Effects and impacts of components of coal handling system on coke quality and yield of coke plants

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Summary

Under the existing conditions of a sharp international competition and fluctuating coal bases, the reduction of production costs in coke manufacturing is one of the most important challenges of steel making industry. Many tests and experiences with different coke oven types and coal blends have shown that there are several effects and impacts in the course of the coking process influencing both coke quality and yield in a significant way. In particular, aside from composition of coal blend and heating settings like coking time and heat flue temperature, the processes forming the coal preparation plant have substantial importance on that issue. A main parameter of operation is the bulk density of the coals which can be controlled within the coal handling system upstream of the batteries by screening, crushing, drying and adding additives to the coal blend with the final objective of achieving uniformity of coke quality. It is widely accepted that grain size distribution, moisture content and oil addition rate are the most significant parameters among many other minor variables affecting the bulk density, additionally. Moreover, these parameters have secondary effects on coal fluidity and on the degree of pressure exerted to the chamber walls during the course of coking. Consequently, it is essential to react on inconsistent coal bases and to consider all influencing factors during the engineering phase of a new coal handling system, ensuring both operating reliability and product quality. However, an adequate planning and engineering, long-lived equipment and redundancy are always associated with increased investment costs. The paper investigates various attractive process steps regarding its simultaneous cost-and process effectiveness and describes suitable components of coal preparation plants like selective crushing of coal types and moisture/density-control devices.

Key Words

coal handling and preparation system for coke oven plants, selective coal crushing, bulk density, moisture/density-control, grain size distribution, coking pressure, coke quality

Introduction

The existing conditions in the steel marked lead to a sharp international price competition. Responding on these conditions and being focused on a high coke quality, considering declining coal bases at the same time, is one of the big challenges of the coke making industry, at present.

In general, the properties of a coal mixture filled into an oven chamber determine the coke quality in a significant way. However, the availability of sufficient coking coals showing appropriate properties for pyrolysis decreases all over the world. For that reason, according to the spirit of time a coke plant manager tries to purchase reasonably priced coals on the market, unfortunately, frequently associated with unfavorable characteristics.

From the praxis of coke oven operation it is well-known to coke oven experts, that feeding of mechanically hard coals characterized by high fraction of Durit into a chamber results in high internal coking pressure associated with extraordinary mechanical loads on the heating walls. In such cases, horizontal refractory-spalling may occur in longitudinal direction at the edges of two liner wall layers directly above each other near the chamber bottom, initially, which may be followed in a long-term scenario by serious damages of the entire wall. Those operational conditions would require selective crushing and preparation of the individual pressure-producing fractions of the coal forming the mixture, stringently, in order to save the oven structure sustainably. On the other hand, also soft coking coals require selective crushing to a corresponding grain size in order to achieve a sufficient coke quality.

Another measure to equalize oven operation, internal gas pressure as well as coke quality consists in the continuity of water contents within the coal charges.

The objective of the paper is to indicate general ways how to achieve, nevertheless, a respectable coke quality based on careful coal preparation even from different and low-grade coals, considering the operational circumstances described above.

Petrographic composition of coal

Coal is not a simple substance showing a homogeneous microstructure, because it received a specific treatment under the influence of local geological pressures followed by numerous transformations over a long period of time. This leads to different characteristics of each coal seam with regards to its particle hardness and melting characteristics.

Because both the coke formation properties and the coke quality are fluctuating frequently even when a constant VM-content of a coal blend is in use, the distribution of maceral fractions of the individual coals with respect to the caking ability of the complete blend is of high importance and has to be carefully taken into account when designing of a coke preparation plant is intended.

The external appearance of the coals is determined by the organic, rock-forming components of coal, the macerals, and varies in terms of hardness:

- *Fusit* has a minor mechanical strength. It decomposes already under finger-pressure to dust. It has black-coloring properties.
- *Vitrit* has a significantly higher mechanical strength than fusit, but this strength is weakened greatly by the presence of separation joints in the binder. Vitrit frequently contains vitrinite-macerals.
- *Durit* has a significant hardness, because it is quite compact. It is ten times as hard as vitrit. Its components are generally liptinite-macerals.
- *Clarit* has a mechanical strength ranging between that of vitrit and durit, depending on its composition. In fact, it is a hybrid material having the same binder as vitrit but also durit inclusions (Exinit, Resinit). The durit-fractions are often significant justified by the presence of durit-binder (Mikrinit, Sklerotinit, semi-Fusinit). The mineral admixture in general has a very high hardness.

Grain size distribution

The particle size distribution has a direct influence on the bulk density of dry coal according to ROSIN and RAMMLER. Especially the fine particles below 0.5mm affect the bulk density. The higher the amount of small particles, the lower the bulk density. Moreover, with a decreasing mean diameter of the coking coal blend the bulk density decreases. The mean diameter of a coking coal mixture can be determined using a RRSB-diagram. Eq.1 shows a commonly used functional form to determine the packing of coal particles and is known as ROSIN-RAMMLER-function.

$$F_{RR}(d) = 1 - exp\left[-ln2\left(\frac{d}{d_{0.5}}\right)^n\right] \; (0 \leq d < +\infty) \qquad (1)$$

Where "$d_{0.5}$" is the median of a distribution function. The bulk density is defined as the mass of particles of a certain material divided by the volume they occupy [1]. In coke making it is strongly influenced by three parameters, the moisture of the coal, amount of oil additives and the particle size distribution. Therefore, a lot of efforts have been made to understand and quantify the effects of these factors. The optimum grain size distribution for a coal blend is shown in fig.1.

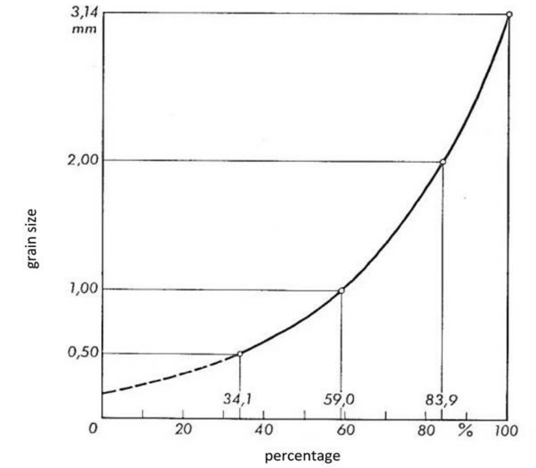

Figure 1: Optimum grain size distribution [1]

In comparison, fig. 2 shows the particle size distribution of a typical coal blend. [1]

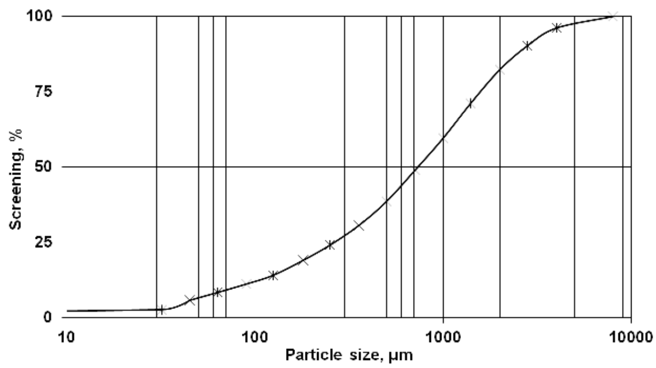

Figure 2: Typical particle size of Australian coal blend

Further, the grain size distribution of the coal mixture has a direct influence on the M10 and M40 value of the coke, as shown in fig.3.

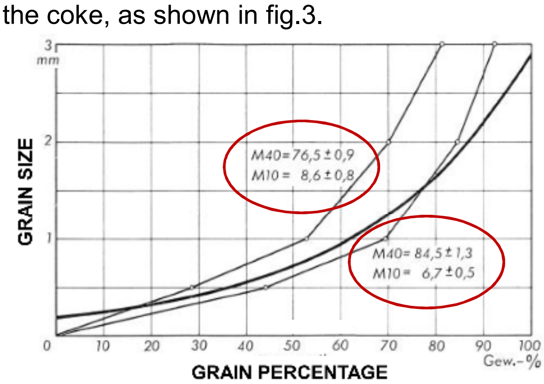

Figure 3: Coke quality in relation to the grain size distribution [1]

Every coal has its own hardness and needs its own crusher settings. It is important, that the fraction of fines is close to the optimum range in order to achieve:

- Optimum fusing and melting of coal grains
- Formation of high quality lumpy, rigid, high strength coke with low abrasion

Further, at a higher bulk density the CRI-value is decreasing, as shown in fig. 4, while the CSR-value is increasing.

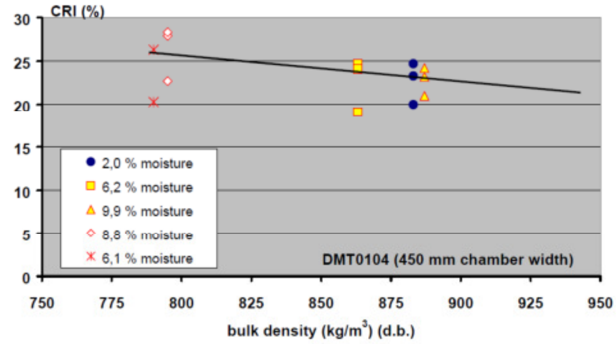

Figure 4: Coke quality in relation to bulk density [2]

Coal crushing

The different grain size distribution of the raw coal is cause by the different structural strength, methods of mining and processing. This effects the requirements for the coal handling system of the coke oven plant. The main equipment for this process is the crusher station. Normally it is equipped with hammer mills.

After the feed material enters into the crusher, the coal is hit by the hammer heads and crushed by impact against the grinding wall. A further crushing takes place in the lower region between the rotor and the grinding wall. Factors effecting the grinding efficiency include the rotor speed, the gap between the hammers and the grinding wall as well as the quantity of coal fed through the crusher.

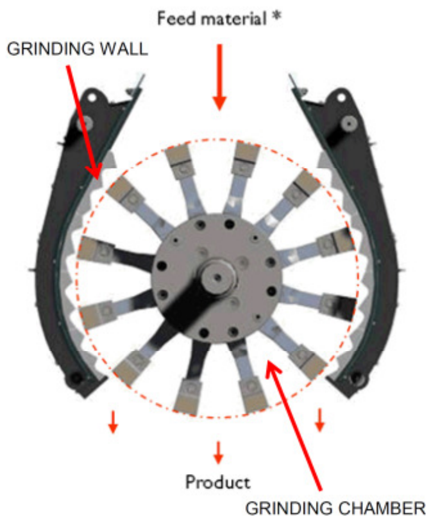

Figure 5: Cross section of a hammer mill; made available by SANDVIK MINING

Every coal has its own crushing properties and its own optimum grain size depending mainly on the hardness of the coal, but also on the melting properties, volatile matter content and many others, which should be considered individually in order to achieve a good overall result.

Adjustment of coal bulk density

There are several ways to adjust the bulk density of a coal blend.

Oil addition

It is possible to adjust the bulk density of the coal by addition of oil in relatively small amounts of 0.1% to 0.5%. This shows positive effects as described in the research papers of LUX et al. [3] and Poultney [4]. In cases of adding oil to compensate the reduction of the bulk density due to increasing percentage of particles smaller than 0.5mm, it was found that the gas pressure of the coal did not increase simultaneously. In cases of constant particle size distribution, the gas pressure of the coal was even slightly decreasing because of the addition of oil. Furthermore a better flow characteristic inside of the chamber during charging could be confirmed in many test runs by coke oven battery operators. Therefore a more even coal distribution inside the chamber with a constant coal line could be achieved and a reduction of carry-over was observed.

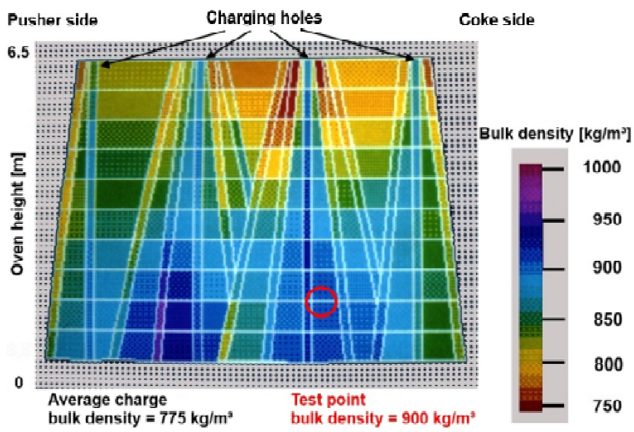

Figure 6: Distribution of bulk density in a gravity charged coke oven [5]

This leads to less spillage coal and uniform carbonization of the coal over the entire coke oven chamber. Moreover, also the heat consumption will be optimized and overheating of the gas collecting space above the coal can be avoided. This reduces the building of carbon from cracking reactions which takes place at temperatures above 850°C.

Moisture content

The moisture content has a direct influence on the bulk density of the coal blend, as shown in fig.7.
There is a minimum bulk density at a moisture content of around 8% to 9% for a grain size range from 0mm to 10mm.

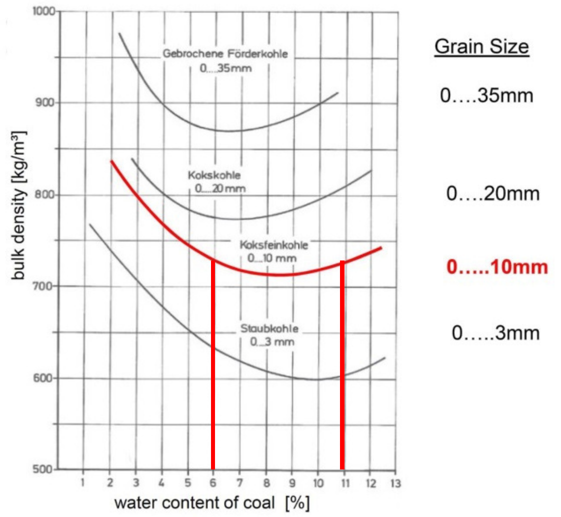

Figure 7: Bulk density in relation to the water content of coal [6]

From fig.8 it is obvious that the bulk density of the coal blend should be kept below 800kg/m^3 (d.b.) in order to achieve an acceptably low wall pressure.

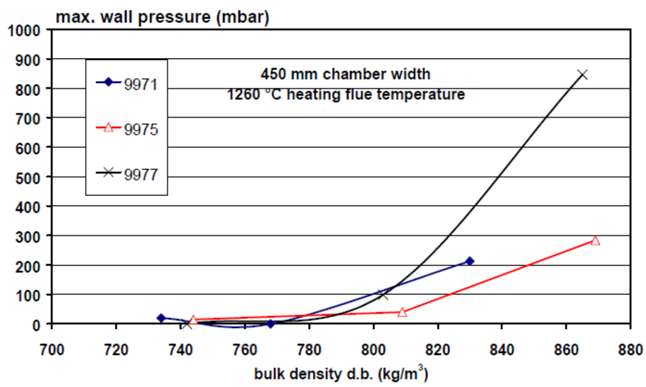

Figure 8: Influence of bulk density on maximum wall pressure at a constant grain size distribution and at 450 mm chamber width [2]

Therefore, the moisture of the coal blend should be kept within a range of 6% to 11% (fig.7 & fig.8)

From many references like LUX et al. [3] and Poultney [4] it is confirmed, additionally, that moisture contents between 6% and 9% are the most successful to ensure low wall pressures.

Grain size distribution

As derived from fig.7, fine crushing of the coal blend increases voids and reduces the bulk density. On the other hand, large lumps of coal increase the bulk density. Both extremes cause a reduction of the coke quality and yield, as already described under the topic "Coal crushing" above.

Typical plant concept

A Typical coal handling plant concept, very commonly used in the world, is the blend crushing or so-called "brutal milling" of the coking coal, as shown in fig.9.

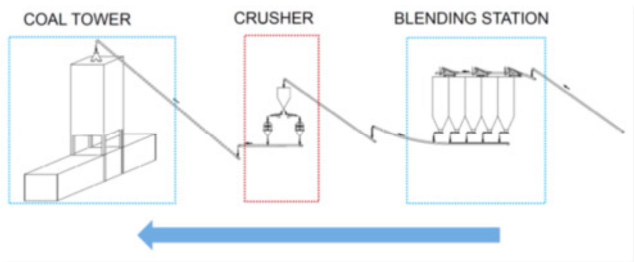

Figure 9: Blend crushing or "brutal milling" concept

The different coal types from the yard are transported directly to the blending station and stored in individual bunkers. The storage capacity of the blending station generally allows for a high mass flow, usually between 1,000t/h to 1,500t/h.

After blending, the coal mixture is transported by belt conveyors to the crusher station with a reduced mass flow depending on the capacity of the crushers, which is usually between 200t/h up to 600t/h. During the crushing process, the entire amount of coal is crushed all together and is mixed by the same process step. The crusher settings are modified with every variation of the coal mixture. The measuring of the moisture content of the coal takes place upstream, at the end of the belt conveyor to the coal tower.

In this concept, the adjustment of the coal crusher has to be set in relation to the coal type with the highest hardness in order to achieve a grain size of 80% to 90% below 3.14mm. In consequence, hard coals with a tendency of producing high gas pressure are not ground sufficiently while soft coals are ground to an extremely fine grain size. Due to the large content of fine particles produced by this method the particle size obtained is very far away from the ideal grain size distribution, which reduces the bulk density in the coke ovens, resulting in a lower productivity and coke quality. Further, by the significant increase of the fraction below 0.2mm, the specific surface of the coal blend is increased significantly, which strongly reduces the caking ability of the coal blend.

Usually the range of grain sizes of a blend of uncrushed coal types is varying more than the grain size of a single coal type. This is increasing the difficulty to adjust the crusher settings and to avoid a fluctuation of the grain size distribution as well as of the bulk density of the crushed coal, which shall remain constant. A fluctuation of coal blend properties results in inconsistent coking conditions, thus effecting the coke quality in a negative way.

Selective crushing plant concept

The basic concept for selective crushing of the coal is shown in fig.10. It comprises of the surge bin, crushing station, blending station, coal mixer and routes the coal up to the coal tower at the coke oven batteries.

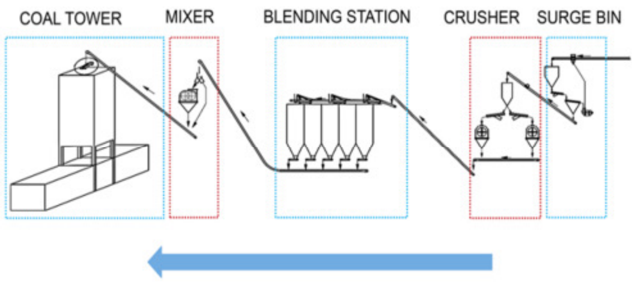

Figure 10: Selective crushing concept

The coal is transported by belt conveyors from the coal storage yard to the surge bin, which buffers the high mass flow from the coal yard against the reduced mass flow to the crushing station.

At the crushing station, the coals are crushed type by type with individual crusher settings. After the crushing process, the crushed coal is transported to the blending station. Each coal type is stored in a separate blending bin. Adapted to the number of coal types and their percentage relative to the coal blend composition, different amounts and sizes of bins are designed. Downstream of the blending bins, the different types of coal are fed to the outgoing conveyor by belt weighing feeders. From the blending station, the coal is transported to the mixer. Additives, like oil, water and coke dust, are fed to the coal in the upstream transfer chute before the mixer. In the mixer, the coal blend is homogenized. After the mixing process, the coal is fed to the coal tower. The moisture measuring of the coal takes place upstream at the end of the belt conveyor to the coal tower.

In this concept, the adjustment of the coal crusher is changed automatically following pre-settings for every coal type. This provides the possibility, to obtain the optimum grain size of every single coal type in consideration of the coal blend composition and to react on changing coal properties at any time. For example, coal types with minor baking abilities are crushed to a larger average grain size to ensure a lower specific surface. Soft coking coals with a large amount of inerts can be ground to a lower average grain size in relation to the coal blending composition. The coal blend is more homogenized than in case of blend crushing. The inerts as well as the reactive contents of the coals are uniformly distributed in the coal mixture and not concentrated in certain grain fractions. This results in less fragile spots in the coke and avoids differences in terms of shrinkage by inhomogeneously distributed inerts.

Pre-screening before crushers

An additional and recommendable process step is the pre-screening of coal before it is routed to the coal crushing station. Most raw coal types contain 30% to 50% of a grain size < 3mm, which does not need to be crushed further. Removing that grain size from the coal before the crusher has the positive effect that the capacity of the crushers can be reduced considerably. Further, the portion of fine particles can be controlled more effectively.

The separation of the fine coal can be effected by pneumatic classifiers or by flip-flop screens. The additional investment for this equipment is partly compensated by the reduction of the capacity of the coal crushers.

By the reduction of fine particles, the average grain size of the coal blend is reduced effectively, increasing the bulk density with a positive effect on the coke oven productivity. Further, the baking properties of the coal blend are enhanced by reducing the specific surface. This allows the use of a higher percentage of low-grade coking coals in the blend.

Coal drying

Especially in Asian coking plants drying of the coal to a constant moisture level is a common feature of coal treatment plants, known as coal moisture control plants (CMCP). The constant moisture level provides for a stable operation of the coke oven batteries. The drying is done by means of rotating tube dryers or fluidized bed dryers and arranged behind the blending station.

Another favorable, but not yet realized option, is the combination of pneumatic classifiers for removal of the coal fines and drying of the coal by the air stream in front of the crusher station. Such a system would combine the advantages of pre-screening and pre-drying in one process station. The basic equipment required for such process is available on the market, but its combined application was not yet adopted practically in coal treatment plants.

Recommendations

- Selective crushing of each individual coal grade provides control of the grain size distribution.
- In case of harder coking coals, caused by high fraction of Durit, a coarse grinding is suggested, producing a high mechanical strength.
- In case of harder coking coals linked with high swelling indexes, fine crushing is required.
- In case of softer coals, fine crushing is recommended.
- However, a particle size of less than 0.1mm results in graphite deposits on the chamber walls within the gas collecting space. Further, it is asso-

ciated with unwanted carry-over effects in the by-product plant.

- In case, the fraction of fine grain is >40%, oiling of the charge (0.1% - 0.5%) is advisable.
- Removal of fine particles from the coal before crushing is of advantage for improvement of coke quality.
- Drying of the coal to a constant moisture level provides for constant operation conditions of the coke ovens.
- Combination of pneumatic classifying and drying of the coal before crushing may be an effective option.

Conclusions

As the cost for the coal is largely influencing the coke price in a range of up to 80%, it is most economical to invest in a well-conceived coal preparation plant. The return of investment for an appropriate engineering and high quality equipment will be realized in a very short time as it allows for the use of extended quantities of low-grade coking coals, results in an improvement of the coke quality and extends the lifetime of the coke oven batteries significantly.

Abbreviations

avg.	average
d.b.	dry base
Eq.	equation
Fig.	figure
VM	volatile matter
CSR	coke strength after reaction
CRI	coke reactivity index

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