Doosan Lentjes

Application of Doosan Lentjes' CFB Technology to Discard Coals

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Abstract

The CFB boiler technology has been especially developed to cope with the challenging combustion properties of low quality, low calorific fuels ensuring efficient combustion control. Such fuels with high moisture and/ or high ash content often demonstrate characteristics like low reactivity, low ash fusion temperatures, high abrasiveness, as well as being particularly challenging of the mechanical handling equipment and concepts.
South Africa is a country with huge coal reserves but nevertheless are limited and usage should be maximised for efficiency. In the past, lower quality coals not suitable for application at that time for PC firing or for the gasification process utilized in SA (Fischer Tropsch – Sasol process) have been dumped in huge quantities. Today, these dumps represent a remarkable reservoir of valuable fuel, especially for power and heat production.
The large variety of coals in the available dumps and their specific characteristics needs to be taken into consideration when designing a concept for a proper combustion process.

This paper will describe the Doosan Lentjes' advanced modularized CFB Technology and its application to discard coals, showing on examples the variation of properties and their impact on the CFB process.

Introduction into Discard Coal

Discard Coals are residues resulting from raw coal treatment, identified as having no value or unusable in the processes of the day.
They arise as:

- Tailings – more or less coarse coal from washing
- Slurry- fines from washing process
- Fines from screening.

In South Africa, raw coals have been treated/ washed in the past to get:

- high calorific coal fractions for export
- a middle calorific quality for internal use for power and heat production , LHV- approx. 18- 30 MJ/kg

Lower calorific coals have been dumped as discard coals.

This has changed nowadays. Washing and sorting have been optimized to higher efficiencies, so that the resulting discard coals to be dumped are of calorific values often lower than approx. 5-6 MJ/kg. This paper hence will concentrate on the older discard coals to be found on dumps.

Dumps can either be found as:

- covered dumps, which means the dumps have been, after closing of their operation, mechanically brought into a stable form and then covered with soil to avoid pollution to the environment; dust, leaching, risk of fires etc. For many of these dumps the government respectively the responsible municipalities have taken over responsibility.
- uncovered dumps. These dumps may be still in operation or already closed. Those dumps which still are in operation belong to mining companies utilising them.

Much has been published about about available discard coals- from the government [1], [2] as well as from mining companies.

Discard Coals from Dumps in Mpumalanga

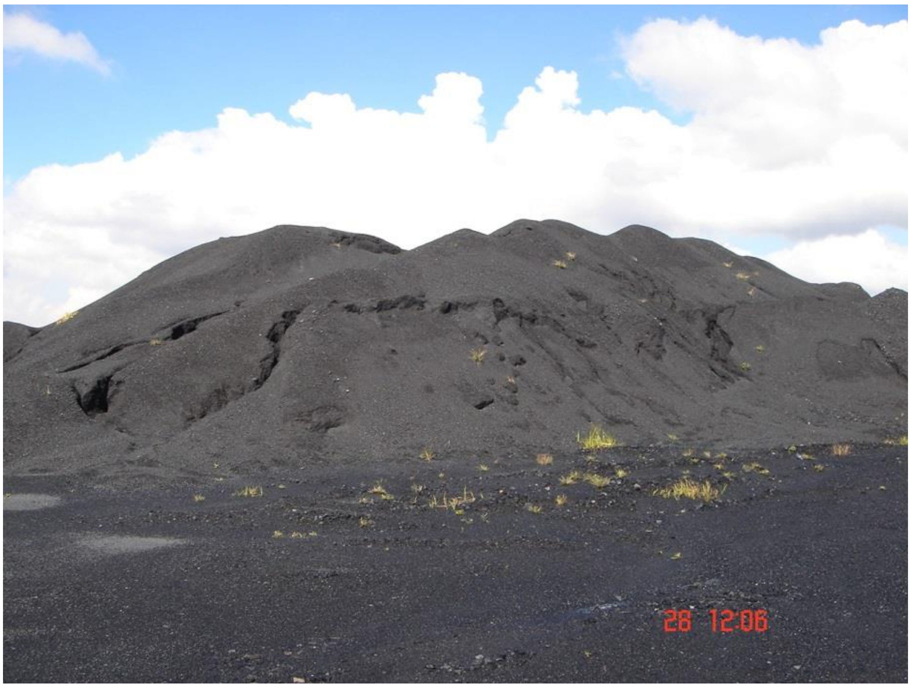
The Mpumalanga area- the province located east of Johannesburg and Gauteng province- is used here as an example to demonstrate available and valuable dumped discard coals.

Most of the mining locations in Mpumalanga are opencast mines, the other being deep mining. The residues from coal treatment have often been back-filled into the mining pits. This applies especially to older closed dumps therefore they may have a remarkable depth. A summary of information about coal mines in South Africa is given in [1].

Area of Kendal – Ogies

Kendal is a central, already historically used area of coal mining west of Ogies, south west of Witbank. Dumps, covered and uncovered, can be found near Bankfontein. The uncovered dumps are still in operation. Examples of covered and uncovered dumps are given below with pictures 1 and 2. Additionally a slurry dump is shown in picture 3.

Picture 1 Covered Dump in Kendal



Picture 2 Uncovered dump in Kendal, partly still in operation

Picture 3 Slurry dump, adjacent to a coarse discard coal dump

Qualities of Discard Coals

Examples of the discard coals to be found in the Kendal area are given in Table 1 with their analysis. The samples have been taken from uncovered dumps.

Table 1 Analysis of Discard Coals from the Kendal area

Coal Analysis Kendal Dumps						
		Sample 1	**Sample 2a**	**Sample 2b**	**Sample 2c**	**Sample 3**
Components	**Unit**	**a.r.***	**a.r.**	**a.r.**	**a.r.**	**a.r.**
Carbon	wt%	44,3	38,4	42,6	38,2	44,8
Hydrogen	wt%	2,3	2,2	2,4	2,2	2,4
Oxygen	wt%	4,2	7,7	7,6	7,3	8,1
Nitrogen	wt%	1,1	0,9	1,0	0,9	1,1
Total Sulphur	wt%	3,8	0,4	1,1	0,4	0,5
Moisture	wt%	5,8	14,2	11,6	14,9	27,5
Ash	wt%	38,5	36,1	33,7	36,1	15,6
Chlorine	wt%	0,0	0,0	0,0	0,0	0,0
HHV	kJ/kg	17006,1	14297,7	16048,0	14142,1	17303,1
LHV	kJ/kg	16361,2	13475,6	15250,2	13306,2	16106,6
Volatile	wt%	18,8	17,2	18,0	17,4	19,4

*a.r. = as received

The discard coals originate from bituminous coal and show relatively high calorific values, between 13 to16 MJ/kg (LHV, a.r.). The ash content at 33-38% is rather high.

Sample 3 is a discard coal originating from a slurry dump and shows a relatively low ash content of 15 wt%, but higher moisture content than the coarse discards.
Remarkable is the high range of sulphur but it has to be pointed out, that this is only true for the total S; it gives no information about the content of combustible S.

Table 2 provides the ash composition that result from the combustion of these discards.

Table 2 Ash composition of Discard Coals corresponding to Table 1

Ash Composition						
Components	**Unit**	**Sample 1**	**Sample 2a**	**Sample 2b**	**Sample 2c**	**Sample 3**
Na_2O	wt%	0,08	0,06	0,06	0,08	0,07
K_2O	wt%	0,3	0,5	0,5	0,6	0,5
CaO	wt%	6,3	2,4	3,6	3,6	3,5
MgO	wt%	0,63	0,22	0,33	0,24	0,51
Fe_2O_3	wt%	12,01	1,84	4,55	1,98	19,09
SiO_2	wt%	60,1	76,5	69,1	69,3	56,9
Al_2O_3	wt%	13,84	17,44	19,68	22,92	18,15
P_2O_5	wt%	0,51	0,44	0,42	0,38	0,48
SO_3	wt%	5,83	0,51	1,48	0,51	0,32

The corresponding ash composition of sample 3 shows a high content of inorganic S (given here as SO_3. This means that approx. 25% of the total S is inorganic, not combustible S. Inorganic sulphur occurs in form of sulphates, combustible sulphur is organic in nature or associated with pyrite (FeS_2). Both organic and pyritic S will be converted during combustion into SO_2 and hence be responsible for SO_2 emission to the atmosphere, if not limited by design measures.

Discard coals samples taken from dumps 1 and 2 show a rather broad range of particle sizes from fine (< 1 mm) to approx. 200 mm; the majority could be found between approx. 30- 80 mm (see Diagram 1), quite seriously varying from sample point to sample point.

Discard coals originating from slurry dumps are much finer (see Diagram 2); nearly 95% of the coal shows particle sizes smaller than 1 mm. This fact needs to be taken into consideration when designing proper combustion concepts. Since the ash content is significantly lower than that of the coarse discards, the calorific value of the slurry coal on dry basis is comparatively higher. The final calorific value is hence affected strongly by the moisture content.

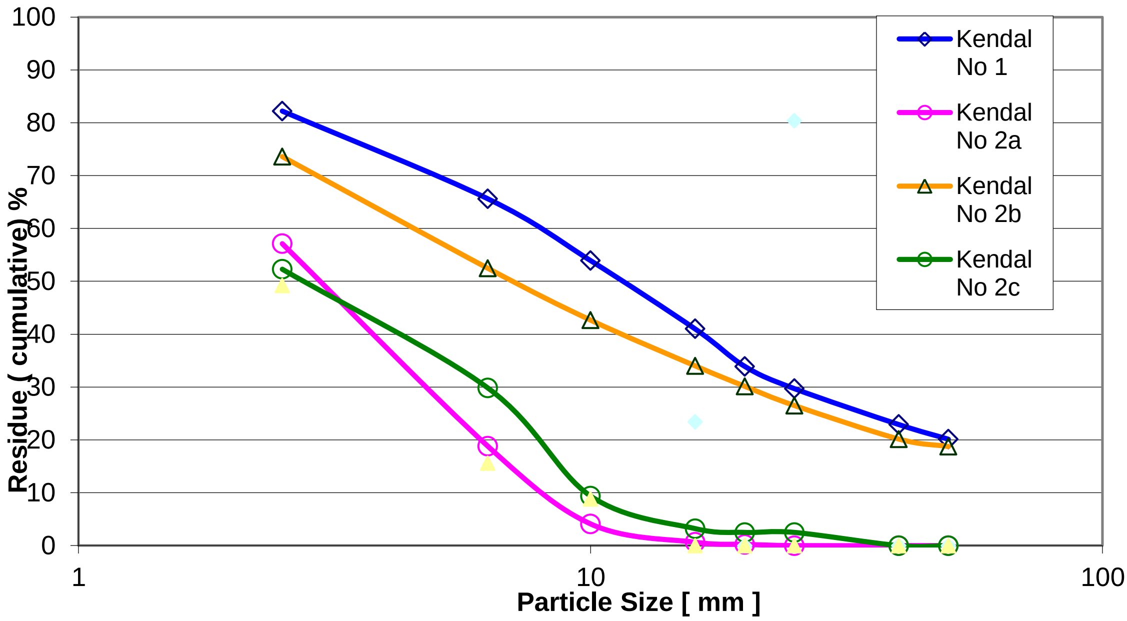


Diagram 1 Typical Particle size distribution for coarse discard coals

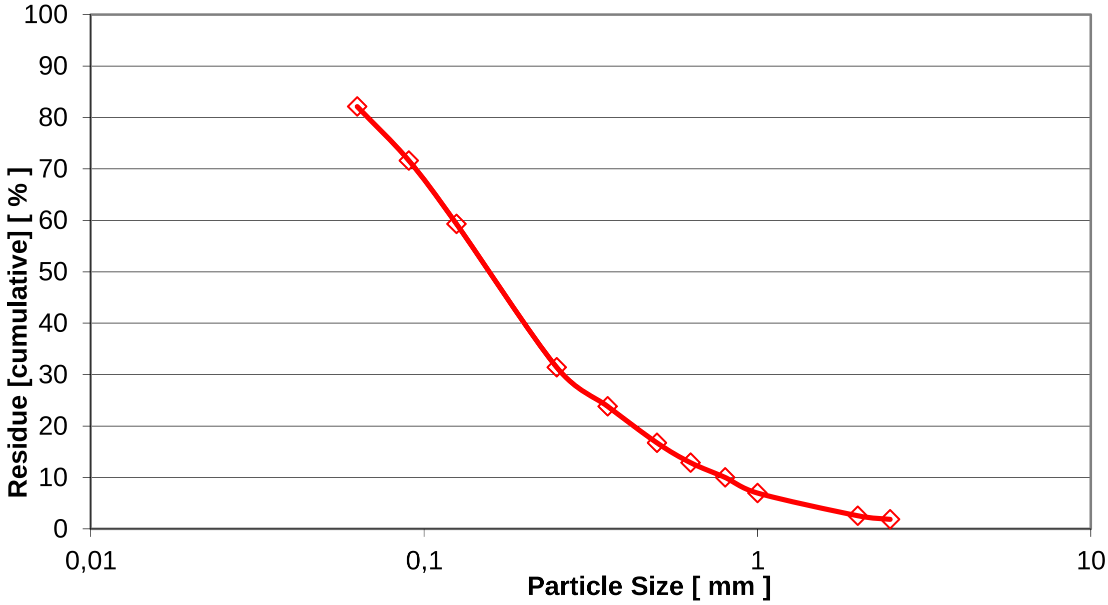


Diagram 2 Typical particle size distributions for coals from slurry dump samples.

The quality of the coals given here as example, fits quite well with the National Inventory Discard and Duff Coal- 2001 Summary report given by DME [2]. There are other sources

available showing qualities down to approx. 10 MJ/kg due to higher ash contents up to approx. 50%.
According to the DME report, more than approx. 90% of the discard coals on dumps in South Africa should have calorific values Hu > 11 MJ/kg and more than 50% >14 MJ/kg. The sulphur content of the coals is described with a wide range of up to 5 %. As already mentioned, care should be taken here, as the S content is mostly given as total S and does not differentiate between combustible and non-combustible S.

The discard coals in Mpumalanga as descroibed here are bituminous coals, but Anthracites are available in the east as well. In total, more than 1 billion tons of discard coals are estimated as being available on dumps, disregarding the discard coals resulting from ongoing operations of coal treatment.

Specifics about dumped Discard Coals and treatment requirements

Dumped discard coals demonstrate the following characteristics:

- Low to middle calorific values
- High ash contents
- Low volatile matter for coals originating from bituminous coal mines
- Even lower volatile matter for coals originating from Anthracite mines
- Wide range of S content- which may , but need not be, due to respective content of combustible S

Additionally, it has to be taken into consideration that the discard coals have been dumped outside after washing and screening, thereby being exposed to the oxygen of the atmosphere. This has caused oxidation reactions at the surface of each coal particle, resulting in a surface which is inactivated to ignition and combustion. This is termed “weathering of coals” and has been extensively reported upon for its effects [3]. Whilst such weathering does not necessarily significantly affect coarse particles(because by final crushing new, active surfaces will be formed), it may seriously reduce the reactivity of smaller particles.
Such specifics hence result in:

- lower combustion reactivity with the necessity for
  - higher ignition temperature and
  - higher residence time for coal particles to be combusted
- high quantities of ash and
- the requirement for a highly flexible combustion process accepting coals with wide range in composition (e.g. S, ash) and calorific range.

Principal features of the CFB Technology

A proper combustion process has to take all of these characteristics into consideration and additionally has to offer flexibility to the variation of such characteristics, because discard coal, provided from a dump, is not a homogeneous product and may vary significantly over the dump site.

Only the CFB combustion process (see Picture 4) offers such features, mainly:

- Increased residence time at homogeneously mixed conditions and controlled optimum combustion conditions and temperature
- Applicability for a wide range of fuels especially for lower grade solid fuels
- Due to in-situ desulphurization with the help of limestone and controlled, staged combustion, the present day emission limits for SO_2 and NO_x can in most cases be met without the need of external emission reduction equipment.

Features of Doosan Lentjes CFB Technology

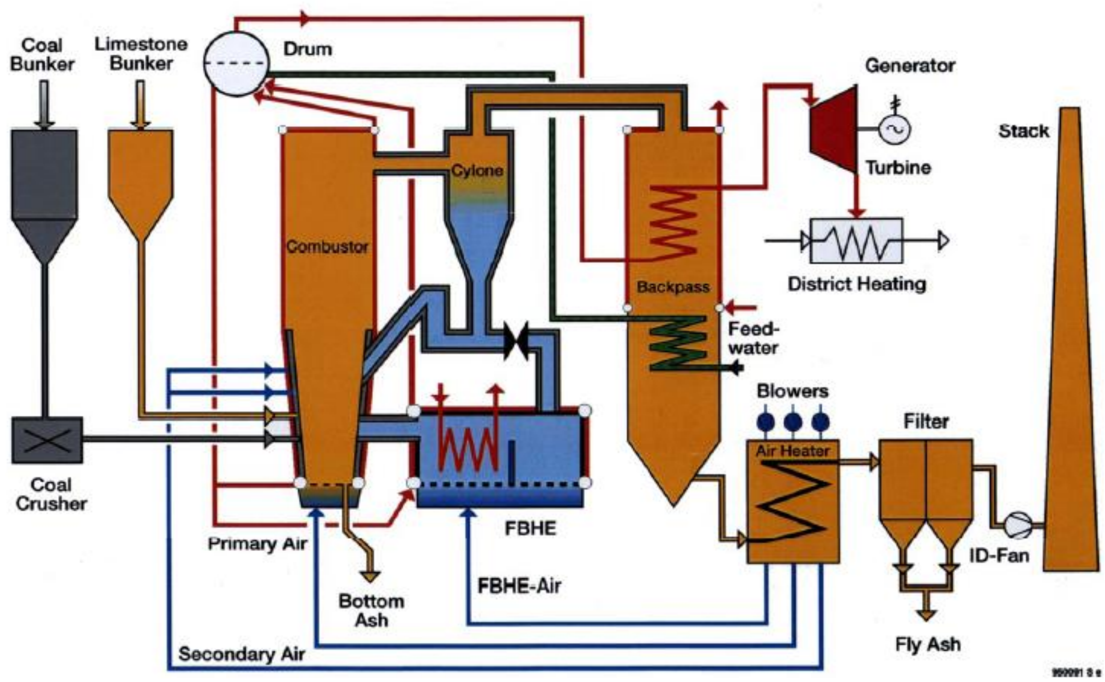
Additional to these features the Doosan Lentjes CFB Technology makes use of fluidised bed heat exchangers (FBHE) as part of the boiler. Such FBHEs are used to cool hot ash extracted from ash circulating from combustor via a cyclone back to combustor (see picture 4). Since the FBHEs are integrated into the boiler cycle the extracted heat is utilized to evaporate feed water, superheat final steam as well as reheat steam.

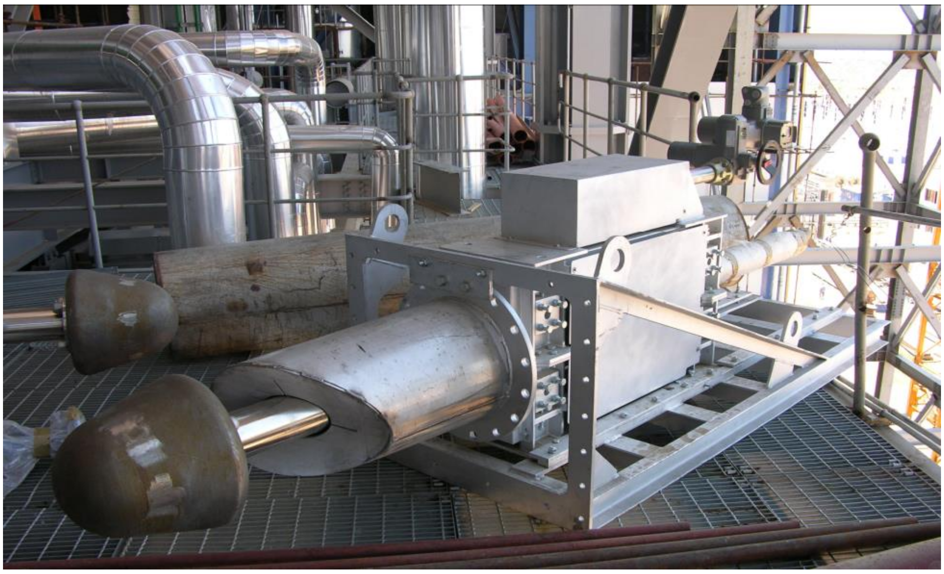
After cooling the ash is transferred to the combustor where it is rapidly mixed with the hot ash in the combustor, thus reducing/ moderating the combustor temperature. With the help of a so called “Spiess Valve” (a kind of “oversized” needle valve), the extraction of hot ash can be controlled between 0- 100% flow allowing optimum control of the combustion temperature even under variation of the fuel quality, load range and adjustment of the boiler capacity (see Picture 5).

The FBHE is an important feature of the Doosan Lentjes’ CFB Boiler Technology offering following advantages:

- Constant combustion temperature at optimum level, even over a wide load range, resulting in
  - Suppression of thermal NO_x formation
  - Minimising limestone consumption for desulphurization
  - Achieving good carbon burn-out performance over the full load range
  - Avoidance of sintering and agglomeration or even melting of ash at low fusion temperatures
- High fuel flexibility, i.e. use of a wide range of fuels in individual CFB boilers while showing all features mentioned above
- High efficient heat transfer in a none corrosive atmosphere
- Varying fuel qualities during boiler operation
- Opportunity to place high temperature super heater surfaces into the FBHE rather than into a corrosive flue gas atmosphere in cases of chlorine containing fuels, thus reducing the risk of high temperature chlorine corrosion from chlorine containing fuels.

Picture 4 Doosan Lentjes' CFB Combustion Flow Diagram

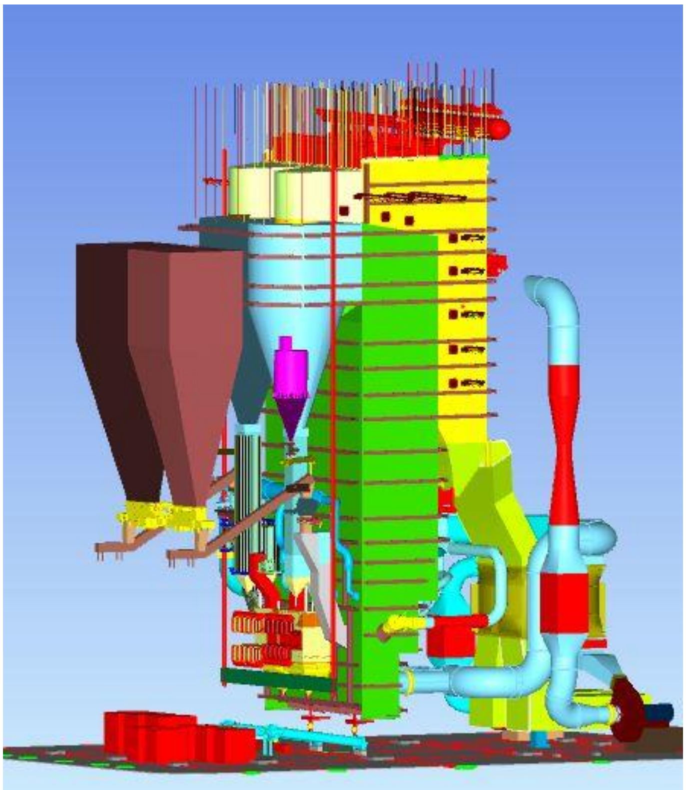




Picture 5 Spiess Valve for FBHE control

Application Range of Doosan Lentjes' CFB Concepts

Over the years Doosan Lentjes has successfully optimised its design to a modern modularized, highly compact design, based on 2 and 4 cyclone concepts (see pictures 6 and 7). The standardized 2 cyclone design for 150 MWe can be doubled to form a 4 cyclone concept on the same standard design platform, applicable to capacities of about 300 MWe.

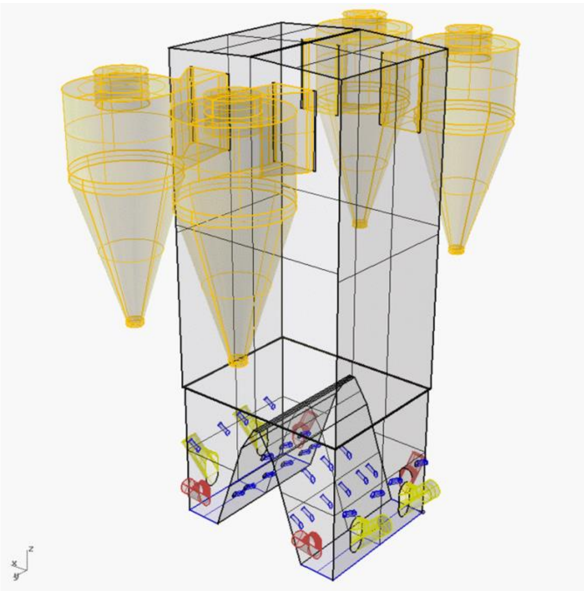


Key Aspects:

- Water cooled CFB components like cyclone, ash return, FBHE casing, integrated into the boiler
- No expansion joints
- Common walls
- Reduced refractory
- Compact arrangement
- Modular arrangement and parametric design
- Designed for 150 MWe
- To be extended to 4 Cyclone concept with capacities above 300 MWe

Picture 6, 2 Cyclone, standardized compact design

For low calorific coals, especially high ash and/or high moisture coals, a 4 Cyclone concept based on a so called pant leg design combustor is available, taking into account high fuel and ash flows as well as high flue gas flow. This concept has been applied very successfully for CFB boilers up to 250 MWe.



Key Aspects:

- Compact design with integrated FBHEs
- Hot or cooled Cyclone design applicable
- Common walls
- Reduced refractory
- Compact arrangement
- Fluidized bed ash coolers

Picture 7, 4 Cyclone "pant leg" based compact design

Doosan Lentjes now have 1, 2, and 4 Cyclone Concepts available, which allow optimal application to required project specific conditions and corresponding capacity, as is shown in Diagram 3.

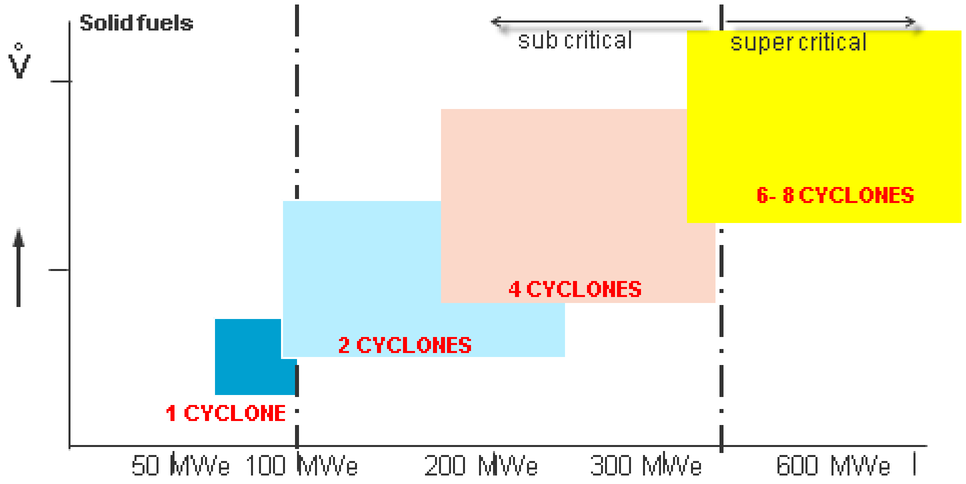


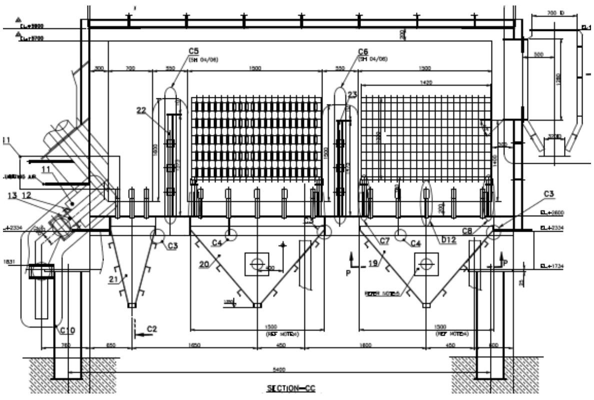
Diagram 3 CFB Application Range

The decision for the right module type is dependent on the steam capacity and is principally influenced by the volumetric flue gas flow, taking into consideration the limited flue gas velocities in the combustor and the required diameter of the cyclone, which is usually limited to approx. 9- 9.5m. The specific nominal volumetric flue gas flow resulting from fuel combustion, will be governed by the calorific value and rather strongly by the moisture content of the fuel and not to forget the atmospheric pressure, which decreases with increasing elevation above sea level. The nominal flue gas flow at a site elevation of 1600 m like in Mpumalanga e.g. some 22% higher than at sea level.

Bed Ash Cooling Systems

Another parameter influencing the concept of a CFB boiler is the ash content of the coal. Bed ash will be discharged usually from CFB combustors at about 850 °C and has to be cooled down to some 150°C to allow further treatment. The cooling will usually be done utilizing a cooling water system in heat exchange against the atmosphere- that means the extracted heat is lost.

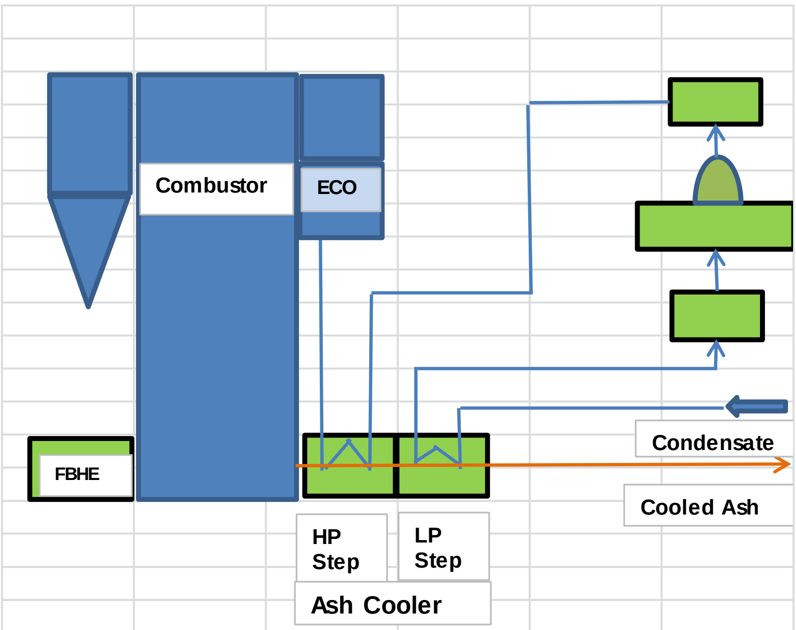
For coals with low ash content, simple cooling ash screws are utilised. They are applicable for approx. 5-7 t/h ash per screw. For higher capacities, fluidized bed ash coolers conforming to Doosan Lentjes' design are applicable- they are available up to approx.40 t/h ash (see Picture 8).



Picture 8 Fluidized Bed Ash Cooler

In comparison to screw coolers or drum type coolers the fluidized bed ash cooling system can be designed for high pressure cooling water application and allow therefore integration into the preheating of condensate and feed water circuits of the steam and water cycle, thereby enhancing the overall power production efficiency. Such fluidized bed ash coolers are of similar design as the fluidized bed heat exchangers

The principle sketch in Picture 9 shows one integration possibility of ash coolers into the steam water cycle. The fluidized bed ash cooler will usually be designed with two heat exchanger bundles. The second bundle has to ensure final cooling of the ash to approx. 150°C and hence has to be cooled by low temperature water, for which low pressure condensate from the condenser is applicable or normal cooling water. Within the first bundle the ash has to be cooled from the outlet temperature of approx. 850°C to approx. 400°C. High pressure feed water down stream of the final feed water pre-heater still has a suitable temperature level to allow applicability as cooling medium whereby it will be heated up to the required entrance temperature into the economizer.
Since the ash flow from the combustor fluctuates with load and calorific value of the coal, the cooling system has to be designed properly to control the final feed water temperature in spite of this ash flow fluctuation.



Picture 9 Integration of fluidized bed ash cooler into the steam water cycle

Summary

Doosan Lentjes CFB Technology is well suited for application in the combustion and utilization of such difficult fuels as Discard Coals. This is directly applicable to the South African market and its adoption will realize the massive opportunity for power and heat production utilising the enormous waste dump reservoirs of discard coal [4].
To properly design a CFB boiler to the requirements of each application, it is important to analyse and understand the specific characteristics of the fuel. A proper analysis of the fuel is essential, giving the Proximate and Ultimate Analysis in full scope and over the full fuel range, preferably on the "as received basis" and establishing the Sulphur content as total sulphur as well as separately the combustible S including the pyritic S. The fusion characteristics of the fuel, preferably at reducing as well as oxidising conditions, should be well understood as well.
The specific characteristics of "weathered" coals should not be underestimated. It is highly recommendable to perform combustions tests in order to properly adjust the CFB design to such properties. Such tests can be executed at a number of well-known and experienced institutes worldwide at costs which are reasonable compared with the development costs of a power plant and costs which may arise out of poorly understood fuel characteristics.

Literature

[1] Directory D2/2009, Operating and Developing Coal Mines in the Republic of South Africa 2009, Directorate: Mineral Economics

[2] DME 2001, National Inventory Discard and Duff Coal- 2001 Summary Report. Department of Energy, Pretoria (www.energy.gov.za/Coal/coal_discard_report).

[3] N.J. Wagner, The Abnormal Condition Analysis used to characterize weathered discard coals. Science Direct, International Journal of Coal Geology 72 (2007) 177–186

[4] Hans Piechura, CFB Technologies for Combustion of Difficult Fuels, Paper presented at PowerGen Europe 2013