



Prediction of coke oven wall pressure

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HIGHLIGHTS

- An oven wall pressure development mechanism has been described.
- A physical IGP and statistical OWP model are expressed with the same predictors.
- The predictors are commonly available to the cokemaker.
- Extrapolation from a pilot oven to an industrial oven is possible.

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ABSTRACT

Internal gas pressure (IGP) developed by coking coals upon carbonisation accounts for oven wall pressure (OWP). If not controlled, this OWP may be potentially dangerous as it can easily exceed the 10 kPa acceptable limit. In this work, a simple, physically based, expression of IGP in a slot-type coke oven is presented, validated on data available in literature and modified into a ready-to-use expression of OWP fitted on measurements from the movable wall pilot oven of the Centre de Pyrolyse de Marienau (CPM) over a wide range of single coals. Expressed as a function of coal characteristics and carbonisation conditions, this OWP prediction is accurate enough to serve as a process tuning tool. However, probably because additivity rule does not apply easily to inert content, the model fails to predict OWP in case of blends. Extrapolation from the pilot oven to the industrial oven has been proved.

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1. Introduction

Upon continuous heating in the absence of oxygen, coking coal passes through a plastic state over a relatively narrow temperature range before transforming into a solid porous coke. This transient phase transformation, accompanied by a release of volatile matter (VM) is explained by two competitive reactions, respectively of decomposition and condensation. Coal softens at about $T_{soft} = 400$ °C and then both fluidity and gas evolution increase until a maximum around 450 °C. With increasing temperature, condensation takes over decomposition and growth of large aromatic structures within the plastic mass leads to resolidification near $T_{res} = 500$ °C. Gas evolution, which continues long after resolidification, causes the coke contraction. It is within this plastic temperature range that the fundamental coking processes, which convert granular coal into massive porous coke, take place. In a slot-type coke oven, plastic layers, delimited by the two isothermal planes

T_{soft} and T_{res} , are initiated at the two opposite walls of the oven, then move inwards from the walls, as a result of heat transfer, and meet at the centre plane.

Plastic layer swells when gas evacuation proceeds slower than gas generation and, as a result of gas entrapment, internal gas pressure (IGP) builds-up in the plastic layer. Transmission of IGP to the walls by the surrounding semi-coke/coke gives rise to oven wall pressure (OWP) but lateral shrinkage (LS) may explain why OWP and IGP have been somewhat considered as separate phenomena. Indeed, a sticky charge does not necessarily mean that the coal exerted a pressure on the walls and conversely, lateral shrinkage does not mean that, at a given time of coking, walls have never been subjected to the coking pressure. It nonetheless remains true that OWP implies IGP and a mechanical contact between the charge and the walls.

The operational problems or dangerous situations the cokemaker can be faced with in case of high OWP (hard pushes, stickers) and the significant economic implications (wall damage) explain why much attention has been paid to the pressure generation mechanism. Besides, interest is not waning, not only because reserves of good coking coals with low-pressure characteristics are

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Nomenclature

μ	gas dynamic viscosity (Pa s)	Q	gas evolution rate ($\text{kg m}^{-3} \text{s}^{-1}$)
ρ_g	gas density (kg m^{-3})	R	gas constant ($8.314 \text{ J K}^{-1} \text{ mol}^{-1}$)
$\rho_{\text{coal}}^{\text{db}}$	dry coal bulk density (kg m^{-3})	R_{or}	rank, random or mean random vitrinite reflectance (%)
Φ	gas flux ($\text{kg m}^{-2} \text{s}^{-1}$)	SF	semi-fusinite (vol.%)
CR	coking rate (mm/h)	t_0^{900}	time required for the temperature to reach 900 °C at the middle of the charge (s)
$EOWP$	equivalent oven wall pressure (Pa)	TIC	total inert content (vol.%)
F	fusinite (vol.%)	T_{soft}	softening temperature (K)
h	charging height (m)	T_{res}	resolidification temperature (K)
I	inertinite (vol.%)	T_{MF}	temperature at maximum fluidity (K)
IGP	internal gas pressure (Pa)	T_g	gas temperature (K)
k	ratio of vertical plastic layer area to wall area in a movable wall oven	T_w	wall temperature (K)
K	gas permeability (m^2)	u	gas velocity (m s^{-1})
LS	lateral shrinkage (m)	V	vitrinite (vol.%)
M	gas molecular weight in the plastic range (kg mol^{-1})	V_{170}^{175}	vitrinite with reflectance greater than 1.7% (vol.%)
MF	maximum Gieseler fluidity (ddpm)	V_{155}^{175}	vitrinite with reflectance between 1.55% and 1.75% (vol.%)
MM	calculated mineral matter (vol.%)	VM^{db}	volatile matter, dry basis (wt%)
OWP	oven wall pressure (Pa)	W	moisture content (wt%)
P	absolute gas pressure (Pa)	w	oven width (m)
P^{rel}	relative gas pressure (Pa)	x_0	half low permeable layer thickness (m)
P_0	atmospheric pressure (Pa)		

becoming depleted and/or expensive but also because adjustment of the production to the fluctuating demand requires frequent changes in blend and operating parameters which do have an impact on the battery life time.

Low-volatile high-pressure coking coal is a normal component of the blend as it improves coke yield and quality indexes. The difficulty consists in finding a compromise between throughput, yield, quality, and preservation of the oven against possible damage. The best one should be obtained by blends developing the maximum permissible pressure. The maximum safe coking pressure above which wall damage can be anticipated depends on the oven geometry: the smaller 4 m tall walls in older ovens can withstand higher pressures than the tall 6 m walls in more modern batteries. Even if identification of a universally-accepted, single value of a safe coking pressure appears unlikely, it may reasonably be expected that the maximum allowable pressure is around 10 kPa [1].

Considerable effort has been expended in attempts to develop a reliable test, capable of determining the capacity of coals to generate excessive wall forces. Of these, the movable wall oven is the only universally recognized test tool for selecting coking coals. However, it is a rather expensive, time, resource and coal consuming test. With the objective of reducing heavy testing requirements, this paper presents an empirical formulation of OWP expressed as a function of parameters deduced from a simple physical model of IGP. In this context, the model can be viewed as a preliminary assessment tool to guard against unsafe wall pressures: it can help to formulate low coking pressure coal blends, assess economic future blends, investigate a replacement coal, identify coking pressure generating coals, monitor the wall pressure, etc.

2. Mechanism of coking pressure generation

Evolution of volatile matter from the coal charge is a necessary but not sufficient condition for coking pressure generation in a conventional slot-type oven, since the large majority of high-vol coals are usually low pressure ones. The other condition for a pressure to be developed is the resistance to gas flow. It is now established that restriction of VM release by two low permeable regions sandwiching the plastic layer causes the VM to be trapped within

the plastic coal [2–4]. But evolving gas must first escape the plastic layer itself before passing through these low permeable regions. Hence, there are three barriers to the motion of the evolved gas. The mechanism of coking pressure generation is summarized in Fig. 1: both the process parameters and genetic factors determine the coke properties and structure on which depends OWP. The process parameters can be satisfactorily represented by the dry bulk density and the thermal gradient, and the genetic factors by the vitrinite reflectance and the total inert content. The respective contribution of the three main components of the charge (semi-coke, plastic layer and coal) to the OWP is explained below. The schematic cross-section of the charge in both cases of respectively high and low-pressure coals is sketched in Fig. 2. The symbols are explained in the nomenclature.

2.1. The plastic layer

Events taking place in the plastic layer largely determine the structure of the semi-coke. Plastic layer permeability is related to its rheological properties. Duffy et al. [5] point out the analogy between coke and polymer foams. These are both cellular materials resulting from entrapment of a blowing agent in a temporarily liquid organic matrix. During foaming, expanding bubbles subject their walls to stretching. The resistance to the stretching force is viscoelastic character. If the stretching force is high and/or the resistance to the stretching force is low, walls rupture, gas escapes and finally, foam collapses. Otherwise, bubbles press up against each other, get organised into a close packed structure without coalescing and the foaming structure is maintained. By contrast, in the case of polymer foam, the blowing agent evolution rate and the rheological properties of the polymer matrix can be adjusted separately, while in the case of coking coal, gas evolution rate and fluid rheology are linked. High volatile, high fluidity coals, having not only a high stretching force but also a low resistance to the stretching force, are thus more prone to cell rupture than low volatile low fluidity coals.

For high fluidity coals, pore wall thinning and consequently cell opening progress at a high rate. A permeable interconnected pore network is established early in the carbonisation process enabling volatile matter to be vented out of the plastic layer. Volatile release

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