EXTENDING BATTERY LIFE BY IMPROVING COKE CONTRACTION

Mohammed A. Khan [1]
John F. Gransden [2]
John T. Price [3]

Abstract: Measures to prolong battery life include ensuring adequate coke cake contraction to avoid hard pushes and "stickers". Pushing forces and coke contraction in the oven has been investigated by a number of workers using different techniques. In this work charges in a 300 kg capacity Carbolite pilot-scale oven were cooled in-situ and filler gauges used to measure the minimum space between the convex coke lumps and the oven wall. An average of about one hundred such measurements is obtained for each charge and are as low as 2 mm for low-volatile coals or blends and as high as 18 mm for high volatile coals. For a typical Canadian steelmakers blend increasing coal bulk density from 750 to 940 kg/m^3 decreased contraction from 14 to 4 mm, while changing coking rate from 22 to 13 hours produced a decrease from 12 to 7 mm. Wall clearance during coking has been examined and is improved by 40% by a three hour soak. Contraction was unchanged for this strongly coking blend after two years storage and presently a weaker blend is being tested. Measurements show contraction is not uniform so even a high contracting charge has some coke lumps left close to the wall. Results are examined in light of other coking parameters and industrial pushing forces obtained in a Canadian steelplant.

Footnotes: 1st International Meeting on Ironmaking, September 24-26, 2001
Belo Horizonte, Brazil

[1] Manager, Technical Services, Fording Coal Limited, 205 - 9th Avenue SE, Calgary, Alberta T2G 0R4
[2] Research Scientist Carbonization.Canmet Energy Technology Centre, Ottawa, Canada
[3] Manager Canmet Energy Technology Centre, Ottawa, Canada

Introduction: Research to investigate the contraction behaviour of coke was undertaken by the Canadian Carbonization Research Association to extend the life of industrial coke ovens and to understand the problem of hard pushes from sometimes encountered in industrial coke ovens.

Experiments were done in a movable wall test oven that has the same width as an industrial oven to simulate industrial contraction.

Coke was quenched in the oven and the shrinkage from the walls and width of the centre 'crack' was measured in several places along the length and height of the oven.

Pushing difficulties - "heavy pushes" or "stickers" - must be avoided as they cause incremental damage to the walls of coke ovens decreasing battery life. Many operating conditions are known or thought to contribute to the problem including uneven heating, over or under charging ovens, carbon build up, coal contamination, blend composition and uneven masonry. This work covers some variable amenable to investigation - coal density, blend composition, coking rate, blend storage and uneven heating as well as the progression of coking.

Hard-Pushes/Stickers Cause & Effect
85% of the Time:

- over/under charging ovens
- uneven charging - slumped ends
- over/under heating/over soaking
- green/dark coke, ends and tops ie. incomplete/uneven heating
- ΔC^0 - too high at end of cycle
- coking time changes - too often
- insufficient vertical/lateral shrinkage
- small or highly fissurered coke
- too many door leaks
- uneven oven-floors/bulging walls
- excessive carbon build-up on oven walls

15% of the time:

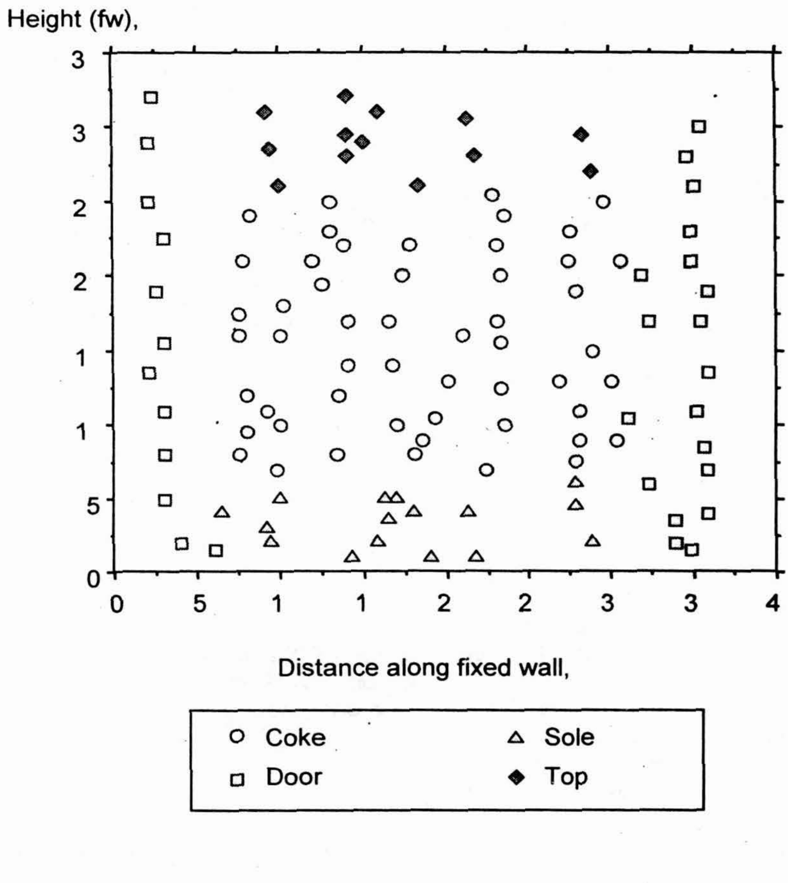
- contaminatin in coal/coal blend (slag, pellet fines, sinter fines etc.)
- low volatile too high in the blend
- blend inerts - too low
- coal blend, ash fusion too low
- blend moisture too low
- blend changes - too often

Experimental:
Coal blends were carbonized in a Carbolite cokingoven (350 kg capacity) normally operated with a coal density of 816 kg/m^3 and a flue temperature programmed to increase from 875^0 C to 1130^{0}C at 15^{0}C/h. At the end of the carbonization period the coke cake was cooled in-situ. Power was shut off, the flues opened to allow the

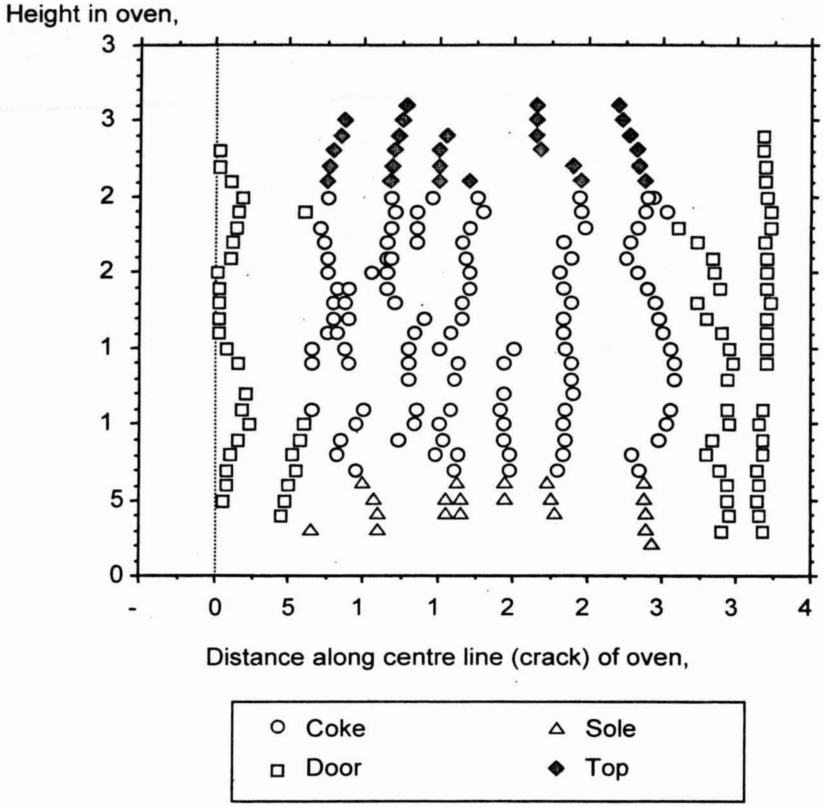
heating walls to cool by natural convection and a small quantity of nitrogen introduced to the coke cake centre to provide an inert atmosphere. The temperature in the middle of the coke cake took 6-7 hours to cool to below 500^{0}C when the doors could be opened. Any hot spots were gently sprayed with water.

The cauliflower ends of the coke lumps are generally close to the wall and thwarted any attempt to measure the distance from wall to coke using an imaginary grid system. Instead the coke aspices closest to the well were measured with feeler gauges, the coke lump then carefully removed from the oven and the next lump measured. In this way 50 or 60 readings representing coke closest to each heating wall was obtained. The crack width at the oven centre was measured in about 200 places throughout the oven. Measurements within 15 cm of the top, bottom and side of the charge are not included in the averages reported here.

Insitu Coke Quenching of Pilot Coke Oven
(Places where coke measurements were taken along the fixed wall of oven)
Figure-1



Measurement of Coke Distance
(Places where coke measurements were taken along centre line crack of oven)
Figure-2



Results:
Seven projects that investigate variables that effect coke contraction have been completed.

Project 1	Effect of coal density in the oven
Project 2	Effect of blend composition - Appalachian coals
Project 3	Effect of blend composition - Western Canadian coals
Project 4	Contraction during coking and effect of soaking
Project 5	Effect of coal storage
Project 6	Effect of coking rate
Project 7	Uneven heating

Properties of the coal blends used are given in Table 1a and Table 1b.

Table-1a Properties of Coals and Coal Blends

Oven No	Project	Sole-Heat exp/cont %	Melting Range C	Maximum Fluidity dd/m	Dilatation %	Ash %	Volatile Matter %
C-626	1	-8.02	81	1771	60	6.39	28.8
C-631	1	-8.02	81	1771	60	6.39	28.8
C-628	1	-8.02	81	1771	60	6.39	28.8
C-636	2	-17.2	87	22400	171	6.02	35.33
C-641	2	-6.7				5.8	32.9
C-639	2	-2.5	81	2906	59	5.77	30.44
C-638	2	4.9	71	186	38	5.47	24.73
C-670	3	-15	50	26	4.5	11.1	25.7
C-673	3	-8.2	37	4.9	-22	9.88	23.2
C-672	3	-4.4	34	2.6	-25	8.68	20.99
C-674	3	-2.2	17	1.3	-27	7.6	18.76
C-669	3	-0.6	28	2.33	-21	6.56	16.91
C-705	4	-9.1	86	3450	82	5.74	29.83
C-709	4	-6.6	86	3450	82	5.73	29.57
C-698	4	-8.1	86	3450	82	5.91	29.86
C-693	4	-5.9	86	3450	82	5.9	29.52
C-699	4	-6.6	86	3450	82	5.93	29.64
C-693	5	-5.9	86	3450	82	5.9	29.52
C-737	5	-7.2	78	1094	49.5	5.82	29.18
C-799	5	-4.9	70	705	32	5.96	29.65
C-797	6	-7.4	83	3601	114.5	5.8	29.93
C-792	6	-7.4	83	3601	114.5	5.8	29.93
C-791	6	-7.4	83	3601	114.5	5.8	29.93
C-794	6	-7.4	83	3601	114.5	5.8	29.93
C-651	3	-11.4	62	109	25.5	9.39	22.56
C-841	5	-3.6	66	295	25	5.81	28.9
C-864	5	-8	64	255	22.5	5.86	28.3

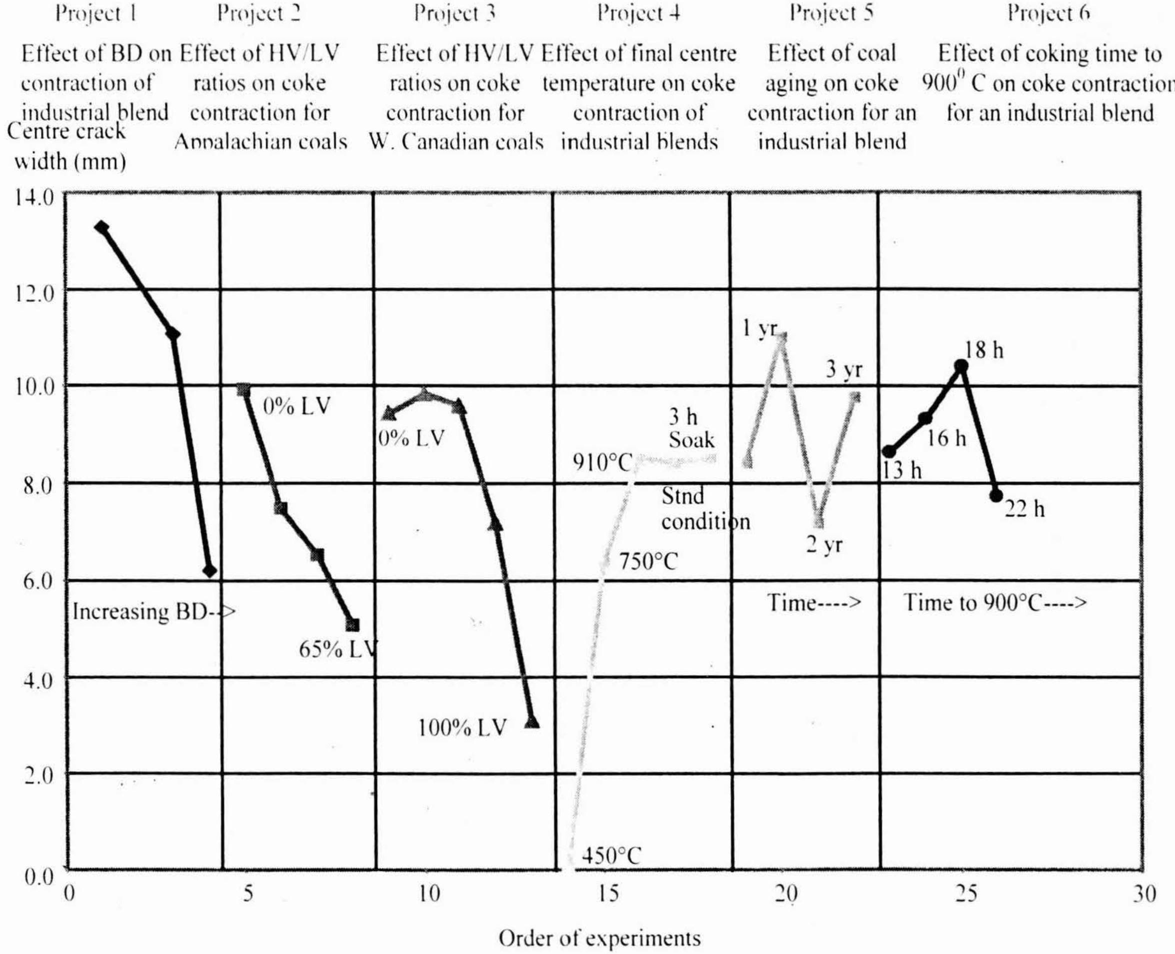
Table-1b Properties of Coals and Coal Blends

Oven No	Project	Crack Mean Width mm	Wall Contraction mm	Total Contraction mm	Time to 900^{0}C hours	Final Temperature ^{0}C	Caol Density kg/m^3
C-626	1	13.3	5.275	23.83	12.75	1080	746
C-631	1	11.1	3.38	17.83	14.63	1065	821
C-628	1	6.2	1.73	9.66	15.5	1090	945
C-636	2	9.91	4.71	19.33	13.42	1085	829
C-641	2	7.49	3.245	13.98	14.23	1085	834
C-639	2	6.51	2.775	12.06	15	1080	830
C-638	2	5.06	0.845	6.75	15.17	1090	830
C-670	3	9.45	7.63	24.71	15.75	1050	826
C-673	3	9.84	5.095	20.03	16.42	1035	823
C-672	3	9.6	3.96	17.52	16.17	1084	824
C-674	3	7.19	2.94	13.07	16.25	1050	828
C-669	3	3.11	0.998	5.105	14.92	1095	822
C-705	4	0.04	2.63	5.298		450	824
C-709	4	6.36	1.69	9.74		775	825
C-698	4	8.49	2.855	14.2	15.17	905	821
C-693	4	8.41	3.09	14.59	16.25	1045	822
C-699	4	8.51	4.325	17.16	16.25	1058	823
C-693	5	8.41	3.09	14.59	16.25	1045	822
C-737	5	11	3.78	18.57	15.75	1045	824
C-799	5	7.19	4.395	15.98	15.83	1055	831
C-797	6	8.62	5.565	19.75	22	1045	829
C-792	6	9.33	3.96	17.25	17.83	1051	828
C-791	6	10.4	3.69	17.78	16	1052	827
C-794	6	7.72	2.89	13.5	13	1055	828
C-651	3	9.73	5.14	20.01	13.66	1080	838
C-841	5	9.78	3.28	16.34	15.58	1050	827
C-864	5	8.22	3.428	15.075	15.25	1050	823

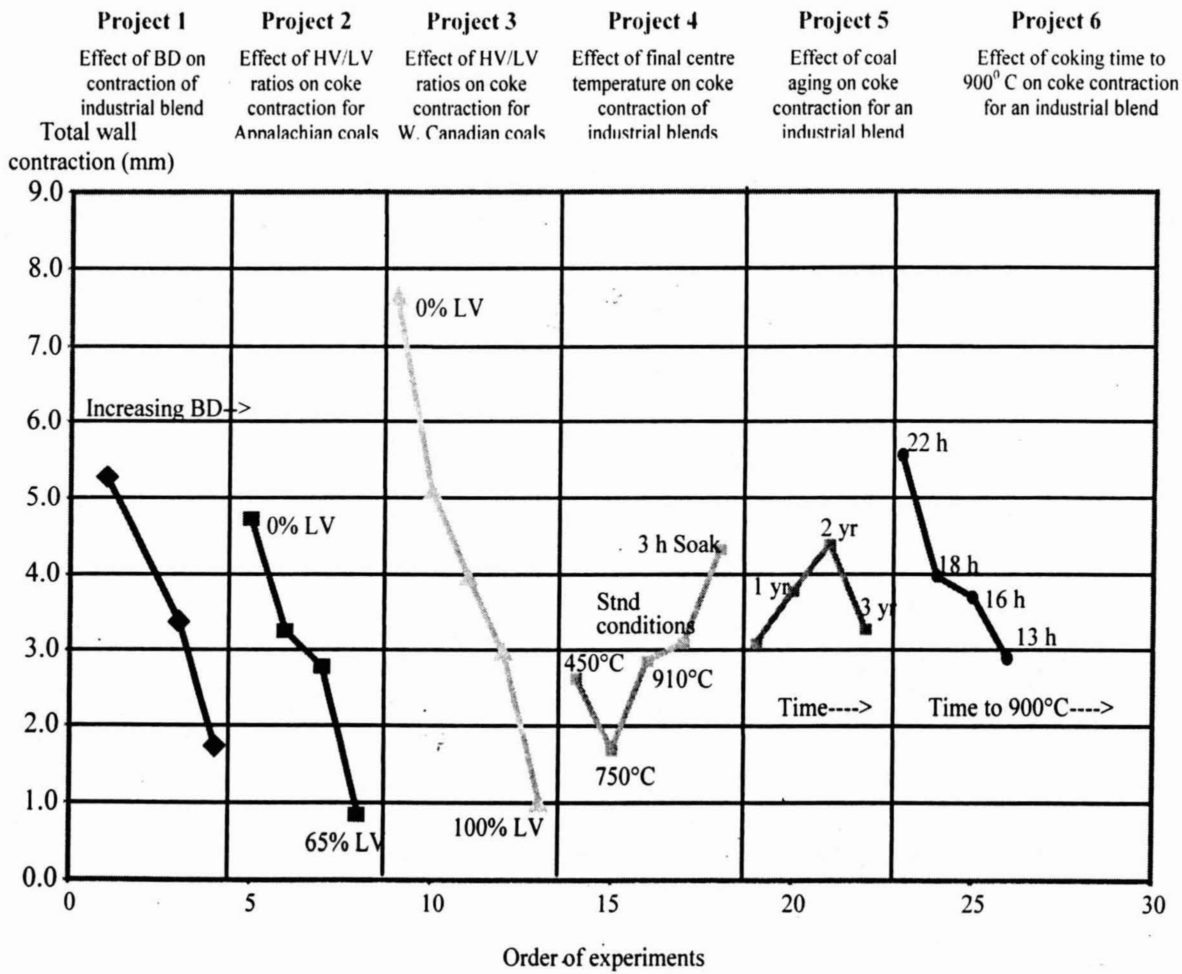
Project 1 - Effect of coal density

A steel company coal blend was carbonized at 3 bulk densities under standard heating conditions. Coal moisture was adjusted to obtain bulk densities of 746, 821 (standard bulk density for oven) and 945 kg/m^3. Mean wall contractions declined with density and were 5.3, 3.4 and 1.7 mm respectively. The centre crack width also declined with increasing density and were 13.3, 11.0 and 6.2 mm respectively. To make comparison easier results for all projects are shown in Figure 2, mean wall contraction, Figure 3 crack width and Figure 4, total contraction (twice the mean wall contraction plus the crack width).

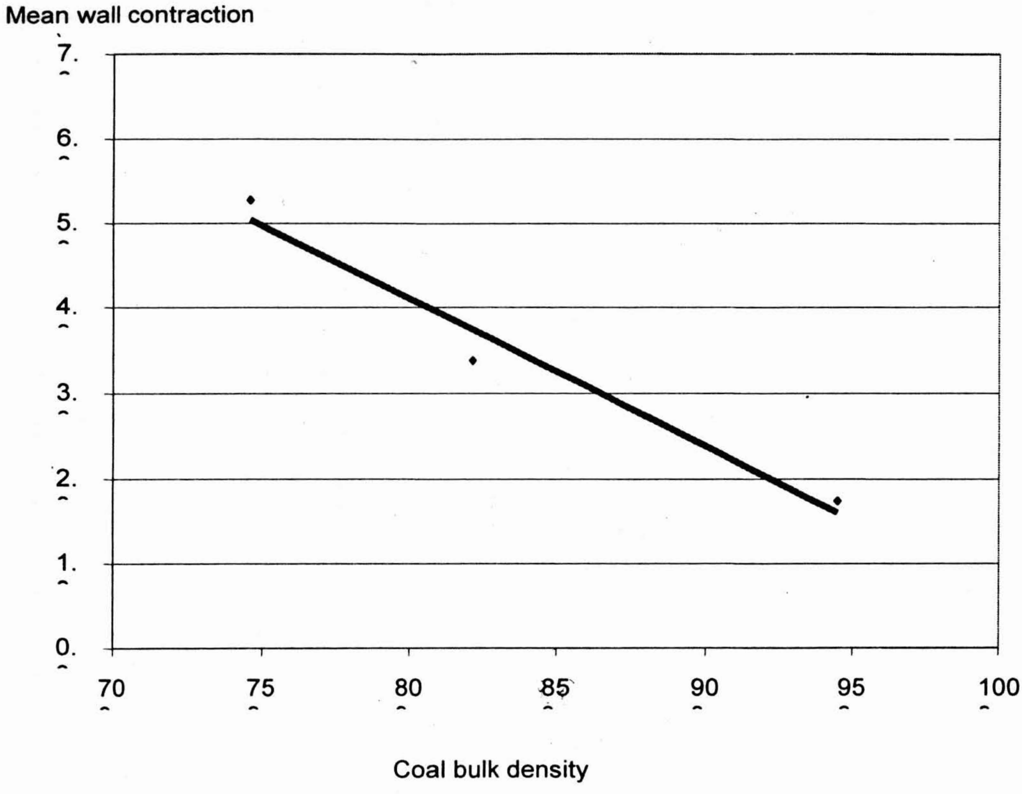
Effect of Coking on Centre Crack Width
Figure-3



Effect of Coking on Total Wall Contraction
Figure-4



Coke Contraction from Carbonization of an Industrial Blend at Different Coal Bulk Densities
Figure-5



Project 2 - Blend Composition - Appalachian Coal

A high-volatile coal used in blends by a Canadian steel company was carbonized using standard conditions. It had a mean wall contraction of 4.7 mm and a centre liine crack width of 9.9 mm. Adding 15, 28 and 65% low-volatile coal successively reduced the mean wall contraction and also the centre crack width. Experiments with more than 65% LV were not done because of exceedingly high wall pressures.

Table-2

Appalachian Blend #	**1**	**2**	**3**	**4**
%HV	100	85	72	35
%LV	0	15	28	65
Crack width, mm	9.9	7.5	6.5	5.1
Wall contraction, mm	4.7	3.2	2.8	0.8

Project 3 - Blend Composition - Western Canadian Coal

Western Canadian coals generally have higher inerts than Appalachian and contraction is higher for similar rank blends, Figures 2-4. A western Canadian high volatile coal was coked alone and in combination with a western Canadian low volatile coal in concentrations of 75%, 50% and 25%. Mean wall contraction varied from 7.6 mm for 100% HV to 1.0 mm for 100% LV coal.

Table-3

West. Canadian Blend#	**1**	**2**	**3**	**4**	**5**
%HV	100	75	50	35	0
%LV	0	25	50	75	100
Crack width, mm	9.5	9.8	9.6	7.2	3.1
Wall contraction, mm	7.6	5.1	3.9	2.9	1.0

Project 4 - Contraction during Coking

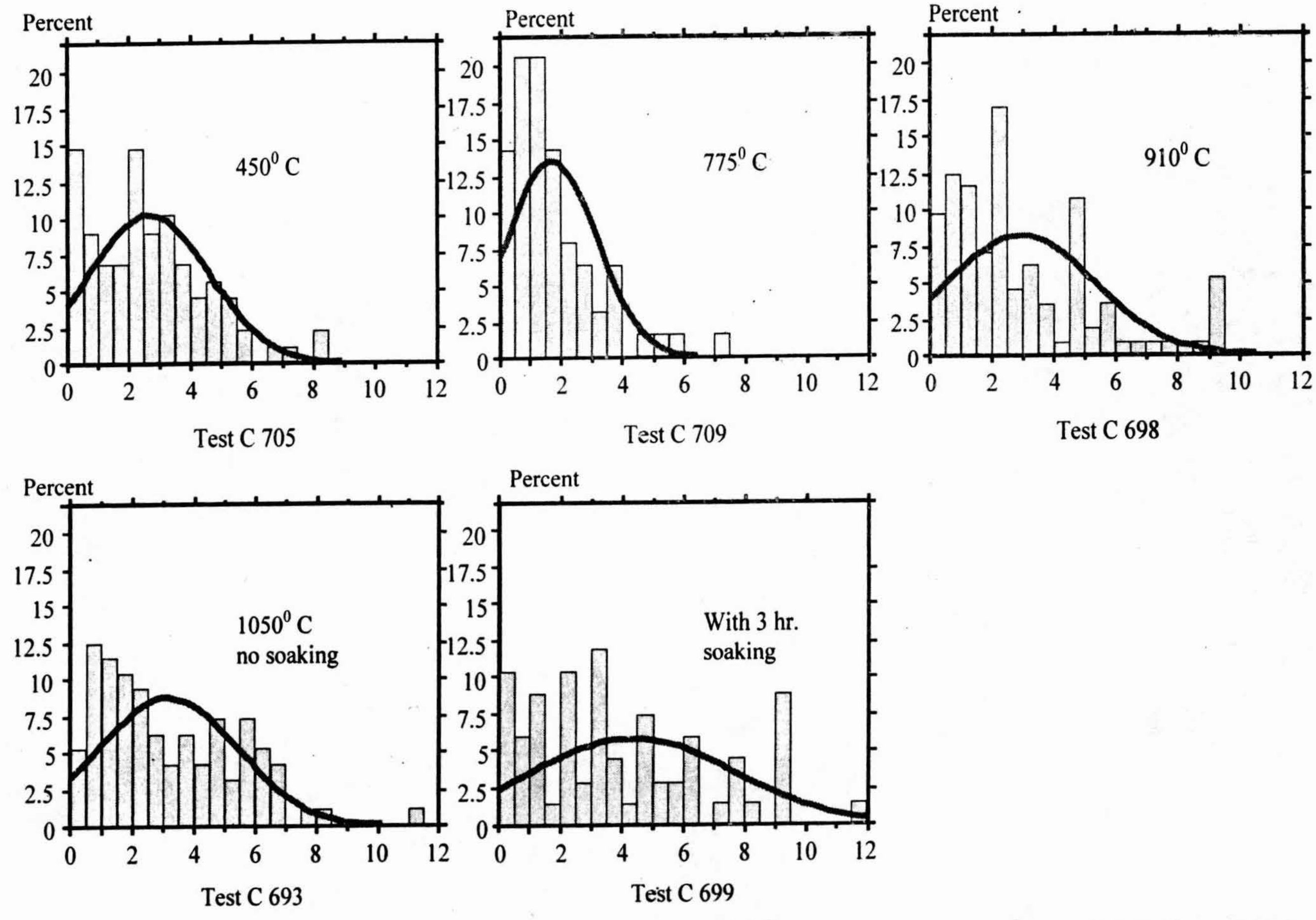
In this project the test oven was switched off and the charge cooled at different stages of carbonization. In the first test the oven centre only reached 450^{0}C so as expected some coal was found at the oven centre and there was no crack. In a second test the centre reached 775 ^{0}C and a crack had now formed at the centre with an average width of 6.3 mm. In a third test with a centre temperature of 910 ^{0}C the crack increased 8.5 mm. Further tests at standard conditions when the centre temperature reached 1050 ^{0}C and one kept 3 hours after the centre temperature reached 1050^{0}C (and had risen to 1095^{0}C) did not increase the crack width.

Contraction from the wall proceeded slowly as finishing temperature increased. With the method of measurement adopted it was already 2.5 mm even while coal was still at the oven centre and considerable pressure was still on the oven wall. Of course for pressure to be on the oven wall some coke must be in contact with the wall. Only six points were recorded to have no gap and a further six a gap of 0.2 mm or less.

For the normal centre temperature of 10500C the wall gap had only increased to 3.1 mm. Soaking for three hours increased the gap by 40% to 4.3 mm showing the importance of soak time for smooth pushing and support for the practice of soaking a "sticker" oven to allow pushing.

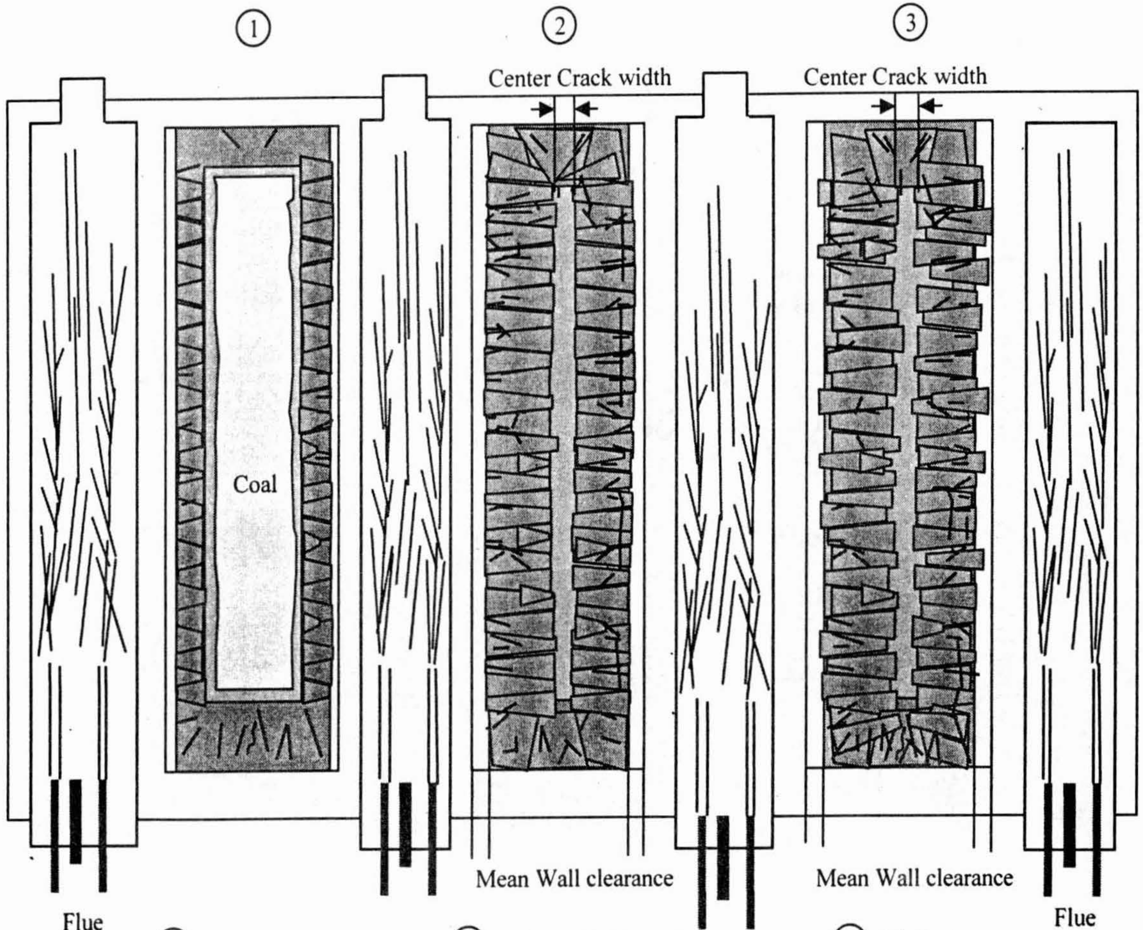
Histograms of wall contraction for all tests are shown in Figure 6. Remarkably all show that a considerable number of coke ends are relatively close to the wall. For example in order of increasing coking time 24, 34, 22, 18 and 15% of the ends are 1 mm or less from the wall.

Effect of Final Temperature of Coking on Wall and Centre Crack Contraction - Industrial Blend
Figure-6



These data therefore leads to quite a different picture of contraction than may intuitively be imagined – a rough plane defined by the coke cake surface moving progressively further from the oven wall with time. Rather time appears to allow more pieces to contract and contract further, but some are left behind still almost in contact with the wall. This new finding may lead to a more fundamental understanding of the nature of cake contraction.

Contraction During Coking
Figure-7



(1) Early coking (2) Coked with No soak (3) 3 h Soak

Project 5 Coal Storage

Companies have often reported pushing problems when using coal near the bottom of their stockpiles. To see if this was related to loss in rheological properties, a steel company coal blend has been stored (in barrels) and tested each year for four years. Figures 2-4 show contraction was essentially unchanged during this period, even though blend dilation decreased from 82% to 50, 32, 25 and 23% after one, two, three and four years respectively. Storage was also found to have no effect on the stability of the coke but its reactivity was continuously increased.

Table-4 (Project 5)

Test	Week	Dilatation %	Wall Crack Contraction		Total Contraction
			mm	mm	mm
C-693	0	82	6.18	8.41	14.59
C-737	51	50	7.56	11.01	18.57
C-799	104	32	8.89	7.19	16.08
C-841	157	25	6.56	9.78	16.34

Table-5 (Project 5)

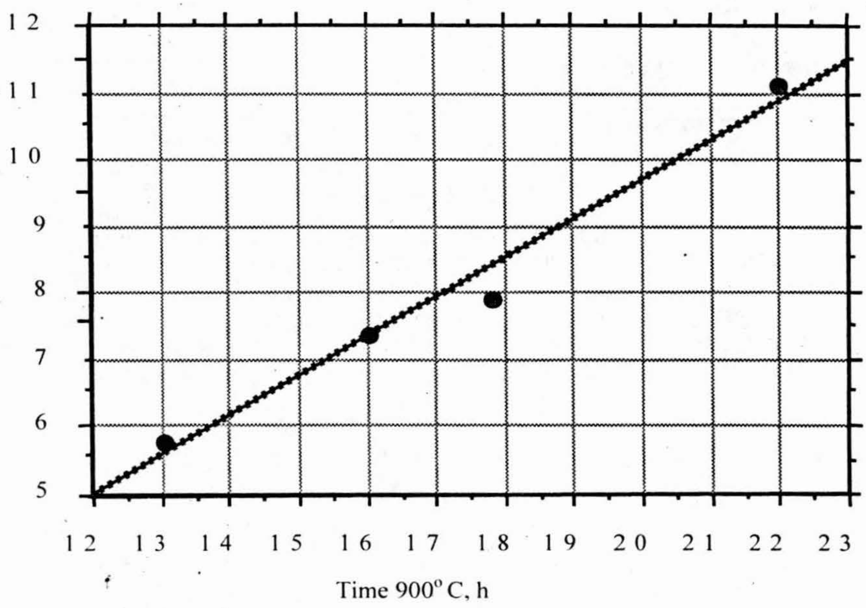
Test No.	C-693	C-737	C-799	C-841
Wall Pressure	11	9.9	5.4	8
MCS	64.2	65.3	62.9	64.7
Stability	61.8	63.9	64.2	65.5
Hardness	66.9	69.5	70	71.6
CRI	25.7	27.7	30.4	31.9
CSR	63.5	63.0	56.2	53.5

Project 6 Coking Rate

A steel company blend was also used in this project and the coking rate of the Carbolite oven was changed by altering the flue temperature program while maintaining bulk density and pushing temperature constant. The average wall clearance increased as the coking rate decreased. Fast, normal, slow and very slow rates with times to a centre temperature of 13, 16, 18 and 22 hours had mean wall clearances of 2.9, 3.7, 4.0 and 5.9 mm respectively. The width of the centre crack was essentially unchanged.

Effect of NCT* Changes on Total ** Wall Contraction
Figure-8

Total wall contraction = -2.034 + 0.587* Time 900°C; R^2 = 0.977
Total contraction (ie. wall contractions plus width of centre crack) of the coke mass shows similar trends



Project 7 Non-uniform coking
Industrial ovens may have significant vertical flue temperature gradients causing coal at the bottom of the oven to be coked faster than that at the top. Uneven coking of wet charges may also be caused by water migration patterns retarding coking.

Non-Uniform/Coking or High ΔTCo*
Table-6

	Upper Half of oven		Lower half of oven	
	(Mean Values)	Standard Error	(Mean Values)	Standard Error
Heating time to reach oven centre temperature of 900oC	14.8 h	0.39	15.7 h	0.39
Mean wall contraction, mm (for both walls)	9.19	0.80	6.37	0.51
Mean width of centre crack, mm	7.31	0.38	10.10	0.58
Total contraction, mm	16.50	1.06	16.60	0.90

We did not set out to investigate the effect of uneven heating, but errors in oven operation produced some important observations. Incorrect heating led to the bottom of the oven being coked slower than the top on a number of occasions. It was then found that the wall contraction was less at the oven bottom but the centre crack was wider. The total contraction – i.e. wall contraction – from both walls plus crack width was the same for the top and bottom of the oven. A typical is:

	Top half oven	Bottom half oven
Wall contraction (both walls), mm	9.2	6.4
Crack width, mm	7.3	10.1
Total contraction	16.5	16.5

This suggests coke is forced to remain near the wall and this may be a common industrial reason for hard pushes when moistures are high and variable.

DISCUSSION

Results show that on average, somewhat more coke contraction takes place from the oven centre than from the oven wall. The mean wall contraction for all tests expect project 4 was 3.7mm or 7.4mm for both walls, while the average crack width was 8.5mm.

Uyemura et al. modelled the increase in clearance between the wall and charge using a heat and mass transfer model, and adding terms for the competing processes of dilation of the charge and contraction of the coke determined in a high temperature dilatometer (1). Calculated results agreed well measurements made in a test oven with a recessed plate in the heating wall forced to follow the charge contraction. Wall contraction increased from 2 to 6 mm as the coal density was increased from 750 to 850 kg/m^3 and these values are also consistent with the measurements reported in this work.

Ades and Barzan investigated vertical contraction in a test oven, and described how they used the sole-heated oven to improve contraction of their industrial blends by adding high-volatile coal from Eastern U.S. allowing them to bring back into production many ovens with poor masonry (2). In a second paper Ades investigated contraction of the coke cake away from the wall of a test oven using ceramic rods passing through holes in the wall (3). He reported values for changes in coal density, blend composition, coking rate and soaking quite similar in numerical value to those in the present work, despite the difference in measurement methodology.

In a recent paper Nomura and Arima report work that used a plate intermediate in diameter between the rod of Ades and the plate of Uyemura (4). They found there was no contraction away from the wall until the plastic layers had met and disappeared from the oven even when using coal producing very low (1-2 kPa) coking pressure and point out there must obviously be contact if there is any wall pressure being recorded. In contrast, Ades reported contraction started shortly after the beginning of carbonisation. Babanin et al. and Duchène have also reported contraction before coking pressure ceases (5, 6).

The present work is believed to clarify the contraction process. For example, it was found only six aspices were in contact with the wall under pressure on cooling (the actual number is greater, as only a sample, not all, of the cauliflower ends were measured). Thus a certain portion of the cauliflower ends have retreated from the wall to varying degrees even while it is under pressure. This suggests that we should not view coke contraction as a plane, albeit a "bumpy" one, that progressively retreats from the wall. Rather, individual lumps contract away from the wall at varying rates perhaps orchestrated in some manner by the coking pressure when present, cracking and relative movement between the lumps. Some lumps may remain on or very close to the wall even after considerable mean contraction has taken place, as seen in Figure 5 for the charge soaked for three hours.

Using only the 20 results obtained under standard operating conditions, wall and total contraction are quite well related simply to the volatile and ash content of the coal or blend:

$$Wc \text{ (mean wall contraction, mm)} = 9.1 + 0.95 \times Ash\ \% + 0.24 \times VM\% \quad R=0.89$$

The contraction measured in the sole-heated oven has long been used by North American cokemakers to ensure smooth pushing operations. Values quoted are usually within the range – 12 to -6% – but vary with the operation. The sole-heat contraction Sc is well related by itself to wall contraction:

$$Wc = 2.15 - 0.25 \times Sc\% \qquad R = 0.81$$

...but is improved if the volatile matter and ash are included:

Wc = -5.48 + 0.68 x Ash% + 0/14 x VM% R=0.91

None of these equations were improved by including a thermal rheological parameter contrary to the findings of Addes that contraction increases with blend Gieseler fluidity (1). In the present program, the low fluidity coals used also have high inerts that increase the contraction. The large fluidity reductions observed for the stored blend also did not result in changes in coke contraction.

Including the tests performed at different coal densities, coking rates and finishing temperatures lead to the following equation:

Wc = -2.11 + 0.97 x Ash% + 0.27 x VM% - 0.021 x BD + 0.25 x T900 + 0.006 x Tfinal

R = 0.90

The equation suggests an increase in mean wall contraction of 1mm occurs for about a 1% increase in coal ash, a 3.8% increase in volatile matter, a 4 hour increase in the coking time to 900°C, a 160°C increase in final temperature or a decrease of 50 kg/m3 in the coal density. The 40% increase in wall contraction for the single test soaked for three hours suggests temperature/time would be fruitful for future investigations.

CONCLUSION

- B.D. has inverse influence on the centre line and wall contraction.
- L.V. in blend has inverse effect on wall clearance and centre line width.
- Wall clearance and centre line width larger with Western Canadian coal in comparison to other coals.
- 3 hr. soaking significantly increased the mean wall clearance.
- Increasing coking rate decreases the wall contraction.
- Ageing of coal up to 3 years has minimum effect on the coke contraction, coke stability, and hardness, in spite of decreased rheology.
- CSR/CRI deteriorated significantly after 2 years ageing.
- Test oven data indicates total contraction is strongly related to SHO contraction, VM and ash content.

REFERENCES

(1) Uyemura, N., Mabuse, H., Nakano, T. and Nishida, S. "Estimation of Growing Clearance between the Heating Wall and Charge in a Coke Oven." Proceedings AIME Ironmaking Conf., 45, 453-457, 1986.
(2) Ades V. I., Barazan, D. R. "Coal Charge Contraction and its Relevance to Coke Oven Pushing Performance" Proceedings AIME Ironmaking Conf., 45, 459-467, 1986.
(3) Addes, V. I. "Coal Charge Lateral Contraction in the Slot Oen", Proc. AIME Ironmaking Conference, 52, 303-313, 1993.
(4) Nomura, S. and Arima T. "Coke Shrinkage and Coking Pressure during Carbonization in a Coke Oven." Fuel, 79, 1603-1610, 2000.
(5) Babanin, B. I., Shein, S. Sh. and Malyshev, D. A. "An Experimental Determination of the Extent of Movement of the Coke Cake from the oven Wall during the Coking of Preheated Charges." Koks i Khimiya (in English) No. 4, 16-18, 1983.
(6) Duchène, J-M. "Shrinkage and Thrust in Coke Ovens." Revue de Métallurgie, No. 12, 950-956, 1982.