently small.

One alternative to the use of different types of grids is to replace them by adjustable breaker bars and recesses that efficiently redirect particles. The Hazemag mill may be a step in mill development along these lines. It remains to be seen whether the scavenging efficiency of hammers sweeping past bars can be drastically improved.

An alternative to the improvement of hammer mill grid systems is the coupling of a mill with an external classifier.

4. AIR CLASSIFICATION FOR COKING

Screens as external classifiers for hammer mills have been used in Europe to prepare coal for charging coke ovens[10]. It appears possible that some additional benefits and more flexible operation may attend the coupling of a suitable air classifier with a hammer mill.

A small commercial air separator, made available by courtesy of International Combustion Australia Ltd., was modified at the B.H.P. Central Research Laboratories, (hereafter CRL). After a number of trials and adjustments, it was found that, at various settings, separations with the efficiencies shown in Fig. 2 could be attained; but reliable estimates of the potential capacity of such units were not possible with this equipment. A convenient cheap unit (Fig. 3) was made to estimate capacity and confirm the separation efficiency results.

From the work, the following tentative conclusions were drawn:

(a) Output rates of about 100 tph (and perhaps more) are feasible with 16 ft. dia. units;
(b) Particular attention must be paid to the evenness of the air distribution around the coal distributor plate;
(c) Coals containing 2 in. lumps can be handled;
(d) Total moisture contents up to 12% can be handled without detectable loss in separation efficiency, but the coal should be oiled (about ¼ gal./ton) and a special scraper device is probably essential to prevent build up on the wall.

Since this work was based on a 2'6" dia. unit and used feed rates of up to 20 tph, it is far from fully developed as practical plant. However, it does seem one of the possible alternatives to the use of external screens that could be used to control the sizing of system outputs. Such pneumatic controls may prove more stable and consistent than screen and mill or normal mill systems for the preparation of charges to plant coke ovens.

Since this work on an air classifier was completed, an article on the pneumatic preparation of coking coals has been published(11). It seems that the system used by Lazovskii et al. is likely to be more easily developed to full plant scale than the external air separator technique.

The 2'6" dia. separators did not break the feed coal to any appreciable extent, but corresponding studies with a small laboratory air separator showed that considerable breakage occurred when feeding -⅛ in. coal. This feature has prevented the use of this unit in preparing coal for small scale coking tests.

5. BULK DENSITY AND SIZE SEGREGATION

The influences of surface moisture and particle size on the bulk density of particulate materials are well known. In coking practice, the interrelations between these three factors become especially important where, one and perhaps more of the factors strongly affect coke strength. Fig. 4 shows the relationship between bulk density (ASTM Box Test) and fineness (% -18 BSS) for Newcastle coals tested at the B.H.P. steelworks. Total moisture was fairly constant. Fig. 5 shows the corresponding relation between fineness and the Rosin-Rammler distribution coefficient. Stability and hardness indices of cokes from the coals increased by 5 ± 3 and 2 ± 1 units, respectively, for every extra 10% in coal fineness. Another factor may also have entered into the complex of relations: segregation of particles with respect to size in the coke ovens.

Bulk density tests with air dried -⅛ in. coal have shown evidence suggesting a dependence of bulk density on feed rate and accompanying changes in size segregation. Fig. 6 shows the "herringbone" segregation pattern developed on allowing randomly mixed coal (large) and limestone (fines) to gravitate through various rectangular slots. The bulk density of the discharged material did not depend on the feed rate (i.e. slot width). It has not been possible to generalise these and other observations as regards segregation in coke ovens, but "herringbone" segregation may occur in large ovens.

A direct assessment of the effect of segregation on coke strength was attempted with C.R.L.'s 15 lb. coke oven (see later). The stability and hardness indices of the cokes from segregated and non-segregated charges were almost identical; but the textures of coarse and fine bands were clearly distinct. In view of the marked effect of coal size on these indices, work to elucidate the apparent paradox is being carried out.

6. THE USE OF 15 lb. TESTING OVENS

Pilot (850 lb.) coke ovens are used at the Newcastle and Port Kembla steelworks' research departments, but the associated coal preparation facilities(12) and coking units are too large for the Central Research Laboratories. Small testing ovens(8) (Figs. 7, 8) that coke 15 lb. of coal, have therefore been developed. At this scale, many different preparation methods are easily studied and factors that normally interact (e.g. fineness and bulk density), can be controlled independently of each other. These small ovens, also, provide an easy means of carrying out preliminary surveys prior to confirmation of important observations at the steelworks.

The correlation of the cokes from the small ovens with those from plant and pilot ovens is not yet completed; but appears good (Fig. 9). The reliable prediction of plant coke qualities from those of 15 lb. oven cokes, also, necessitates a similar dependence of coke qualities on various factors.

A series of 15 lb. oven tests to evaluate blending effects and those of certain preparation factors has separated the relative significance of coal fineness and charge density, as well as confirming the usefulness of this small test for complex blending studies.

The preparation of three blends (Table 3) of either 8 or 7 coals is outlined in Fig. 10. The reproducibility of the preparation of the coals' samples is shown, by the ash variance (between samples within coals) of 0.16% (15 deg. freedom), to have been satisfactory. Average ash percentages of washed coals correspond to those of Table 1. The main advantages of the preparation methods were: reduction in amounts of coal washed; the easy prevention of oxidation during storage, and the ease of dewatering coal samples before blending.

The high reproducibility of the characteristics of oven charges is shown by the variances in Table 4. Rotary sample dividers (20 and 100 lb. capacity) were used. Further evidence for the adequateness of the overall reproducibility of the coke tests, is shown in Table 5. It appears from the significance of coking time variations ($\pm \frac{1}{4}$ hr. test to test), that greater control over the rate of heating and the wall temperature-time relationship is desirable.

The separate effects of fineness and charge density are illustrated by Fig. 11. Apart from coking time (possibly a measure of heating rates), other variables were not significant by virtue of either their comparative constancy or not influencing coke qualities.

The effects of the controlled factors (coal fineness and charge density) are similar to those observed during plant and pilot-scale coking tests(8). They also agree with the trends deduced(8) from certain American studies. As a rough rule, each additional one percent of coal fineness (% -18 mesh) leads to an increase of about $\frac{1}{4}$ stability units for higher volatile blends of both Australian and American coals.

The very close equivalence of the qualities of the cokes from the four blends confirms the obvious deduction from Table 1: the Newcastle coals are too alike for blend proportions to be very important. This position appears to apply at the steelworks, provided the percentages of ash for all components are reasonably close.

Since the 15 lb. oven yields only about 10 lb. of coke from the high volatile Newcastle coals, some modifications of the ASTM tumbler test have been adopted. The drum is the same as the ASTM drum except its length is 6 ins. The coke charged to the drum is 90% -3" +2" and 10% -2" +1½" and the weight of the coke feed is 3 1/3 Kg. Results show that these changes do not significantly affect the stability and hardness indices for cokes from the Newcastle and Port Kembla steelworks; but, for run-of-wharf coke, the reproducibility is worse than when using the standard test. The reproducibility using cokes from duplicate oven tests appears better than is obtainable with 3 1/3 Kg samples of run-of-wharf coke.

The 15 lb. oven studies, which have involved well over 100 runs in recent months indicate the utility of small ovens. Firstly, they have shown that small scale preparations can be closely controlled and that the greater independence between preparation factors, achievable with small scale work, can lead to results that facilitate the appreciation of results gathered by pilot or plant scale work. Secondly, they have shown that with proper control, 15 lb. ovens can be used for preliminary studies and, in the future, they may enable the restriction of 850 lb. ovens to work immediately prior to plant trials. The successful use of these ovens depends on, (a), proper control over preparation and charging, and, on (b), a controlled coking programme appropriate to the type of coal e.g. high or low volatile. Our observations in this regard suggest some less specific needs than those of Price et al[13]; but there is a large measure of agreement.

ACKNOWLEDGEMENTS

The author thanks The Broken Hill Proprietary Company Limited for permission to publish this paper, and Dr. H.K. Worner, Director of Research, for his continued encouragement. He also thanks his immediate colleagues Messrs. N.A. Brown, J.A. Innes, R.H. Jones and P.L. Muir for their parts in the team effort concerned with the laboratory studies.

REFERENCES

1. N.A. Brown, T.G. Callcott, N.Y. Kirov: Paper A6. Preprint. Inst. Fuel Symposium on 'Australian Fuels and Their Utilisation', August 1959.*
2. Coal Research in C.S.I.R.O.; 1959, No. 7, p.13.
3. Nadziekiewicz: Coke and Gas, 1957, May, p.193.
4. T.G. Callcott, P.L. Muir, J.A. Innes: B.H.P. Tech. Bull., 1960, 4, No. 1,
5. P.L. Muir: Paper A8 Aust. Symposium.
6. T. Thompson: B.H.P. Tech. Bull., 1959, 3, No.2, p.20 (also pte. comm.)
7. T.G. Callcott: Paper No.16; Symp. "Sci. in Use of Coal" Inst. Fuel, 1958.
8. T.G. Callcott and R.H. Jones: Paper B10, Aust. Symposium.
9. T.G. Callcott: Paper B5, Aust. Symposium.
10. E. Burstlein: Chaleur et Industrie, Dec. Jan., 1954-55.
11. Lazovskii et al; Koks i Khimia; 1959, No.6, pp.5-8.
12. J.A. Gregory: B.H.P. Tech. Bull. 1959, 3, No. 1, p.23.
13. J.G. Price et al: Proc. Blast Furnace, etc. Ctee., 1959, Vol.17.
14. J.A. Gregory: Paper B11 Aust. Symposium.

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* Paper ...., Preprint. Inst. Fuel. (Aust. Membership). Symposium on 'Australian Fuels and Their Utilisation', August 1959, will be given as "Paper ...., Aust. Symposium." in refs. 5, 8, 9, 14.

TABLE 1: CHARACTERISTICS OF NEWCASTLE COALS, NORTHERN N.S.W.

COALS SEAMS: Borehole, Victoria Tunnel, Young Wallsend, Dudley.
COLLIERIES: Burwood, John Darling, Stockton Borehole, Lambton.
SIZE GRADING EX BRADFORD BREAKER: $0.74 \leq \bar{x} < 1.06$ in.; $n = 0.75 \pm 0.05$ (Rosin-Rammler Eq.)

Seam	Percent Ash of Floats at 1.45 S.G.
Borehole; Dudley	6½ to 10% (d.b.)
Victoria Tunnel	10½ to 12% (d.b.)
Young Wallsend	13 to 14% (d.b.)

AVERAGE ANALYSES WASHED COALS (7 TO 14% ASH ALL COALS)

BASIS	V.M. %	C %	H %	N %	S % (org)	O + Errors
d.a.f.	39.4	83.5	5.6	2.1	0.45	8.35
Parr dmmf	38.7	84.85	5.55	2.15	0.4	7.05
Direct dmmf	38.8	84.4	5.55	2.2	0.4	7.45

COMPARISON OF BASES FOR FLOATS AND SINKS (Victoria Tunnel Seam)

	BASIS	dry basis % Ash	dry basis % MM	VM%	C%	H%	N%	S%	O+Error	δv (Seyler)
Floats	daf	11.2		38.9	83.6	5.52	1.96	0.36	8.49	
	Parr dmmf		12.5	38.1	84.9	5.48	1.98	0.36	7.31	1.2
	Direct dmmf		12.1	38.3	84.5	5.49	1.98	0.40	7.67	0.6
Sinks	daf	51.8		41.8	76.4	5.50	1.84	0.40	15.85	
	Parr dmmf		58.2	35.4	88.1	5.17	2.12	0.38	4.21	5.7
	Direct dmmf		56.4	38.4	84.1	5.50	2.03	0.37	7.75	0.5

LABORATORY CARBONISATION TESTS (c.10% ASH d.b. ALL COALS)

B.S. SWELLING INDEX	$7\frac{1}{2}$	GRAY KING COKE TYPE	G4/G5
GIESELER PLASTOMETER		AUDIBERT-ARNU DILATOMETER	
Initial Move.	380°C	Initial Move.	396°C
Fusion	415°C	Max. Contraction	30%
Log. Max. Fluidity	2.7-3.0	Max. Contraction	438°C
Max. Fluidity	435°C	Ult. Dilation	40%
Resolidification	465°C	Ult. Dilation	465°C

PENETRATION PLASTOMETER (0.6 Kg/cm^2)

Layer Thickness	25 mm	Top Temps.	330°C
Shrinkage	22 mm	Bottom Temps.	440°C

HARDGROVE INDEX 55

TABLE 2: COKE STRENGTH

Coke	Percentage Index $+1\frac{1}{2}$in. Shatter	Percentage Index +1in. Stability	$+\frac{1}{4}$in. Hardness
Newcastle (Northern N.S.W. Coals)	73	18	63
Port Kembla (Southern N.S.W. Coals)	85	45	60

TABLE 3: BLEND PROPORTIONS (DRY WEIGHT %)

COAL	BLEND No. 1	BLEND No. 2	BLEND No. 3
A	6.1%	NIL	NIL
B	10.1%	13.0%	12.2%
C	9.1%	19.7%	8.3%
D	16.1%	13.5%	13.7%
E	15.85%	14.1%	13.9%
F	12.0%	10.7%	12.1%
G	20.6%	20.8%	31.0%
H	10.15%	8.3%	8.8%

TABLE 4: REPRODUCIBILITY OF OVEN CHARGES

	Ash % (d.b.)	Moisture % (total)	% -18 BSS	Charge Density (lbs./c.ft.)
Variance	.04	.06	2	1/4
Deg. Freedom	60	49	20	30

TABLE 5: ANALYSIS VARIANCE OF FACTORIAL DESIGN FOR TESTS OF TWO BLENDS

Factors: a, 43% and 73% -18 BSS; b, 37, 43, 49 lbs./cft; c oven No.1 & 2, d, Blend 2 & 3

Effect	Stability Index Mean Square		Hardness Index Mean Square	
Grand Mean	19,136.55		2470.5	
Fineness (A)	444.6	(Sig)	313.2	Sig
Ch. Density (B_1)	0.04		194.6	Sig
Ch. Density (B_2)	8.7		2.0	
Ovens (C)	7.2		2.87	
Blend (D)	73.6	(Sig)	0.01	
Coking Time**	17.9	(Sig)	N.S.	
Res M/s	2.565; 10 d.f.		1.91	
Total	19,755.17		3018.41	

NOTE: Mean square of each interaction (e.g. AB_1D) was estimated separately and unless specified was not significant at 10% level.

** If coking time significant, at 5% level; reduced res. m/s is given and mean squares of other effect carried to average time.

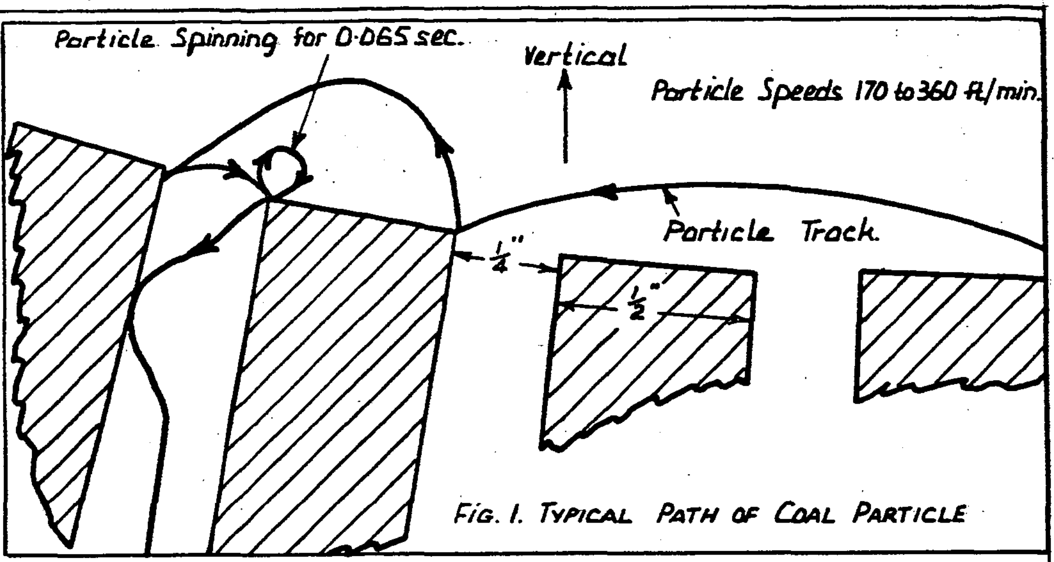


FIG. 1. TYPICAL PATH OF COAL PARTICLE

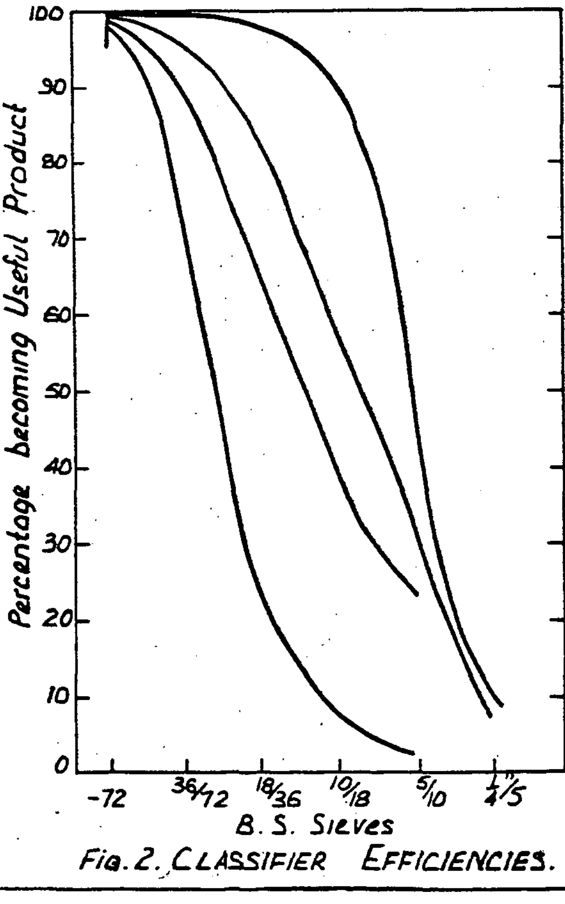


FIG. 2. CLASSIFIER EFFICIENCIES.

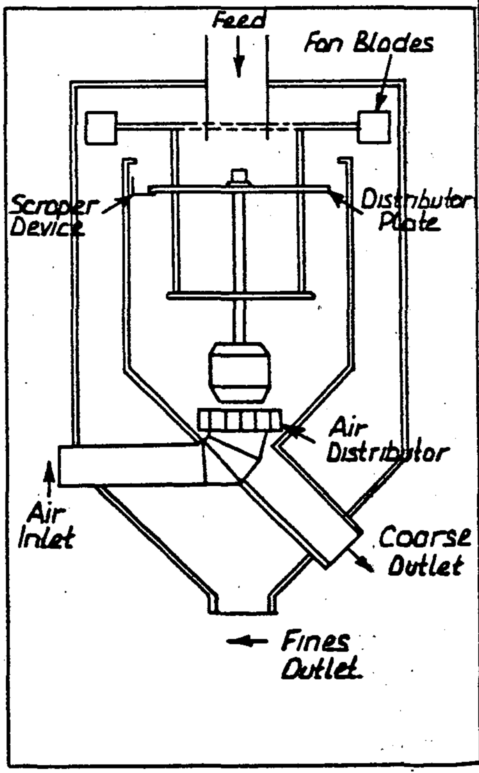
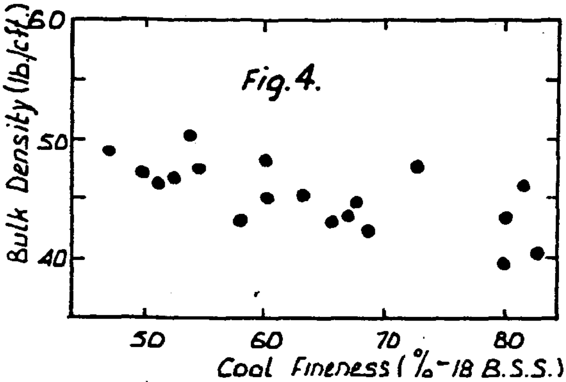
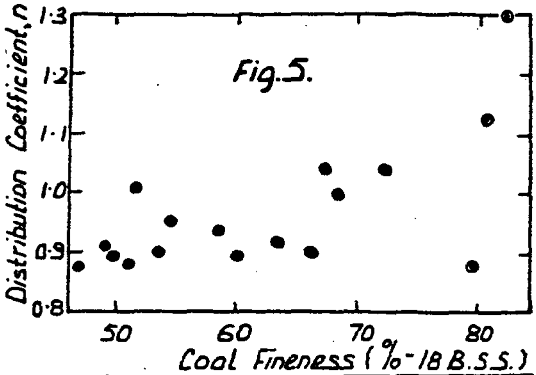


FIG. 3. C.R.L. AIR SEPARATOR





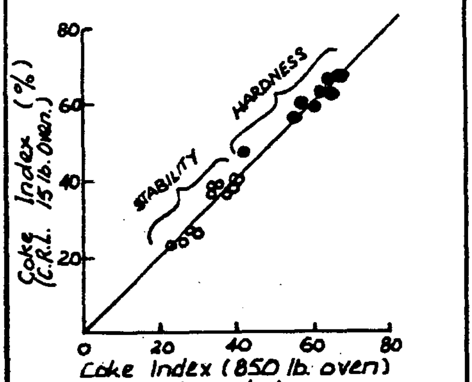
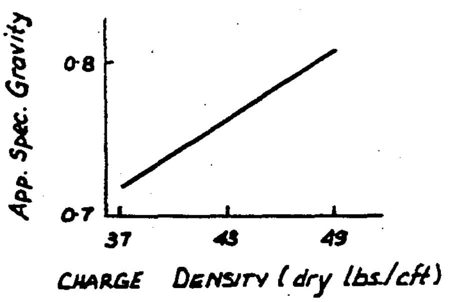


Fig 9. Coke Correlation.



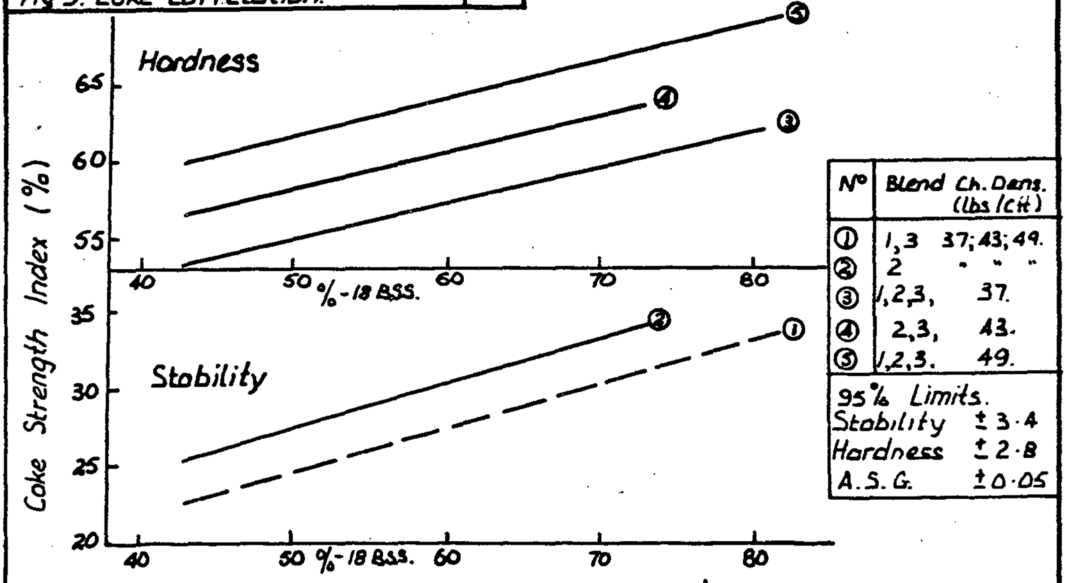


Fig. 11. Effect of factors on 15 lb. oven cokes.

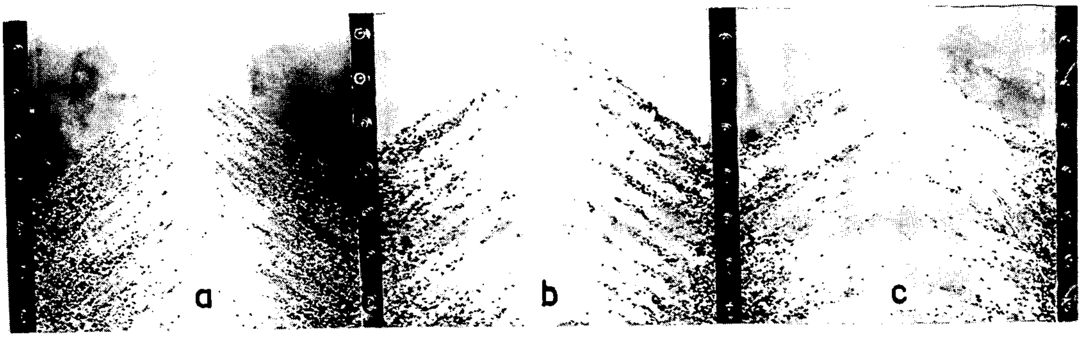
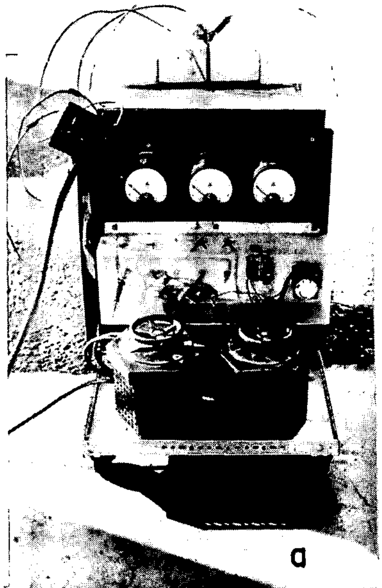
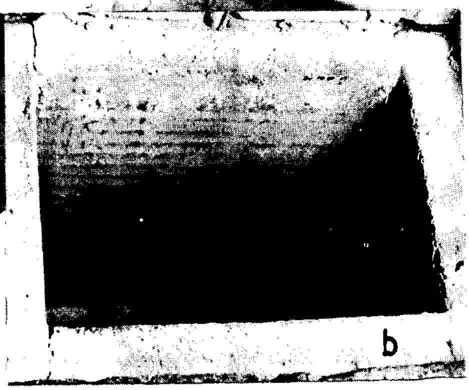


Fig. 6. Segregation Patterns. Dicharge Apertures a = 1/4", b = 1/2", c = 1".

Fig. 7. Coke From 15lb. Oven.





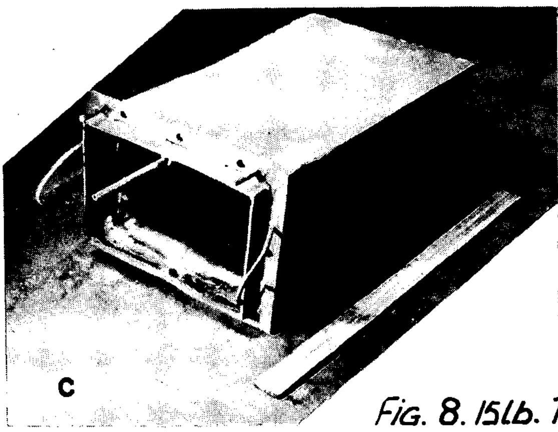


Fig. 8. 15lb. Test Coke Oven
a. Assembled Oven.
b. Oven Chamber
c. 25/20 Stainless Steel Retort.

FIG 10. PROCEDURE: PREPARATION BLEND OF 8 COALS.