

**COKING PRESSURE AND COKE QUALITY  
AT DIFFERENT LOCATIONS IN AN  
INDUSTRIAL OVEN**

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INTRODUCTION

The properties of coke produced in an industrial oven are not uniform. Higher coal density near the oven sole, segregation of coal during charging, non-uniform heating, the oven taper and the variation of static loads on the coal during coking may all contribute to a heterogeneous product. Normally little can be learned of the magnitude of these effects as the coke is homogenized during oven pushing, quenching and discharge onto the coke wharf. A previous paper described the properties of coke produced at nine locations in a 5-meter oven at Algoma Steel (1). This paper describes the results of an expanded program in which coke was collected from nine locations in four ovens and the temperature and gas pressures at these locations were monitored.

PROCEDURE

To sample coke made in different locations wire mesh "cages" were placed in the oven. Cages measured 280 x 280 x 360 mm and were fabricated from steel mesh with 50 mm openings. During brief delays in coal charging these were lowered into the oven through the three charging holes with fibre rope to 0.5, 2.5 and 4.5 m below the coal line. Their actual positions in the oven were obtained from depth markings on the fibre rope. The cages were recovered after the oven had been pushed and quenched from a temporary wharf. Gas pressures were measured with slitted tubes containing thermocouples for temperature measurement as described previously (2). They were placed in the oven charge immediately prior to or

after the charge containing the cages.

RESULTS

The following abbreviations are used:

- BD = bulk density of coal in the oven on a dry basis, kg/m<sup>3</sup>
- CT = final temperature reached at the centre of the oven, °C
- FT = flue temperature of coking oven
- S = ASTM coke stability factor, %
- H = ASTM coke hardness factor, %
- +50-mm = amount of plus 50-mm coke produced, %
- CSR = coke strength after reaction, NSC test, %
- CRI = reactivity, NSC test, %
- Pg = maximum gas pressure at oven centre, kPa
- Pw = maximum wall pressure in pilot oven, kPa
- Po = average wall pressure in pilot oven, kPa
- R = linear correlation coefficient
- N = number of data points
- SE = estimated standard error of linear regression

Temperature Measurements

From temperature profiles the time required to reach 900°C at the centre of the charge was measured and coking rates were determined from the oven width (432, 457 and 483 mm at the push-, centre- and coke-side charging holes respectively). The average rates for the 4.5 and 2.5 m levels were 35.2 and 34.2 mm/h, the top level coked at a slower rate 28.0 mm/h. The averages across the oven from the push-side were 32.3, 31.1 and 34.0 mm/h.

Gas Pressure

The gas pressure at the centre of the charge increased with time and reached a peak about two hours after charging. This peak occurred when the local temperature had reached 100°C and evaporated water could no longer condense in the charge. The peak height increased linearly with depth at about 2 kPa/m, Figure 1.

A second larger peak in the gas pressure-time curve occurred as the plastic coal layers met at the centre of the charge, Figure 2. The

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magnitude of this peak also increased approximately linearly with depth at 3 kPa/m.

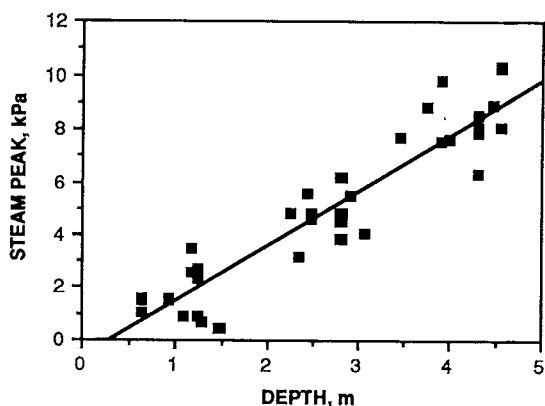


Fig. 1. Steam pressure peaks and depth below coal line

### Coke Quality

Of the 36 cages placed in the ovens six were not recovered. A further five cages are not included in the present analysis as they contained door and/or sole coke which shows

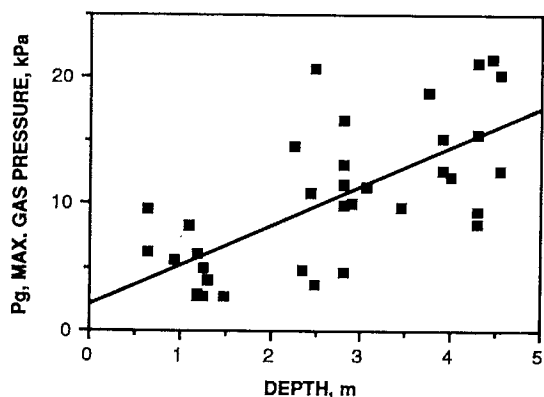


Fig. 2. Maximum gas pressure measured at centre of industrial oven and depth below coal line

they had rolled from their allotted position in the oven. These cokes contained high volatile matter from 1.1 to 3.8% whereas the other cokes were from 0.5 to 0.8%.

The average amount of +50 mm coke in the cages was 30.9% and ranged from 16 to 43%. No significant relationship with depth or along the length of the oven was found. The average amount of +50 mm coke in the wharf

sample, which was collected from all the ovens used in the program, was 55.1%. As this is considerably higher than the average for the cage cokes it must be concluded the latter are not completely representative of the coke as it existed in the oven. In general the cauliflower ends of the coke protruded through the mesh of the cages and on average 70% of these ends had been broken off before the cages were recovered.

The relatively small amount of +50 mm coke in the cages did not allow an ASTM stability determination for each as planned. Therefore cages from different ovens but similar locations were combined. An average stability of 51.8% was obtained which was considerably smaller than the wharf stability of 58.1% because of the small coke size. Averages for the top, middle and bottom levels were 51.5, 50.2 and 53.8% respectively.

As expected the size reduction experienced by the cage cokes did not affect their hardness as the average 68.7% was close to that of the wharf coke, 69.0%. The hardness increased with oven depth. Averages for the top, middle and bottom levels were 67.6, 68.1 and 70.6% respectively.

The apparent specific gravity of the cage cokes varied from 0.820 to 0.962 and the average, 0.887, was also close to the value for the wharf coke, 0.871. This parameter increased with oven depth, figure 3.

The reactivity of the cokes fell within a narrow range 23.0-31.6% with a mean of

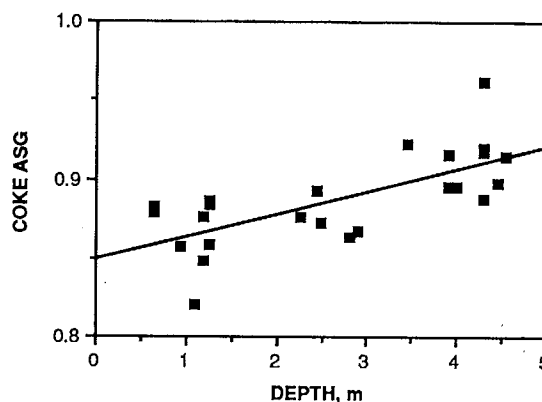


Fig. 3. Coke density and depth below coal line

27.8% which compares well with the reactivity of the wharf coke, 26.2%. The coke strength after reaction (CSR) had a larger range 44.0-68.4% and increased with depth (R = 0.34).

### PILOT OVEN RESULTS

#### Coke Quality

A sample of the coal blend was coked in a silica-brick 460-mm wide pilot oven at three flue temperatures and three coal bulk densities. Figure 4 shows that the size of coke obtained as measured by the percentage of +50 mm coke was predominantly determined by the flue temperature of the oven. Increased coal and hence coke density decreased coke size presumably because of the more severe temperature gradient it induces.

$$\begin{aligned} \%+50 \text{ mm coke} &= 226.54 - 0.1223 \times \text{FT} \\ &\quad - 28.108 \times \text{ASG} \\ R &= 0.99, \text{ SE} = 1.97, N = 19. \end{aligned}$$

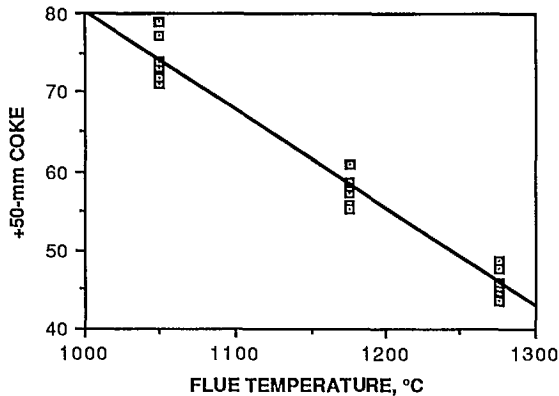


Fig. 4. Relationship between percentage +50-mm coke and oven flue temperature

The apparent specific gravity of the cokes is well related to the initial coal bulk density, Figure 5. The coke density also increases with the final temperature it reaches during coking,

$$\begin{aligned} \text{ASG} &= 0.3003 + 0.00783 \times \text{BD} \\ &\quad + 0.000158 \times \text{CT} \\ R &= 0.96, \text{ SE} = 0.015, N = 19. \end{aligned}$$

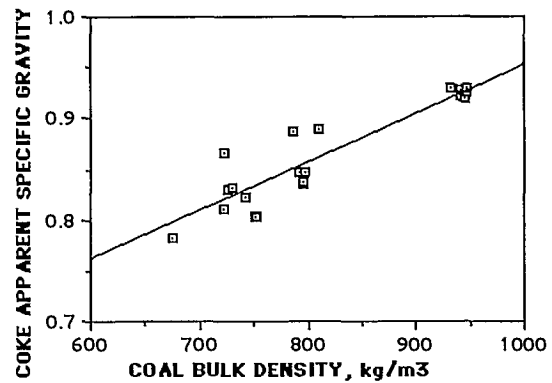


Fig. 5. Relation between coal and coke density

The hardness of the cokes depended on the coke density,

$$\begin{aligned} \text{Coke hardness} &= 30.06 + 45.55 \times \text{ASG} \\ R &= 0.96, \text{ SE} = 0.66, N = 19. \end{aligned}$$

The coke stability depended on both coke hardness (R = 0.46) and coke size (R = 0.6),

$$\begin{aligned} \text{Coke stability} &= -28.11 + 1.068 \times \text{H} \\ &\quad + 0.2388 \times \% +50 \text{ mm coke} \\ R &= 0.95, \text{ SE} = 0.99, N = 19. \end{aligned}$$

#### Coke Strength After Reaction

The results obtained for CSR and reactivity of the pilot oven cokes inadvertently demonstrated that mild oxidation of the coal blend drastically affected the values obtained. In Figure 6 the

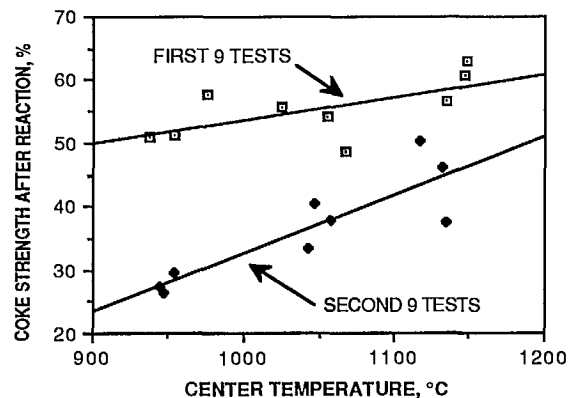


Fig. 6. Effect of centre temperature and coal storage on CSR. The second nine tests were duplicates of the first nine carried out about 29 days later

two lines represent the consequence of performing duplicate oven tests spaced 29 days apart on average. Table 1 shows that changes in conventional coke parameters such as density, stability and hardness caused by storage for this length of time are negligible but CSR decreased by 34% and reactivity increased by 24%.

The coal was taken from the larry car in order to obtain a good sample of the coal being charged to the ovens and therefore had been pulverized which would hasten its deterioration during storage. As the coal remained frozen from shortly after sampling until a few days before the first pilot oven test it is assumed oxidation started on the day of the first test. Thus the following relationship suggests that CSR dropped one percentage point for every three days of storage:

$$\begin{aligned} \text{CSR} &= 23.2 + 0.0346 \times \text{CT} \\ &\quad - 0.314 \times \text{days} \\ R &= 0.92, \text{ SE} = 4.9, n = 18 \end{aligned}$$

A similar equation for reactivity shows this parameter increases by 1% for seven days of storage.

Table 1. Effect of coal storage on coking properties

	Mean 1st 9 tests	Mean 2nd 9 tests	Change (%)
Coal density, kg/m <sup>3</sup>	829	818	-1.4
Time to 900 °C, h	15.2	15.8	4.0
ASG	0.867	0.873	0.7
Centre temp., °C	1049	1042	-0.7
+50-mm coke, %	58.3	60.3	3.4
Stability	59.9	61.4	2.5
Hardness	69.8	69.6	-0.3
Reactivity, %	33.7	41.8	24
CSR, %	55.3	36.5	-34

### Coking Pressure

A typical wall pressure-time curve for a pilot oven test at high coal bulk density together with the gas pressure measured at the centre of the charge is shown in Figure 7. The maximum wall pressures occurred as the plastic coal layers met at the oven centre and figure 8 shows they increase logarithmically with coal density. The relation between the

maximum wall pressure and the gas pressure,  
 $P_{\text{wall}} = -0.99 + 0.504 \times P_{\text{g}}$   
 $R = 0.98, \text{ SE} = 2.16, N = 19$   
 shows the wall pressure was about one half of the gas pressure and hence the plastic layer area at the oven centre is about one half the initial area (3).

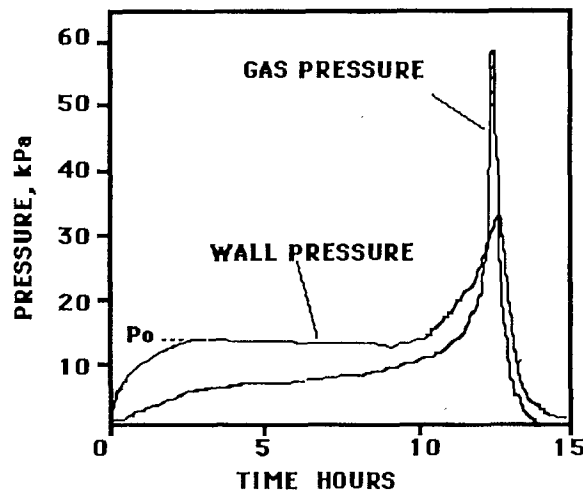


Fig. 7. Wall and gas pressure time curves for pilot oven

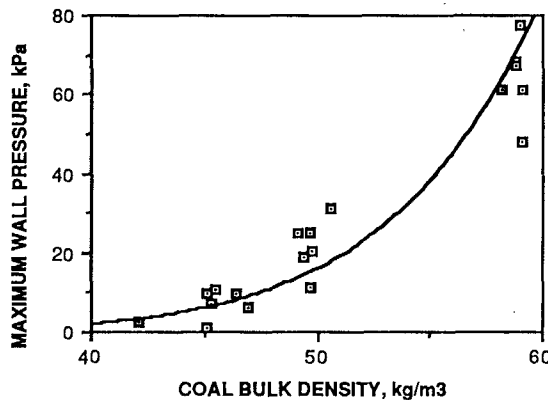


Fig. 8. Relation between maximum wall pressure and coal density

### COMPARISON OF INDUSTRIAL AND PILOT RESULTS

#### Coke Quality

The pilot oven produces a coke size similar to that of the industrial oven when operated at a similar flue temperature. The average flue temperature for the industrial

ovens, 1209 °C, was obtained from the mean of optical pyrometry measurements taken at the oven sole and at the coal line 2-4 h before the oven was pushed. The pilot oven, built from the same silica bricks as the oven battery to ensure similar heat transfer rates, would produce 54% +50-mm coke at this temperature. This is in good agreement with the average wharf value, 55%.

To obtain the average industrial coke density, 0.881, the pilot oven would have to be operated at a dry coal bulk density of 815 kg/m<sup>3</sup> according to the relationship given previously. The mean industrial coal density is not accurately known but is probably considerably less, about 760 kg/m<sup>3</sup>. Therefore it appears the larger static loads in the industrial oven increased the coke density above that expected from the pilot oven coal density-coke density relationship (4).

Figure 3 shows industrial coke density increased linearly with depth. To further explore this relationship pilot oven tests were run at the anticipated industrial coal density. The coke cake was pushed intact into a sheet steel box and cooled by water sprays. This allowed the properties of the coke to be determined as a function of their depth in the oven. The results for coke density appear in Figure 9 together with the industrial data and show coke density in fact increases linearly with the logarithm of depth.

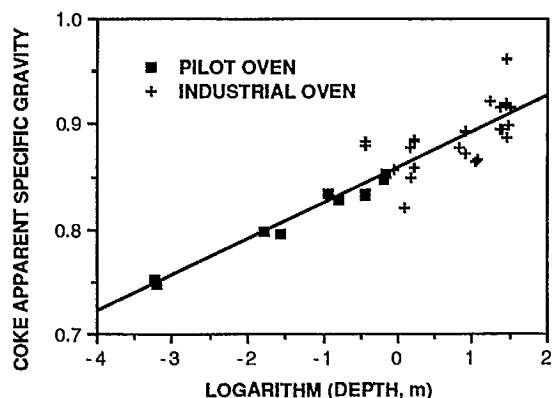


Fig. 9 Relation between coke density and depth for industrial and pilot oven

Direct comparison of industrial and pilot stability factors is not possible because as previously noted the size of the cage cokes had been reduced by handling and stability depends on size. In Figure 10 the stability divided by the hardness, which is a measure of the probability of lump breakage in the tumble test, is seen to be well related to the amount of +50-mm coke for both the cage and pilot cokes. Using the equation of the regression line:

$$S/H = 0.6249 + 0.004057 \times \% \text{ 50-mm}$$

$$R = 0.95, SE = 0.023, N = 27$$

the measured coke hardness and assuming the unaffected size of the cage cokes is equal to the mean wharf size the average stability factors given previously for the top, middle and bottom levels can be corrected to 57.3, 57.8 and 59.9 respectively.

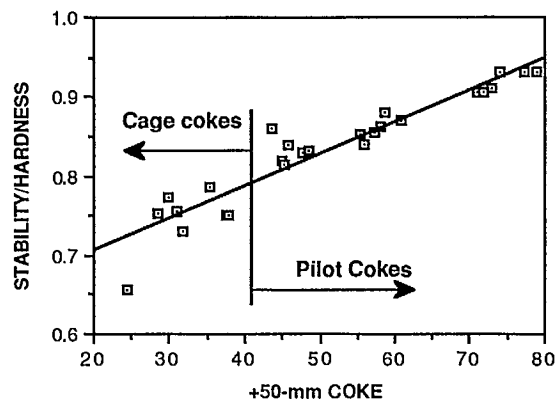


Fig. 10 . Relation between the probability of breakage (S/H) and coke size for cage and pilot cokes

None of the pilot oven cokes had a reactivity as low as or a CSR value as high as the industrial wharf coke sample. Setting storage time to zero in the previously derived equation a high centre temperature is required (1200 °C) to produce a pilot coke with wharf coke CSR. This is higher than the average industrial centre temperature, 1155 °C. Further analysis has shown that the relationship between reactivity and CSR is different for pilot and industrial cokes Figure 11. No explanation can be offered but differences in sample procurement or quenching are suspected.

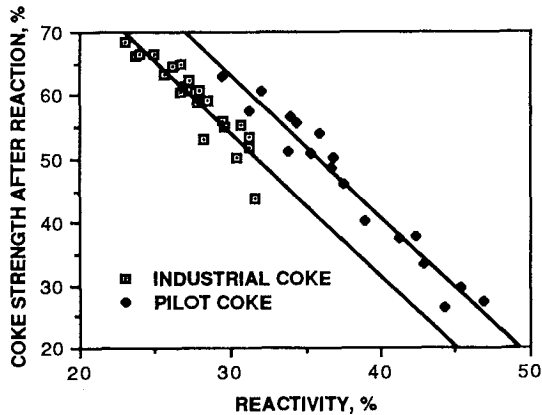


Fig. 11. Relation between coke reactivity and strength after reaction for pilot and industrial cokes

### Coking Pressure

Tests in pilot-scale ovens clearly demonstrated that coking pressure is largely dependent on the initial coal bulk density in the oven. This knowledge is of limited use in deducing pressure in industrial ovens as coal density and its uniformity are not accurately known. A more useful and fundamental relationship can be deduced by considering the well known behaviour of coal during coking in a sole-heated oven under a constant applied load (5). Here it is found that the density of the resultant coke is only dependent on the pressure applied to the coal and is not influenced by the initial bulk density of the coal. This shows that the coal plastic layer reacts in a well defined way to the applied pressure - increasing the pressure decreases its porosity and hence increases the density of the resultant coke.

The relationship between pressure and coke density was obtained by coking the coal blend in the sole-heated oven under four pressures, 0.69, 3.5, 7.7 and 15.2 kPa. Cokes produced in this manner have been heated to about 900°C near the oven sole but only to 500 °C at their upper ends. Therefore they were heated in a retort to 1000 °C for 30 minutes before measuring apparent specific gravity. Figure 12 shows the density is well-related to the logarithm of the pressure.

To compare the pilot oven pressure and coke density results to those obtained in the

sole-heated oven the average pressure under which the coke is formed must be defined. Referring back to figure 7 which shows a typical wall pressure-time curve for the pilot oven we see the pressure slowly decreases from a shoulder in the curve that occurs about 2 hours after charging. The slow decrease is thought to be caused by the decrease in area of the plastic layers due to coking in from the bottom, top and sides and so the best definition for average pressure is that occurring at the shoulder,  $P_o$ , in Figure 8. Values of  $P_o$  and the coke density for each pilot oven test are plotted in Figure 13 where they are seen to agree well with the sole-heated oven data.

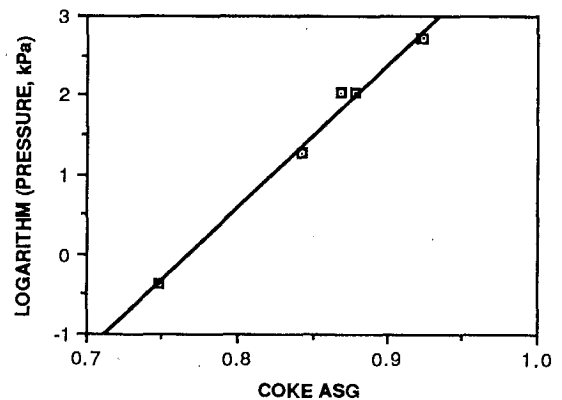


Fig. 12 Coke density and pressure applied to sole-heated oven

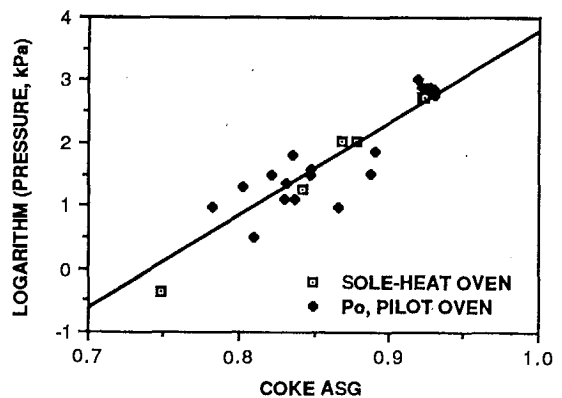


Fig. 13. Comparison of coke density made under applied pressure in sole-heat oven and self-imposed pressure in pilot oven

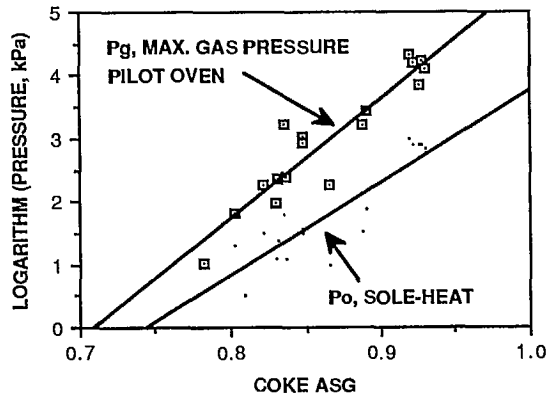


Fig. 14 Maximum and average pressures in pilot oven

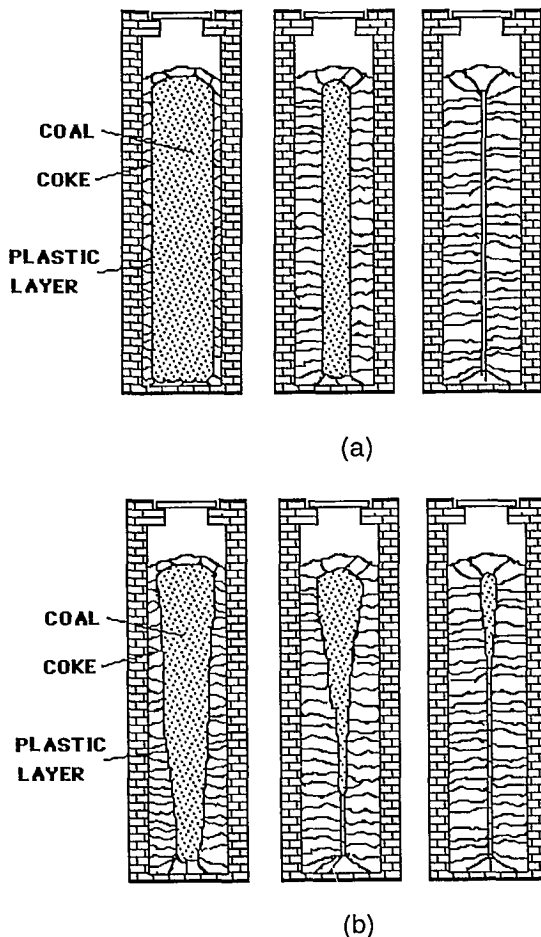


Fig. 15. Schematic diagram showing (a) uniform coking (pilot oven) and (b) coking with vertical temperature gradient (industrial oven)

In Figure 14 the maximum gas pressure observed as the plastic layers met at the centre of the pilot oven charge has been added to Figure 13. These high pressures occur as the plastic layer meet simultaneously over a large area as illustrated diagrammatically in Figure 15a. We have found peak pressures are smaller if the layers meet more than a few minutes apart at the top and bottom confirming the work of others (6). In the industrial oven the vertical temperature gradient caused the plastic layers to come together for the most part in a V-formation as suggested schematically in Figure 15b. From the averaged temperature data the plastic layers met first at the 4.5m level about 30 minutes later at the 2.5m level and almost 180 minutes later at the 0.5m level. Therefore the industrial data would be expected to fall between the two lines in Figure 14 ie have gas pressures generally less than the maximum observed in the pilot oven but at least as high as is necessary to produce coke of the observed density. Figure 16 shows this to largely be the case.

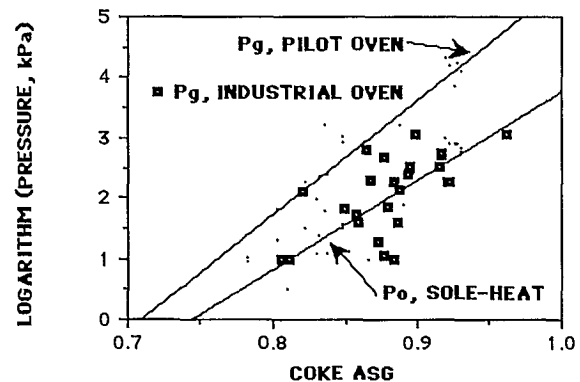


Fig. 16. Comparison of industrial maximum gas pressure with pilot oven maximum and average pressure

### CONCLUSIONS

The physical properties of coke depend on their location in the oven. Coke hardness, density and CSR increase with depth and it is inferred that stability also increases and coke size decreases but the method of coke sampling influenced these parameters. The peaks in gas pressure caused by steam expulsion and the plastic coal layers meeting at the centre of the oven increased linearly with depth. It was shown that coke density is related to pressure during coke formation.

Pressures in the industrial ovens range from the high peak values observed in pilot tests when the plastic layers meet simultaneously over a large area, to lower values when they meet more gradually because of the vertical temperature gradient.

The pilot oven produced coke similar to the industrial average when charged with coal containing 4% moisture and operated at a flue temperature of 1210 °C. The pilot results showed coke CSR is dependent on the final temperature reached by the coke and that this coke property is very sensitive to coal oxidation.

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