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ENLARGEMENT OF MEASUREMENT RANGE OF ERC DROP TUBE

ROZŠÍŘENÍ MĚŘICÍHO ROZSAHU PÁDOVÉ TRUBKY NA VÝZKUMNÉM ENERGETICKÉM CENTRU

Abstract

Better understanding of combustion process in large scale pulverized coal boilers can help with increasing of coal combustion efficiency and decreasing of pollutant emissions, such as nitrogen oxides and arguable carbon dioxide. This improvement cannot be performed without testing in laboratory conditions. For this purpose, a new testing facility called the drop tube has been built in the Energy Research Center (ERC) of VSB-Technical University of Ostrava. This paper describes the methodology of pulverized coal thermo-kinetic properties determination with the use of the Drop Tube Test Facility and the first steps in improvement of this methodology. There is a new design of the sampling probe, an improved one, gas-tight double-wall design, implemented into the methodology lately. The intermediate space is vacuumed for the purpose of better isolating properties of the probe. Further, the probe is newly supplemented with a cryogenic control valve for smooth regulation of small flow rates of cooling media - liquid nitrogen. These innovations bring cooling media savings, especially thanks to increased efficiency of this media's cooling potential. Furthermore, smoother regulation allows a sample cooling in an accurately defined point.

Abstrakt

Lepší pochopení spalovacího procesu ve velkých práškových uhelných kotlích může pomoci se zvyšováním efektivity spalování uhlí a snížením emisí znečišťujících látek jako jsou oxidy dusíku a diskutabilní oxid uhličitý. Tato zlepšení není možné provést bez laboratorního zkoušení. Pro tento účel bylo na Výzkumném energetickém centru VŠB-Technické univerzity Ostrava postaveno nové testovací zařízení nazvané pádová trubka. Tento článek popisuje metodiku stanovení termokinetických vlastností uhelného prášku s použitím pilotního testovacího zařízení Pádové trubky a popisuje první kroky ke zlepšení této metodiky. Do metodiky je nově začleněna druhá vylepšená verze odběrové chladící sondy, která je vyhotovena v plynotěsném dvouplášťovém provedení. Meziprostor je pro zlepšení izolačních vlastností sondy evakuován. Dále je sonda nově doplněna kryogenním regulačním ventilem pro jemně nastavitelné dávkování chladícího média – tekutého dusíku. Tyto inovace přináší úspory ve spotřebě chladícího media zejména díky zvýšení účinnosti chladícího po-

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tenciálu tohoto media. Dále plynulejší regulace umožňuje zchlazení vzorku v přesně definovaném místě.

INTRODUCTION

Thermokinetic properties as a mean for better understanding the nature of combustion process can be determined with the help of the experimental Drop Tube Test Facility (DTTF), the principle of which is described thereinafter. This facility (see Fig. 2) allows simulation of conditions occurring in pulverized coal-fired boilers which burn pulverized coal of given granulometry under exactly given boundary conditions, such as temperature, oxygen concentration and reaction gas flow velocity [2]. The results of the experiments are so called burn-out curves which characterize properties of given fuel during the process of burning in the oxidation reactive medium.

1 EXPERIMENTAL FACILITY

The system has been designed in order to achieve the exactly set boundary conditions of the fuel burn-out process. The facility consists of preparation of the defined reaction gas, heating and keeping the required temperature of reaction gas in the reaction chamber. At the end of the reaction chamber, there is a probe for the reaction media cooling and sampling (see Fig.1). The system is divided into 5 sections. The major component parts are controlled by a PLC (Programmable logic controller) automatic regulation unit via visualization on PC station.

I Reaction gas preparation to desired oxygen concentration and for required flow rate
II Heating of reaction gas mixture to desired temperature
III Reaction chamber
IV Probe for fuel sample batching into the reaction chamber
V Sampling with simultaneous cooling of the probe to temperature below 50 °C

The facility is able to prepare oxygen concentration in reaction gas ranging from 0 to 21 % vol. This mixture results from air which is supplied into the mixing part by a blower, being mixed with CO2 which is supplied through several steps of pressure reductions from a bundle of pressure cylinders. Pursuant to the set oxygen concentration required in the mixture, the system adds a proportional amount of air and CO2 automatically with regard to the amount needed. Both gases are jointly batched into a blender and this prepared gas flows into a reaction gas heater with built-in heating spirals. The heater has two sections. In the first section, gas is preheated to 600 °C temperature and in the second section, it is warmed up to the required temperature ranging from 800 up to 1200 °C. Then, reaction gas enters the drop tube reaction chamber which is tempered to the demanded temperature (ranging from 800 up to 1200 °C as well). The gas velocity in the reaction chamber is set within range of 1 - 4 $m \cdot s^{-1}$ in accordance with orders.

Setting and keeping the required velocity is also controlled by the PLC automatic control system.

The drop tube reaction chamber is a vertically hinged, 4,800 mm long metal tube with inner diameter of 66 mm, manufactured of material being high temperature resistant in oxidation environment. Eight batching holes with constant distance of 500 mm one from another are situated in the reaction chamber. In dependence on the demanded residence time of a sample, one batching hole is chosen into which the water cooled batching unit charges a pulverized coal sample.

The whole batching facility consists of a vibrating feeder, carrier gas supply and the water cooled batching probe and it is placed on a separate sliding platform which is counterweighted so that smooth movement to any batching hole of the reaction chamber is available.

A sample is transported into the reaction chamber pneumatically by a small amount of gas which is supplied from a by-way (branch pipe) placed before the reaction gas heater (see Fig.1, section IV). Continuous sample batching is provided by the gas-tight vibrating feeder which pours the sample into the stream of carrier transportation gas. The flowing transportation gas carries the sample through the batching unit into the reaction chamber.

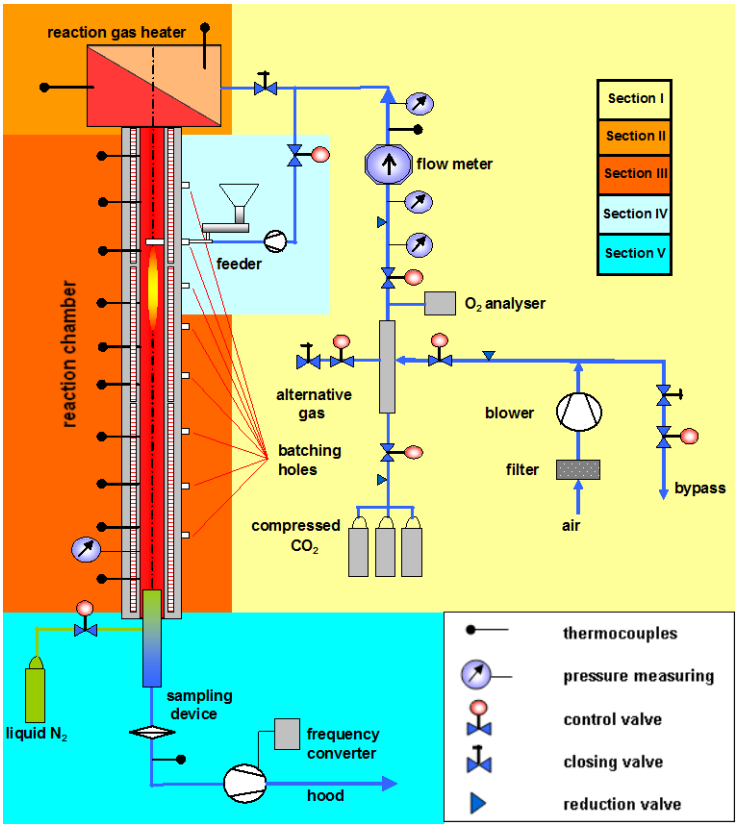

Fig. 1 Schematic view of DTTF system.

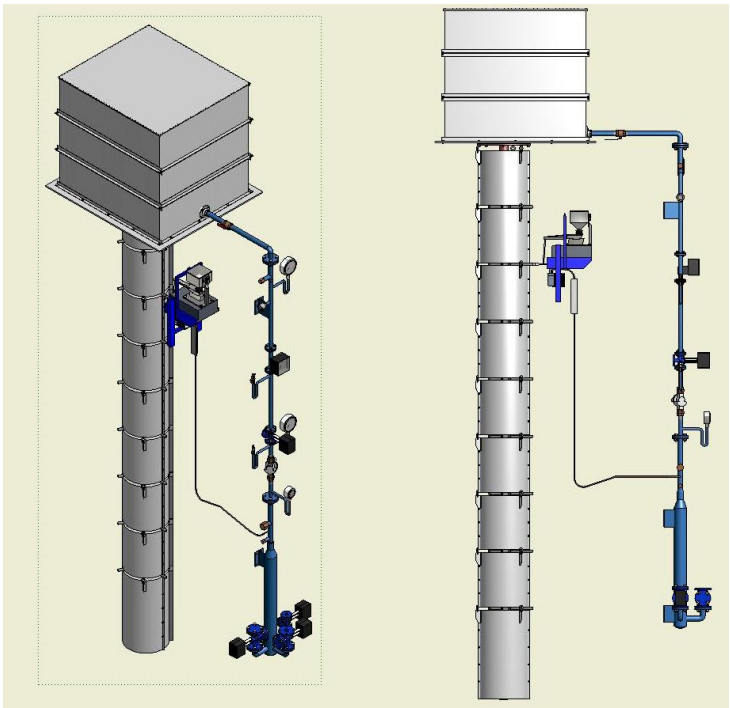

Fig. 2 3D view of Drop Tube Test Facility of ERC.

Sampling for determination of one point of the burn-out curve is being performed for a period of 15 minutes; during this time, approximately 5 g of a sample is being batched into the reaction chamber. By burning the sample, exothermic reaction and oxygen content exhausting in reaction gas occurs. By reason of that, only a small sample amount needs to be batched in order to avoid affecting the set reaction environment in the reaction chamber.

At the end of the reaction chamber, a cooling sampling device is placed which guarantees sudden cooling of sample-containing hot reaction gas to temperature below 50 °C. Cooling is provided by liquid nitrogen injection into the mouth of the cooling sampling device. On the mouth of the cooling sampling device, evaporation of liquid nitrogen occurs, mixing with sample-containing hot reaction gas which causes cooling and discontinuance of all the running reactions. Follow-up, this mixture is sieved-through onto a planar (flat) filter of 300 mm diameter (the size is given by the amount of the mixture and requirement for ensuring an acceptable pressure loss) which is able to catch particles larger than 2.5 μm and it is made of ash-less material (pure cellulose with maximum ash content 0.007 %). Then, the mixture is being sucked-off out of the laboratory by the Roots blower. Suction delivery of the Roots blower is regulated in order to keep overpressure of few Pa in the reaction chamber.

Residence time of a sample in the reaction chamber is given by combination of the batching hole distance from the sampling probe and the set velocity of reaction gas in the chamber.

During "fall" of fuel particles (a sample) in hot reaction gas towards the sudden cooling point, its heating, drying, volatile fraction burning occurs and, in the end, fixed carbon burning occurs.

The sample, which was subject to the environment of the defined temperature, in reaction gas with defined oxygen content, which has been catched on the filter, is then analyzed for unburnt fraction determination.

These values serve for drawing the burn-out curve that characterizes the given coal fuel with given granulometry under the set reaction conditions.

2 NEW SAMPLING PROBE

In order to improve the methodology of pulverized coal thermo-kinetic properties determination, a new sampling probe (Fig. 3), which enables more accurate sampling of pulverized coal from the reaction chamber, has been designed, built and tested.

- The system of transportation of liquid nitrogen to the sampling probe mouth has been improved. At the original probe, liquid nitrogen evaporation occurred just in the supply piping and it was very difficult to maintain stable conditions of liquid nitrogen outflow at the cooling probe mouth.
- Furthermore, isolation properties of the probe have been improved, so that the sampling probe can be inserted into the hot reaction chamber as deep as to c. 560 mm. By this, the distance between the closest batching hole and the probe mouth can be shortened.

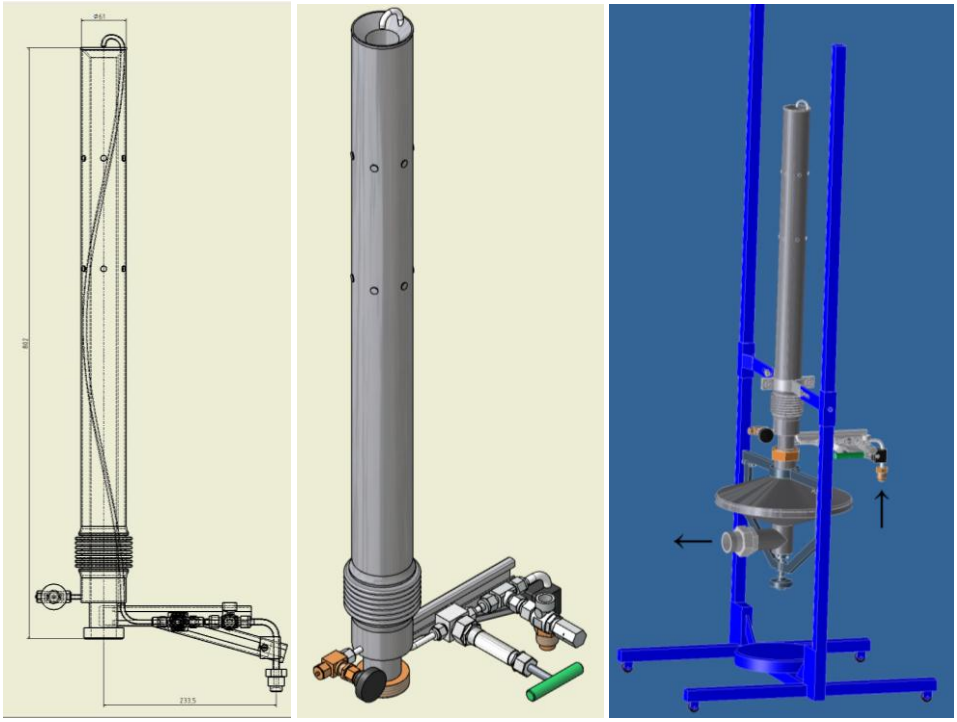

Fig. 3 New sampling probe in 3D view.

The sampling probe has been designed double walled, vacuumed in the intermediate space. Vacuum inside the sampling probe serves for improvement of the probe's insulating characteristics. As the additional insulation, perlite has been added into the intermediate space. The inlet side of the probe is of conic diffuser shape, liquid nitrogen is injected through a special nozzle directly to its centre. Amount of injected liquid nitrogen is regulated by a cryogenic needle valve which is now placed close to the cooling sampling probe. This valve enables to regulate batching of small amount of liquid nitrogen smoothly. This purpose made solution has been designed with aim to decrease the reaction gas temperature of 800 - 1200 °C to temperature below 50 °C in few milliseconds.

3 ADVANTAGES OF THE NEW SOLUTION

In the last version, the regulating valve was situated directly on the cryogenic tank with liquid nitrogen and thus the pipeline length behind the regulation unit was much longer which caused easier evaporation of liquid nitrogen just inside the pipeline and also longer time for stabilizing the system was needed, which resulted in higher consumption of nitrogen then. Moreover, the cooling medium consumption was increased of vaporization heat which had been lost even before reaching the cooling point.

These problems were solved out and, in addition, inserting of the sampling probe into the reaction chamber of DTTF was enabled which reduced the trajectory of a sample in the reaction media. It means that with velocity of reaction gas equal to 3 meters per second, residence time can be decreased to 77 milliseconds by inserting the probe into the reaction chamber as deep as to 560 mm, which was not possible with the original probe.

Thanks to this solution, almost arbitrary duration of residence time of a sample inside the reaction chamber can be achieved and thus more precise determination of the burnout curve progress in the most important time intervals can be accomplished.

4 EXPERIMENTAL RESULTS

For the confirmation test, lignite coal which is characterized with higher reactivity has been used; it burns much faster than black coal and thus the burnout curve needs to be determined in shorter reaction time intervals.

Proximate analysis of tested coal is shown in Table 1.

Table 1 Proximate analysis of tested lignite - granulometry 80 - 90 μm.

proximate analysis of tested coal			
water content	W^a	12,66	%
ash	A^a	24,84	%
volatiles	V^a	32,37	%
fixed carbon	C_{fix}	**30,13**	%
total		100	%

A result of experimental tests is a burnout curve after differentiation of which a curve of combustion velocity of a pulverized coal specific sample of defined granulometry, at defined temperature of reaction gas and with defined oxygen concentration in reaction environment can be determined as well. There are resulting burnout curves plotted in the graph in figure 4. Two curves have been determined with the use of the new improved sampling probe. Both curves have been compiled on the ground of the same pulverized brown coal of granulometry 80 - 90 μm. Oxygen concentration has been different. The results acquired with the new sampling probe show more accurate determination of loss of combustible fraction in different reaction intervals. Curves determined with the former sampling probe showed worse repeatability (in tens percents) contrary to results from new sampling probe, which has repeatability in order of percents.

Then, higher reliability of determined items has been reached and we also assume that uncertainty of unburnt fraction determination has been decreased.

Another essential benefit of the new probe is the possibility of its inserting inside the reaction chamber and shortening the particle trajectory by doing so. This function was tested while determining a burnout curve at temperature of 1000 °C and oxygen concentration 6 $\%_{vol.}$ in reaction gas (the blue curve). Due to the cooling sampling probe inserted into the reaction chamber, sampling could be performed in shorter reaction times and the theoretical assumption of the curve progression was verified experimentally. Even with these shorter reaction times, very good correlative correspondence with theoretical expectations has been acquired.

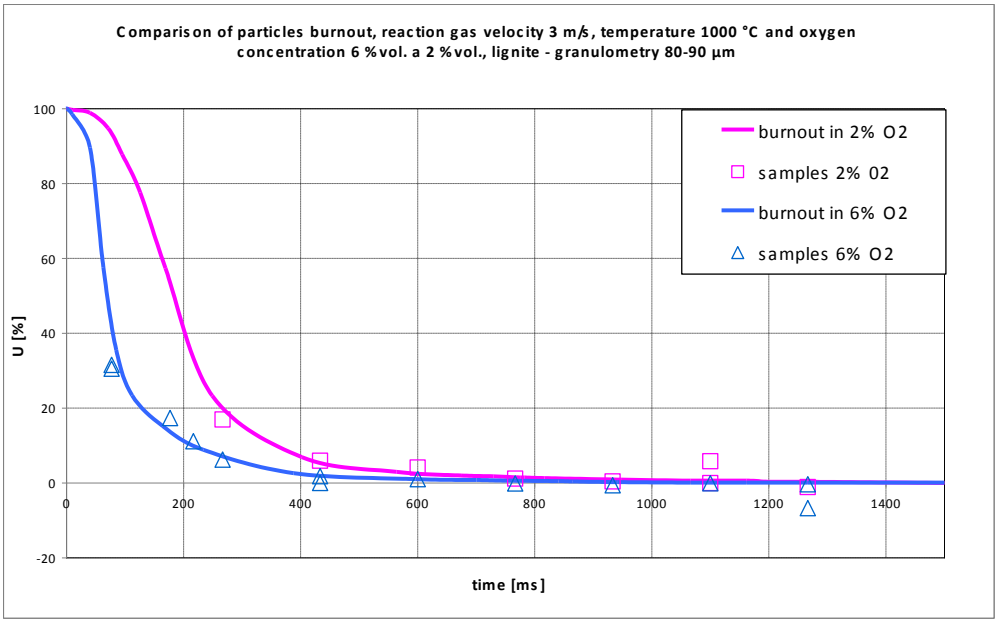

Fig 4 Experimental results with reaction gas temperature 1000 °C and oxygen concentration 6 %vol.

5 CONCLUSIONS

Owing to the newly designed and confirmed solutions, the last fundamental technical problems related with determination of the burnout curves have been removed. Inserting of the sampling probe helps to describe the most critical phase of coal burnout curves, the point of inflexion. Thus the experimental facility is ready for experimental tests in its whole operational range both for black coal and for more reactive lignite. Thanks to this, more precise data for subsequent mathematical modeling as well as for pulverized coal thermo-kinetic properties determination can be acquired. Then, the pulverized coal thermo-kinetic properties can be used for more precise setting of mathematical models of large scale coal boilers.

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