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The BTU Cottbus PFCBC, 2^{nd} Generation Lab-Scale-Plant Experiences and Results

Modern lignite fired power plants have a net efficiency rate up to 43 %. But higher standards for the profitability and the CO_2 reduction require efficiency rates, which are still higher. Computational simulations show that the PFCBC 2^{nd} generation, which is investigated at the BTU Cottbus, has the potential of 55 % net efficiency rate.

The concept bases on the combined cycle technology. The conversion of the lignite (moist or dried) to a gas turbine appropriated gas takes place in two steps. In the first step the lignite is gasified in a circulating fluidized bed at 16 bar and 850 °C. The generated lean gas is cleaned in a hot gas filter (HGF). In the second step the gas is totally burned in a burning chamber. The temperature is now above the ash melting point (> 1100 °C) and a combined cycle process follows.

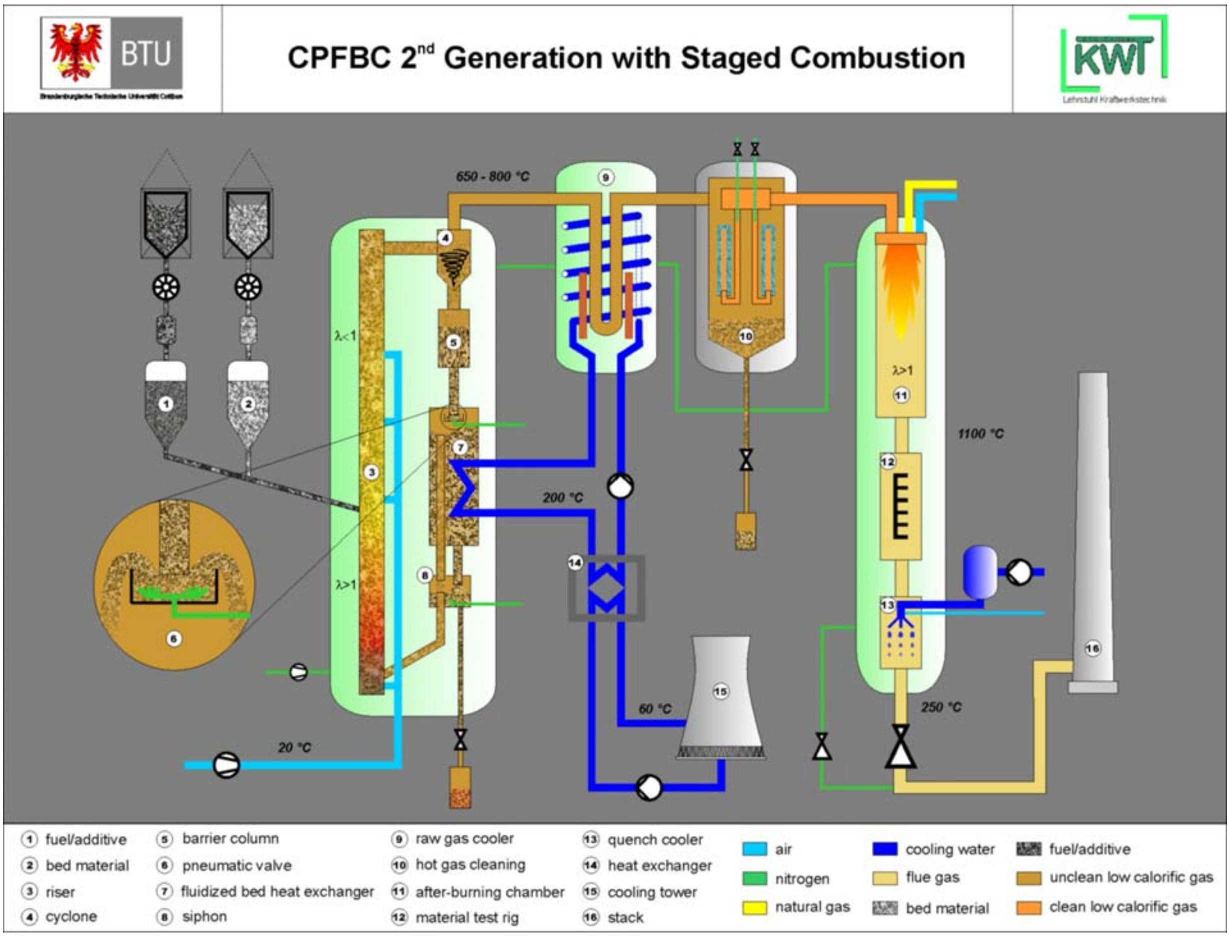

Figure 1: Flow sheet of the BTU Cottbus PCFBC laboratory-scale-plant

The BTU Cottbus operates a 200 kW_{th}- laboratory-scale facility. The plant contains nearly entire power plant equipment. There is a complete combustion part. The objective of the research program is to get the necessary design parameters for a semi-industrial power plant with PCFBC 2^{nd} generation (ca. 1 – 10 MW). The whole plant is constructed in a two-vessel-concept. The reactor, the raw-gas-cooler (RGC), the burning chamber, the material test rig and the quench cooler are embedded in pressure vessels which are rinsed by nitrogen. This nitrogen has the same pressure level as the reactor gases. This means that there is no mechanical stress for the components mentioned before. The hot gas filter is not installed yet because it is subject to further research work. The research work includes all relevant parameters of the operation management. These are especially the lean gas composition, the coal burnout, the pollutant emissions and the control of the circulation in the reactor.

The process advantages of the PCFBC-concept are the high temperatures which can be generated for the use in a gas turbine and the good coal burnout which is effectuated by the fast and strong mixing of coal and bed material in the fluidized bed. Furthermore, the in-situ-desulfurization by feeding of limestone avoids a subsequent flue gas desulfurisation desulfurization and the moderate temperature in the fluidized bed reduces the NOx-formation. As a last point has to be mentioned the broad variety of the fuel range which can be used in a fluidized bed combustion.

The main design parameters are:

electrical air heating:	50	kW
fuel input:	150	kW
ash cooling:	120	kW
max. reactor temperature:	1000	°C
max. reactor pressure:	16	bar
riser height:	6	m
reactor material:	Incoloy 800 HT	
bed material:	quartz (0.1-0.7 mm)	
fuel:	raw/dried lignite (0-6 mm)	

Figure 2: View of the BTU test facility

Fuel analysis		LTBK	LRFK	MRFK
H_2O	[%]	19	57	51.3
ash	[%]	5.5	2.5	6
c	[%]	51.5	27.5	30.2
h	[%]	3.5	2.2	2.6
o	[%]	19	10.2	8
n	[%]	0.7	0.3	0.3
s	[%]	<0.8	0.3	1.6
LHV	[MJ/kg]	19	8.8	10.8

LTBK = Lausitz dried lignite (0-6 mm)
LRFK = Lausitz raw lignite (0-6 mm)
MRFK = Central German raw lignite (0-6 mm)

Table 1: Fuel analysis

In march 2004 the RGC was successfully implemented in the plant. The RGC is necessary for the later installation of a HGF. This means that the concept of the PCFBC 2nd Generation as it is shown in Figure 1 is nearly completely realized. Only the HGF is missing now.
From March 2004 until the end of 2004 the investigation periods included 570 h. 296 h of the total investigation period were with lignite feeding. In 2005 (until end of April) there were 265 h of hot operation, 165 with lignite feeding. Due to the continuous operating system it has

to be ensured that there are at least three operating managers available for every day. Additionally one or two students per shift are supporting the investigation.

1 Experiments

In comparison with the investigations previous to the RGC implementation the operation was much more stable. This was due to the low number of external media failures (compressed air, nitrogen plant, cooling system, etc.) which provoked only one stop in 2004.
In 2005 there were 4 investigation periods until end of April. Among these was also the first experiment with raw lignite. All experiments before used dried lignite.

2 Start-up procedure

The first step in the start-up is the heating of the burning chamber to temperatures higher than 600 °C by atmospheric natural gas. Above this temperature it is changed to pressurized natural gas. Here no flame detector is needed anymore. A different method is used in the riser heating. Air heats the riser to a minimum temperature of 300 °C. For this purpose a heating coil warms the tube for the primary air on 6 m length. The advantage is that there is no need for a flame detector which would be necessary when heating with natural gas. However, this extends the heating phase significantly. As soon as the riser has reached 300 °C the last phase of the start-up is the feeding of dried lignite. This fuel already ignites at quite low temperature. All together the time for the start-up of the facility is nearly 18 h. For this reason, there has been chosen a continuous operating system for the investigation periods. One investigation campaign takes normally 5 days.

3 Results

All experiments were operated at a system pressure of 4 bar. The fuel was nearly all time Lausitz dried lignite (LTBK, see also Table 1). The air feeding was maintained in the area between 0.5 < λ < 1.1.

3.1 Temperature distribution

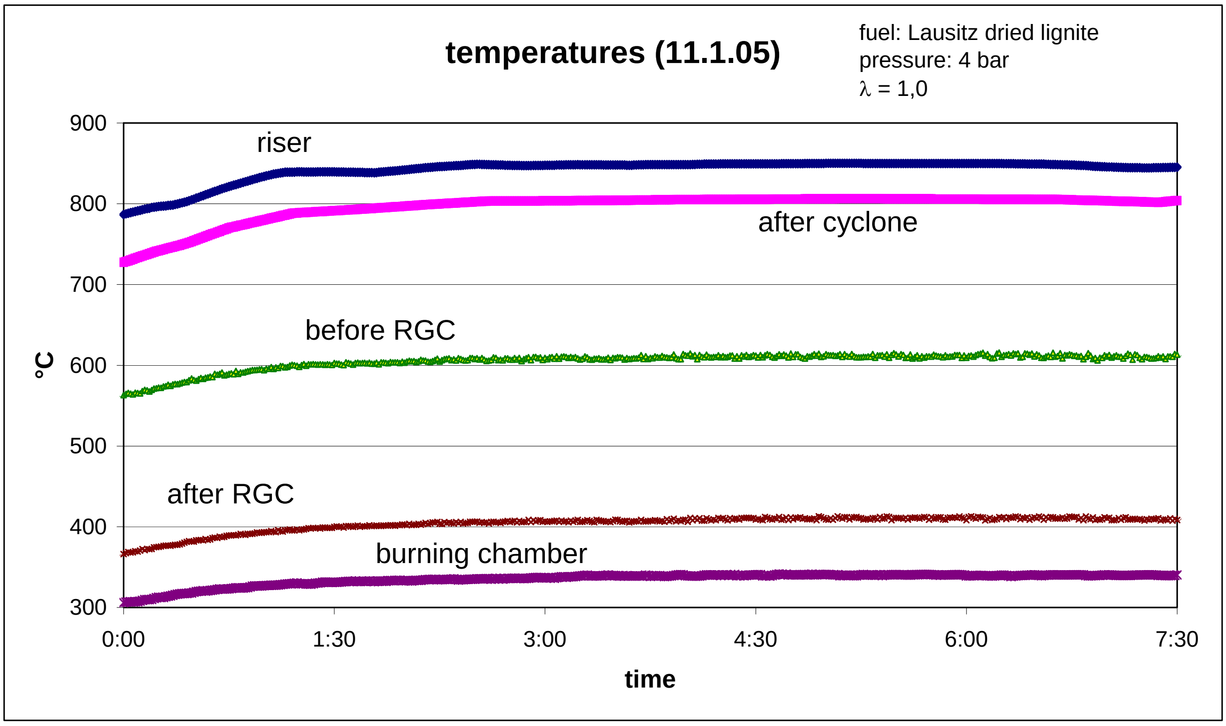

Figure 3: Flue gas temperatures along the plant components

Figure 3 shows the flue gas temperature distribution along the plant components . The figure gives an overview about the influence of the RGC on the flue gas and the heat losses. The riser temperature was held at 850 °C. Remarkably are the great differences between the riser and the RGC or between the RGC and the burning chamber. There are only 2-3 m tube between the metering points, but the gas cools down more than 100 °C. It is expected that these differences are caused by the heat losses in the plant and that a higher throughput can attenuate this effects.

3.2 Substochiometric combustion (gasification) and stochiometric combustion

Figure 4 shows the dry gas composition during the shift from λ = 0.65 to λ = 0.55. The rapid change in the concentration of CO_2, CO and H_2 is well observable. During this measurement there was a nitrogen rinse stream of 5 %. This rinsing shall avoid condensation in the fuel and bed material feeding pipes. The fluidization was done by air.

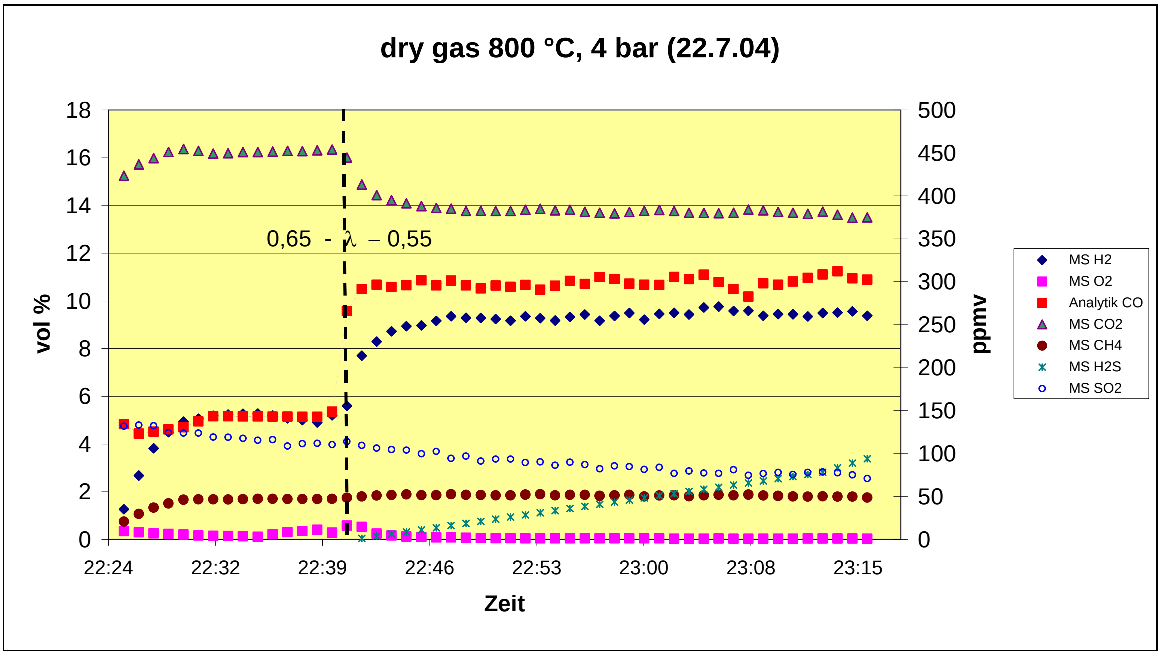

Figure 4: Dry gas composition during gasification (fuel = LTBK)

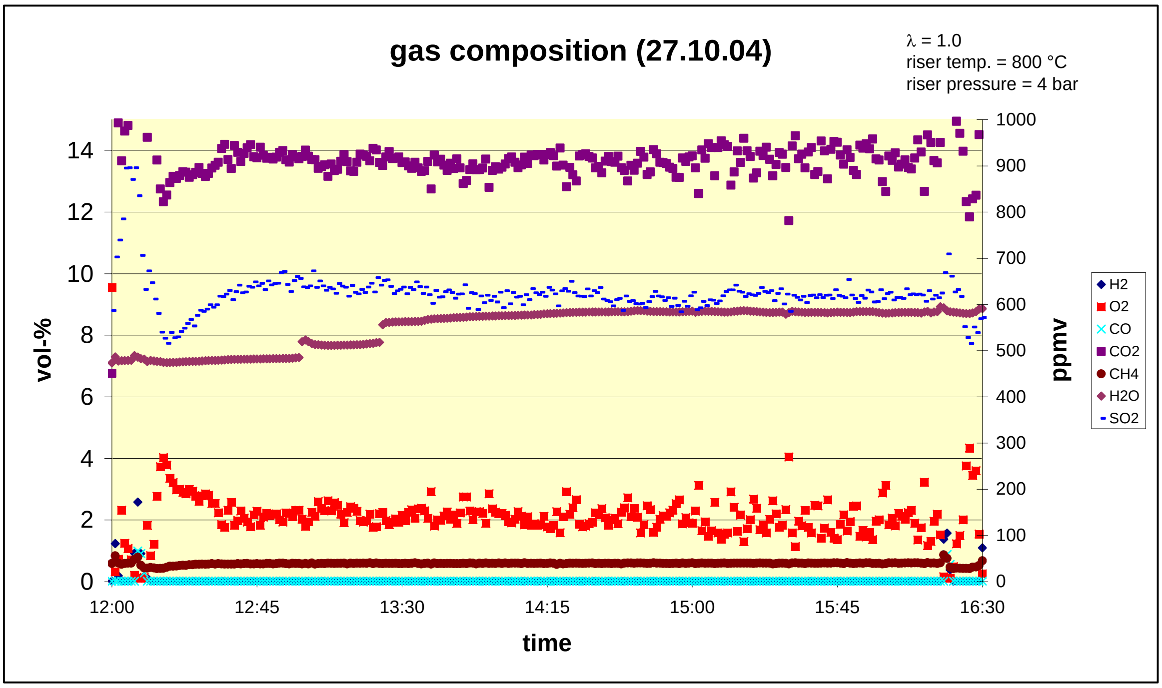

Figure 5: Gas composition at complete combustion (fuel = LTBK)

Figure 5 shows the gas analysis at complete combustion (4 bar, 800 °C) of LTBK.

3.3 Air distribution and valve fluidization

Due to the circulation control of the reactor there are many different air inputs which influence the combustion (Figure 6). The circulation of the bed material and the fuel in the reactor is controlled by L-valves. This means that there is no moved part. Only the amount of the fluidization air determines the circulation speed. The fluidization can be realized by air or by nitrogen (air with a reduced oxygen content of max. 4%). The first investigations were all made with nitrogen. There were no problems with the circulation but the dilution by nitrogen decreased the oxygen partial pressure in the reactor and cooled the riser. Therefore in 2004 the first experiments were made with air fluidization. After some time there came problems with the bed material circulation. After opening the reactor there could be found lumps of ash and also quartz. Though it was calculated before that the temperatures in the ash cooler could not provoke the formation of such lumps by burning remaining coke in the ash cooler, hot spots reached temperatures which led to quartz melting. The lumps were distributed in the whole reactor and remained in narrow locations where they constrained the circulation of the bed material (see also Figure 7). This denotes that ash cooler which is operated as a bubbling bed is not sufficiently stirred by the fluidization air. But it is not possible to increase the air amount in order to avoid the cooling down of the bed material.

Therefore, the fluidization of the ash cooler is now made again by nitrogen. The fluidization of the barrier column and the ash outlet are still made by air. In this combination there were no obstructions observed. The dilution by nitrogen is now ca. 10 % of the incoming air amount.

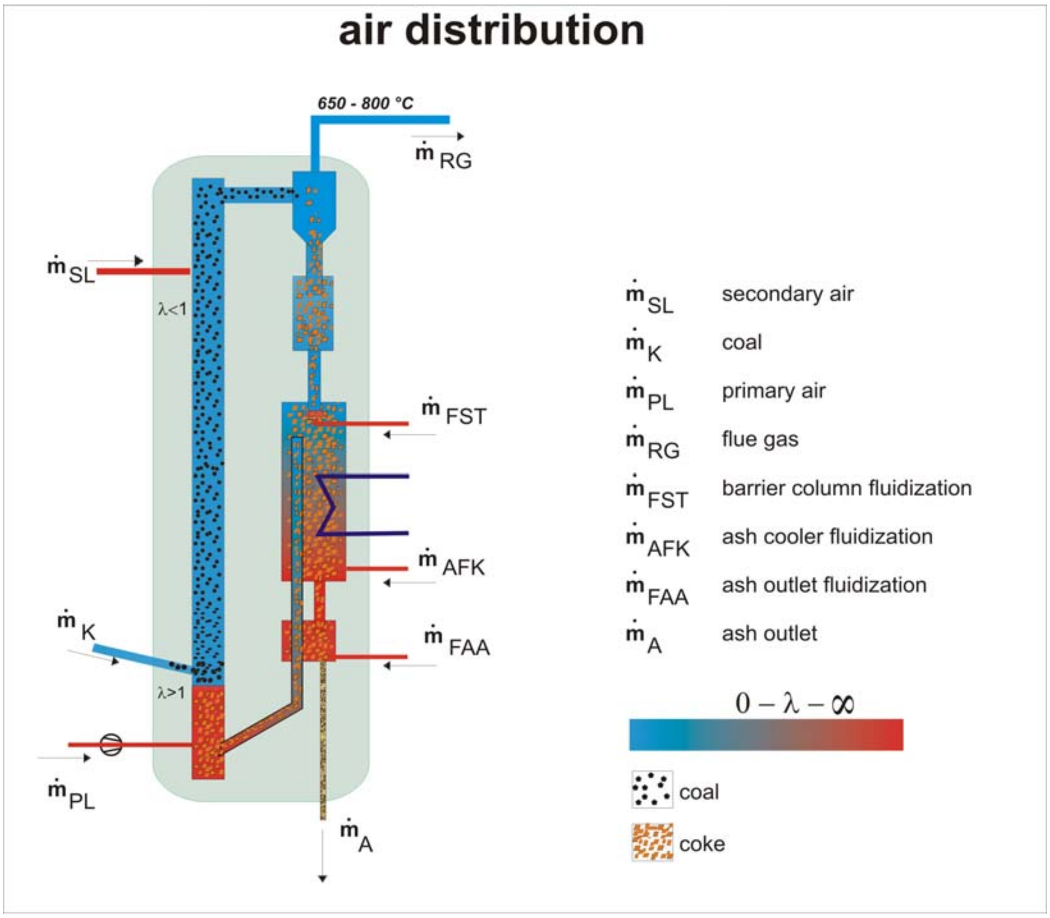

Figure 6: Air distribution

Another aspect of this staging is the formation of areas of different air excess. Beginning at the barrier column the remaining coke which is separated together with the bed material in the cyclone meets an excess of air until it mixes with the fresh lignite from the fuel feeding. This favors the conversion of the not burnt char. The secondary air feeding has still not been used.

Figure 7: Lump below the cyclone

3.4 Carbon conversion rate

One of the most important parameters of a combustion process is the carbon conversion rate. As in Figure 5 shown due to the complete combustion there should not be oxygen in the flue gas anymore, but the content is nearly 2 %. This means that 10 % of the original oxygen content has not converted and subsequently also 10 % of the fuel input. The carbon balance also showed a conversion rate of 90 %. This is still not optimal and will be improved. The unburnt carbon does not leave the reactor with the bed material ash because there is no ash to withdraw. The ash is totally carried out as flue ash. The knowledge of the exact amount of the unburnt carbon is necessary for a closed balance of the carbon conversion but at this time it is not possible to determine it. It was planned to install a particulate measurement together with the HGF which still does not exist. The content of remaining coke in the bed material is nearly 0.5 %. But this figure does not matter because there is no need to extract the bed material as described above.

4 Operation experience

4.1 Reactor material

The evaluation of the welded seams by an endoscope showed no serious damages. Figure 8 shows a part of the ash cooler where the stamping of the material is still very well identifiable. Also the welding seams of the passage from the stock vessel to the barrier column are in a quite good state.

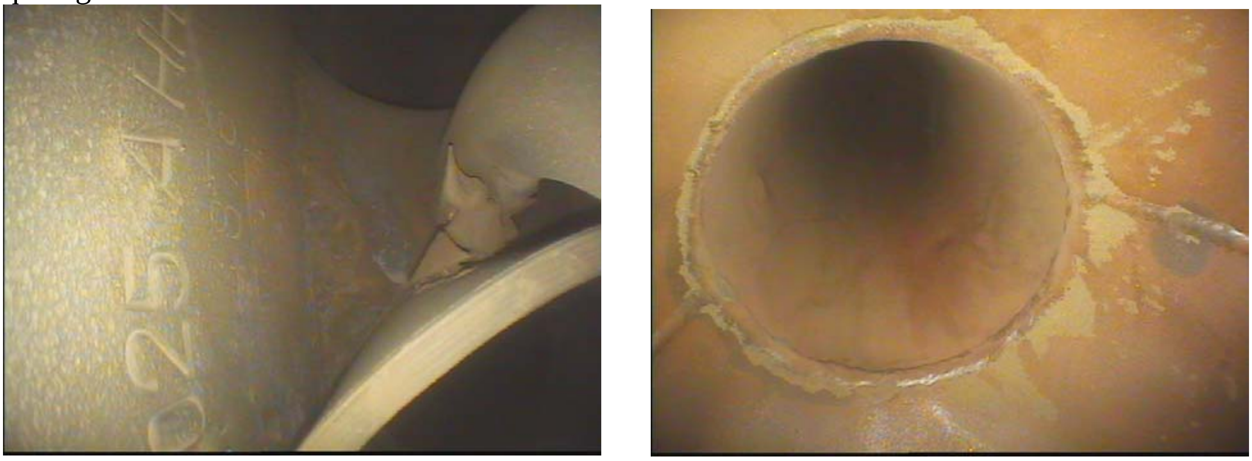

Figure 8: Ash cooler and passage from stock vessel to barrier column

4.2 Bed material circulation

The decisive parameter for the success of the previous experiments was the control of the bed material circulation. Every failure in the circulation has immediate response in all other parts of the plant. The fuel feeding stops when the pressure drop between feeding vessel and reactor exceeds 40 mbar. Thereafter the temperatures are dropping rapidly and it is quite complicated to stabilize the process. Therefore every lump proceeding by ash agglomeration in the ash cooler can end the investigation campaign when it sticks in an unfavorable place. In Figure 7 a lump hangs in the outlet of the cyclone and blocks the circulation up. These lumps are formed in the ash cooler which is a bubbling bed. The speed of the rising air is quite low and therefore in calm edges the formation of lumps takes place. These lumps can leave the cooler and are also carried up with the primary air to the cyclone where they are troublesome. The analysis of the lumps showed that they contain not only ash components but also molten quartz. The melting of quartz needs temperatures far higher than it should be possible to get them in such a reactor.

The circulation of the bed material and the controlling by the air flow shows no problems.

4.3 Burning chamber and quench cooler

In the burning chamber the lean gas is completely burned. In the quench cooler the hot flue gas is cooled down before entering the chimney. After an experiment the quench cooler has to be cleaned because due to the missing HGF condensing water and ash stick at the wall and form lumps. When these lumps fall down during the operation of the plant they will close the outlet sieve which is placed before the pressure valve. And this causes problems for the whole plant. The pressure valve itself is subject to many problems by the high flue ash content because the design was made for an ash free gas.

5 Conclusions and perspectives

In 2004 after the implementation of the RGC there were 570 h of hot operation including 296 h with lignite feeding. From January until April 2005 there 265 h of hot operation and 165 h with lignite feeding. There were investigations in sub- and superstochiometrical conditions. The bed circulation was firstly made by air fluidization instead of nitrogen. This makes the results more realistic. Nevertheless, it was observed that this operation system is still to improve due to the lump formation. Now the ash cooler is always fluidized by nitrogen and the barrier column and the ash outlet by air.

The condition of the used materials and welded seams is quite good.

In April 2005 the first experiments with raw lignite were successfully realized.

The further research program includes the variation of the pressure and the riser temperature. Different fuels depending on origin and water content are as important to test as the addition of limestone for the in-situ desulfurization.

6 Acknowledgements

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