A LAB-SCALE METHOD TO DETERMINE THE FUEL IGNITION CHARACTERISTICS IN FLUIDIZED BED REACTORS

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Abstract – The ignition temperature of coal and biomass is an important parameter for the design of the start-up procedure of fluidized bed boilers. Therefore, the current study presents an approach to investigate the ignition behavior of solid fuel particles in fluidized bed reactors.

In a first step, a batch operated bench-scale bubbling bed reactor was developed to examine the ignition of a small of amount (0.5 g) of fuel. Tests have been carried for two bituminous coals (Auguste Viktoria (AV) and US High Sulfur) a lignite (Rheinbraun), and two biomasses (pine wood and wood pellets). To prove whether the results are transferable to continuously operated reactors of larger scale, experiments with the same fuels has been carried out in a 100 kW circulating fluidized bed combustor (CFB).

The effect of the particle size (200-400, 400-630 and 1000-2240 µm) and moisture content (0.3 and 10 wt-%,raw) has been examined. As expected, ignition temperatures increase with particle size and moisture content. AV did show the highest ignition temperature, the lignite the lowest. Final tests in the 100 kW CFB did show good a transferability of the ignition temperature of the bench-scale bubbling bed reactor.

INTRODUCTION

For the design of start-up burner for circulated fluidized bed reactors and the lay-out of the operation procedure during start-up, the minimum fuel ignition temperature is an important parameter. The better the knowledge of minimum fuel ignition temperature, the lower can be the safety margin for the bed preheat temperature before fuel addition. Cost saving and the avoidance of operational difficulties are the benefit of correct ignition temperature knowledge.

Fuel particles pass through the steps of drying, devolatilization, ignition and combustion of volatiles and char. The heating-rate changes from feeding until ignition continuously. Due to the fact that devolatilization, and, as a consequence, ignition are depending on the heating-rate, it is quite demanding to separate the heat-transfer phenomena from the fuel ignition behavior. Consequently, the tests in lab-scale should be performed at similar conditions as in full scale (Prins 1989) to provide transferability of results. In literature different approaches have been proposed to measure ignition temperature in lab-scale fluidized beds and to transfer the results to larger scale.

For example, Yang et al. (2005) present a bench scale bubbling bed ignition test rig (inner diameter 65 mm) for ignition temperature measurement. They compared their results with recommendations from boiler manufactures for commercial CFBs in China and did find good agreement except for anthracite coals were boiler manufactures recommend higher feed temperatures for safe ignition compared to the measurement in the bench scale test rig.

Another bench scale bubbling bed ignition test rig (inner diameter 100 mm) has been presented by Jia et al. (2006). They compared the ignition temperature results of the bench scale reactor with a pilot scale (370 kW) CFB. The ignition temperatures of the pilot scale CFB were always higher than for the bench scale test rig which is explained by differences in oxygen concentration in the two test rigs.

Prins et al. (1989) studied ignition in a quasi-two-dimensional bed (15x200x400 mm) for coals of different rank. The bed consisted of porous alumina particles (0.6 mm diameter). The ignition temperature was determined by a combination of thermocouple measurements and visual camera observation of the ignition of single particles after feeding Coal with a diameter of $4 < d < 9$ mm was used. Oxygen concentration in the bed has been varied. The volatiles and char ignition temperature increases for decreasing oxygen concentration in the bed. Wet coal particles show a longer volatiles and char ignition times compared to air dried particles.

A standardized method is defined in NFPA85. NFPA recommends ignition temperature determination in pilot scale CFBs with a minimum thermal capacity of 293 kW. NFPA85 also allows bench-scale tests but only if the bench scale results have been verified by ignition tests with the same fuel in full-scale CFBs.

Note that methods of determining the fuel ignition temperature for pulverized coal-fired combustor, as the method of Zelkowski discussed in Becker et al. (Becker 2015), typically overestimate the fuel ignition temperatures in CFB-Boiler as will be shown later in the current paper. This overestimation has to do with the short ignition delay times (< 150 ms) needed for the stabilization of the pulverized coal flame.

The bench scale ignition test unit presented here is equipped with an under-bed heating system and, additionally, a riser heating system, not present in the ignition rigs mentioned above. The additional riser heating system guarantees homogenous bed temperatures for the ignition tests. For one coal (AV) different parameter as moisture, particle size, volatiles are compared in order to estimate the influence. Finally, the transferability has been checked by test at comparable conditions in a 100 kW CFB rig.

EXPERIMENTAL SETUP

Błąd! Nie można odnaleźć źródła odwołania.~~Fig. 1~~ shows a schematic sketch of the ignition test facility. The central elements of the facility are two ceramic pipes with an inner diameter of 40 mm and a length of 500 mm each. These pipes are surrounded by electrical heating elements. The heating elements are separately controlled allowing a maximum temperature of the pipe surfaces of 900 °C. The pipes are connected gas proofed by stainless steel flanges.

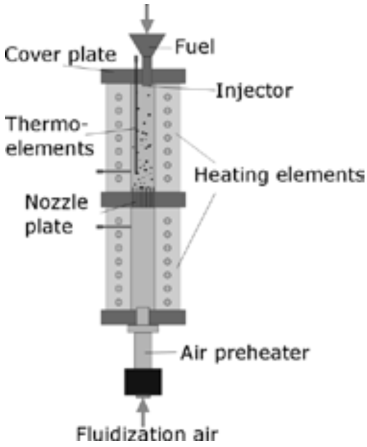

Fig. 1. Schematic sketch of the ignition test facility

The fluidization air is delivered by an air fan through an electric air heater into the ceramic pipes. The air mass flow is adjusted by a mass flow controller. The electric air heater preheats the fluidization air to a maximum temperature of 900 °C. The preheated air is first homogenized in the first pipe section and flows then through ten air nozzles into the second pipe, which forms the bubbling bed reactor. The air leaves each nozzle through two drilling (1 mm diameter) located 3 mm above the nozzle plate.

For monitoring the ignition of the fuel and to control the operation of the test facility, temperatures are measured continuously by two thermocouples one located in the reactor pipe and one downstream of the electric air preheater. The thermocouple in the reactor is adjustable in height (distance to nozzle plate variable). In addition, ignition is monitored by a camera through an optical access in the cover plate of the facility.

The fuel is fed into the reactor through a lock system consisting of two valves. An oxygen sensor allows the measurement of oxygen consumption due to ignition. Quartz sand with a d50 of 90 µm is used as bed material. The bed mass has been set to 250 g. The volumetric flow rate was for all tests at 1 m^3_N/h which leads to a superficial velocity of 1.46 m/s to 2.04 m/s depending on air temperature. Note that for the tests with char (which needed very high air pre-heat temperature), the volumetric flow rate has been reduced to not exceed a superficial velocity of 2.04 m/s to avoid leaving the bubbling bed regime. The typical expansion height of the bed is 110 mm.

Ignition tests with AV and lignite are carried out in a 100 kW pilot scale CFB with the same bed material of identical particle size as in the bench scale test unit. The fuel is fed directly into the bed by a screw feeder. The temperature was measured by a thermocouple type K directly in the vicinity of the fuel addition. For further information about the pilot scale CFB see (Kretschmann 2005).

TEST PROCEDURE

In order to examine the ignition temperature under fluidized bed conditions, the facility is heated up to a temperature above the supposed ignition temperature and sand is filled in the reactor as bed material. After stable conditions are reached, the upper heating element (surrounding the riser) is shut down and the fuel is added batch wise (approx. 0.5 g per batch) into the reactor pipe through the cover plate. The amount of fuel of 0.5 g per batch revealed as optimum between optimal feeding and temperature signal. No major differences are found for the ignition temperature with more than 0.5 g of fuel per batch. In addition, the ratio of fuel mass to bed mass replicates the fuel/bed mass ratio for the CFB pilot test rig for 10 s of operation. Note that for the wood pellets a batch is equivalent to one pellet.

If an increase in the bed temperature is monitored, the minimum ignition temperature is lower than the current bed temperature. The facility is cooled to a lower bed temperature and the procedure is repeated. When the temperature decreases (due to the thermal inertia of non-igniting fuel added to the bed), the ignition temperature is higher than the reactor temperature. The reactor has to be heated-up and the test his repeat until the fuel ignites. The minimum bed temperature where the fuel ignites has been defined as is the minimum ignition temperature.

FUEL CHARACTERISTICS

Fuel ignition tests are performed for two different bituminous coals (AV and US High Sulfur), a lignite (Rheinbraun), biomass pellets and grinded pine wood. Fig. 2 shows the particle size distributions of the fuel samples investigated which were determined by a vibratory sieve shaker. The related particle size d50 and d90 is presented in table 1. Table 2 shows the ultimate analysis, proximate and the calorific analysis of the five different fuels.

Further, tests with dried AV and with a water content of 10 wt.-% are carried out in order to determine the effect of moisture in the fuel on ignition. Additionally, tests with AV with different particle sizes (200-400 µm, 400-630 µm, 1000-2240 µm) were conducted.

To separate the ignition of the volatiles from char, ignition tests were done with char derived from AV. For the release of the volatiles, a sample of AV was put into a muffle oven. The procedure was carried out according to DIN 51720.

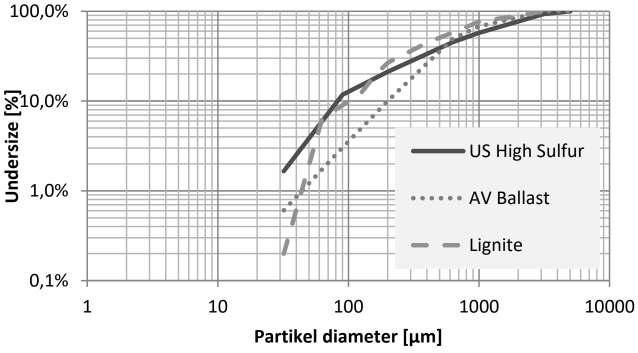

Fig. 2. Particle size distribution of AV, US High Sulfur and lignite

Table 1. d50 and d90 of coal and wood samples and dimension of wood pellets

Fuel	**d50** [µm]	**d90** [µm]
US High Sulfur	768	2,940
AV	642	2,482
Lignite	504	1,259
Pine wood	6,465	13,935

	Diameter [mm]	Length [mm]
Woodpellets	8	13-18

Table 2. Standard fuel analysis

	US High Sulfur	**AV**	**Lignite**	**Pine wood**	**Woodpellets**
Ultimate Analysis [wt.-%, dry]					
Carbon	72.39	79.36	67.07	48.55	50.7
Hydrogen	4.83	4.81	4.85	5.83	6.13
Nitrogen	1.52	1.85	0.77	0.55	0.05
Sulphur	2.33	1.08	0.31	0.05	0.03
Oxygen (Rest)	7.97	5.37	22.4	43.37	41.95
Proximate Analysis [wt.-%, raw]					
Ash	10.55	7.29	4.07	1.54	1.13
Volatile Matter	33.42	27.01	43.14	77.5	73.76
Fixed Carbon	52.31	62.46	41.29	14.06	14.27
Water	3.72	3.24	11.5	6.9	10.85
Calorific Analysis [MJ/kg, dry]					
LHV		31.1	22.2	20.0	17.0

RESULTS

Fig. 3 shows a typical measurement sequence for a given fuel (AV). The bed temperature difference to the initial bed temperature before feeding of the fuel is plotted versus time for 4 temperatures. The initial bed temperature has been defined the average temperature of the bed before feeding of fuel (-20 s < t < 0 s). The maximum temperature difference after feeding (t > 0 s) is used for the interpretation of the ignition temperature.

As soon as fuel is added to the reactor, the temperature drops due to thermal inertia of the fuel. Fuel has to be heated up, devolatilization starts and finally ignition occurs indicated by a temperature rise. Note that a higher initial bed temperature is leading to a steeper temperature increase (see T = 535 °C) followed by a higher maximum temperature difference.

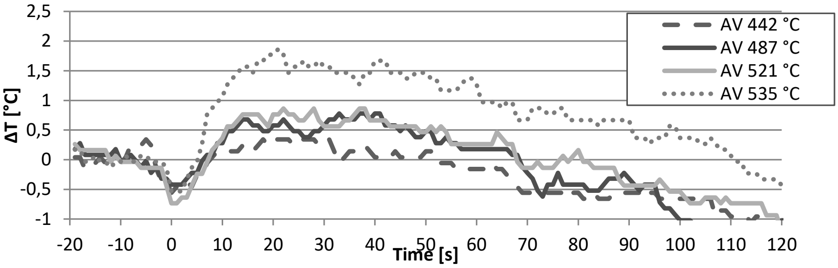

Fig. 3: Bed temperature difference for ignition test with AV for 4 different initial bed temperatures

The condensed results of the tests for lignite, AV, pinewood and wood pellets are summarized in fig. 4. The bed temperature increase due to ignition is plotted versus the bed temperature before feeding. The designated minimum ignition temperature is the bed temperature, where the temperature increase is equal to zero. Compared to the temperature increase of the tests with AV, lignite and pinewood, the results for the tests with wood pellets fluctuate more. This can be a result of the inhomogeneous composition of the wood pellet and its high mass.

The lowest ignition temperature is measured for lignite, followed by the grinded pinewood. As expected, the highest ignition temperature was measured for the bituminous coal AV. The wood pellets show rater high ignition temperatures close to AV which is due to their large size slowing down pyrolysis gas release. Note that attrition in a full-scale CFB could lead to a lower ignition temperature.

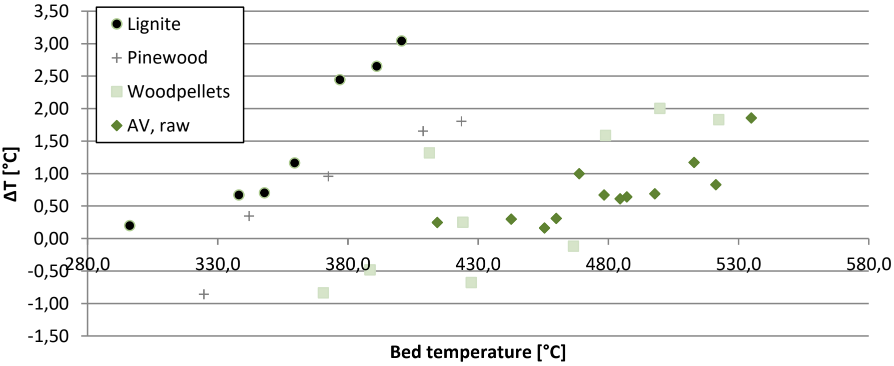

Fig. 4. Bed temperature increase for lignite, AV, pinewood and wood pellets

The influence of particle size for the same fuel (AV) is depicted in fig. 5. As expected, the insertion of smaller particles leads to a faster volatile release and ignition and is followed by a higher temperature increase of the bed. The smaller particles allow a reduced start-up temperature of the bed before feeding of the coal. As a consequence fuel ignition tests should always be performed with the same particle size as fired. Note, however, that the temperature differences are quite small.

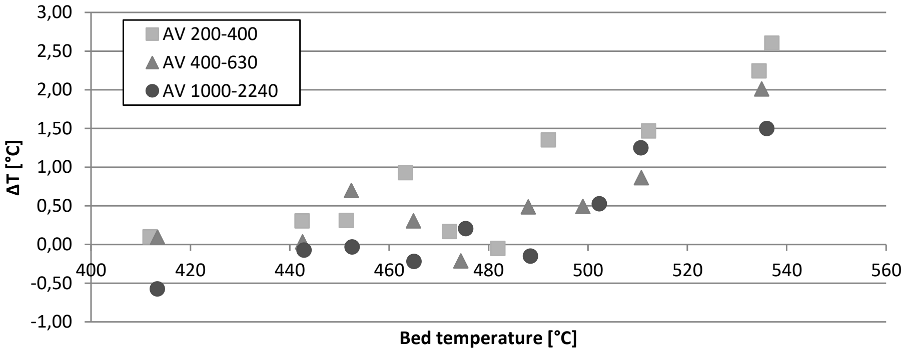

Fig. 5. Bed temperature increase for different particle sizes of AV

The influence of the water content of coal (AV) on ignition temperature is shown in fig. 6. The dried particles cause a higher temperature increase during ignition compared to the particles with a water content of 3 %. The increase in moisture content from 3 % to 10 % leads to a slightly higher ignition temperature.

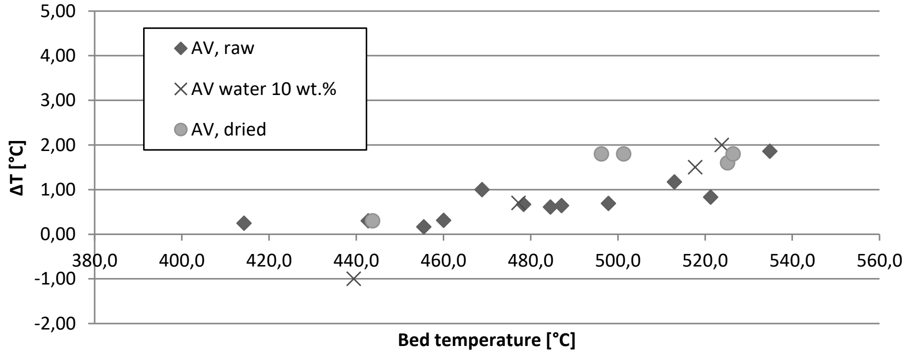

Fig. 6. Bed temperature increase for AV dried, raw (3.2 wt-% water) and with 10 wt-% water

In fig. 7 the results of the ignition tests with char derived from AV is compared to tests with US High sulfur coal and AV. The ignition of char occurred at a bed temperature of about 670 °C, which is almost 240 °C higher than for the raw coal. US High sulfur coal ignites at lower bed temperatures, which is expected due to the higher amount of volatiles in the coal. Above the designated ignition temperature, the US High sulfur coal release more heat compared to the AV. The current results reveal that ignition temperature for coal in CFB is strongly depended on the amount of volatiles in the fuel.

Table 3 finally summarizes the ignition temperatures for all test carried out in the bench scale test rig.

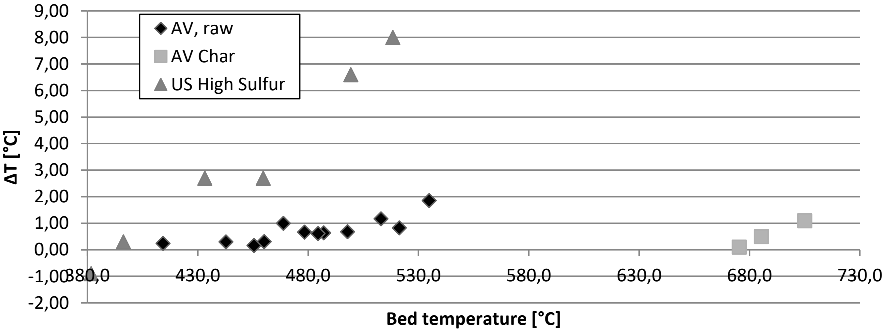

Fig. 7. Bed temperature increase for AV, Char and US High Sulfur

Table 3. Ignition temperatures (bench scale test rig)

AV				US High Sulfur	Pine wood	Wood pellets	Lignite
raw	10 wt-% moisture	dried	Char	raw	raw	pelletized	Raw
430 °C	460 °C	430 °C	675 °C	390 °C	370 °C	420 °C	325 °C

In order to prove the transferability of the bench scale test to larger scales, ignition tests were carried out with lignite and AV in the LEAT 100 kW CFB pilot scale test rig. The ignition temperatures derived from the bench scale tests are in good accordance with the tests at the pilot scale CFB (see table 4). For comparison the ignition temperatures measured in a pulverized coal ignition test rig (according to Zelkowski (Becker 2015)) for the AV coal with the same particle size are given. The measured ignition temperatures under the pulverized fuel conditions cannot be transferred to CFBC, they are too high. As already discussed, the short ignition delay times needed for pulverized fuel flame stabilization lead to higher ignition temperatures. In addition, the high heat transfer in fluidized beds favors ignition.

Table 4. Standard fuel analysis

	Ignitiontemperature		
	Benchscale	Pilotscale	Zelkowski
Fuel	[°C]	[°C]	[°C]
AV	430	430	849
Lignite	325	351	-

CONCLUSION

A standardized bench-scale method for determining minimum ignition temperature for fluidized bed reactors is presented. Tests have been carried for three different coals (Auguste Viktoria, Rheinbraun Braunkohle and US High Sulfur), pinewood and wood pellets. The measured ignition temperatures show the influence of the volatiles on ignition. High volatile content leads to low ignition temperatures, as expected. Higher moisture content leads to higher ignition temperature due to the endothermic process of drying. Coarser particle size leads to a higher ignition temperature, however, the increase of the ignition temperature is small in comparison to the influence of the volatile and water content. Nevertheless, the dependency on particle size highlights the importance of testing the fuels at the same particle size as fired at large scale.

The results from the tests with AV are showing good agreement to ignition tests in a pilot scale 100 kW CFB. However, further tests to verify the transferability of the bench scale ignition temperature to the test rig and to industrial scale CFB has to be carried out.

NOTATION

wt.-%	weight percent, kg/kg	t	time, s
ΔT	temperature difference, K	d	particle diameter, µm

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