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ASPECTS OF BUBBLING FLUIDIZED BED BOILER CONTROL

ASPEKTY ŘÍZENÍ KOTLE SE STACIONÁRNÍ FLUIDNÍ VRSTVOU

Abstract

This paper deals with fundamental aspects of controlling bubbling fluidized bed boilers (BFB) in comparison with air and oxyfuel combustion modes. The paper discusses fundamental requirements for operating parameters of such boilers that must be fulfilled in parallel, particularly fluidized bed temperature, fluidization mode and complete burnout of a fuel.

Abstrakt

Tento příspěvek pojednává o základních aspektech řízení kotlů se stacionární fluidní vrstvou, a to v porovnání se vzduchovým a oxyfuel režimem. Diskutovány jsou základní požadavky na parametry provozu takového kotle, které musí být navzájem splněny, zejména požadavek na teplotu fluidní vrstvy, režim fluidace a dokonalé vyhoření paliva.

Keywords

fluidized bed, combustion, control, oxyfuel

1 INTRODUCTION

Aim of this paper is identification of specific conditions for controlling BFB boilers besides their main purpose – energy generation. These conditions particularly concern requirements of combustion process stability, stability of the fluidization regime and requirements for possibility of controlling and lowering emissions of gaseous pollutants, for example carbon monoxide, nitrogen oxides, sulfur oxides or gas phase hydrocarbons.

2 FLUIDIZED BED COMBUSTION

Combustion of a solid fuel (particularly coal and biomass) in a fluidized bed has several characteristic features in comparison with other combustion technologies. It is a situation, when a layer of inert material is lifted up (fluidized) by a stream of the so-called fluidization medium. This is normally air, air with recirculated flue gas, or in special case of oxyfuel combustion it is a mixture of recirculated flue gas and oxygen. Into this floating layer of inert bed material is supplied fuel with appropriate particle size. Its share in the bed is normally around 5 – 10 %. The fuel burns away floating along with the inert bed material and turbulence of gas and solids streams significantly enhance heat and mass transfer. Therefore, complete burnout of the fuel can be ensured at significantly lower temperature compared to other combustion principles (for example, combustion in flight – pulverized fuel combustion, or fixed bed combustion). Typical operating temperature range of fluidized bed boilers is 800 – 900°C, while the range for combustion in flight is about 1300 –

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1500°C, in a case of smelting boilers even higher. Advantage of the fluidized bed boiler is therefore hidden in this relatively low operating temperature range, which enables effective reduction of formation of unwanted pollutants, in particular oxides of nitrogen and sulfur.

Inert bed material is the key factor, requirements for its properties is discussed in the next chapter. If possible, the inherent mineral fraction of the fuel (ash) is used, but only in the case, when there is sufficient amount and sufficient properties in the particular fuel. This a case of Czech lignite coal, for example. If these two conditions are not satisfied, it is necessary to use external bed materials, for example quartz sand, dolomite or ceramic-based materials. These external bed materials are typically used for combustion of biomass or alternative fuels.

3 FLUIDIZATION

Fluidization can be considered as a case, when a layer of solid particles is lifted up by a stream of fluid and the forces acting on the particles ale balanced – gravity, drag force and buoyancy force. This is illustrated in the Figure 1.

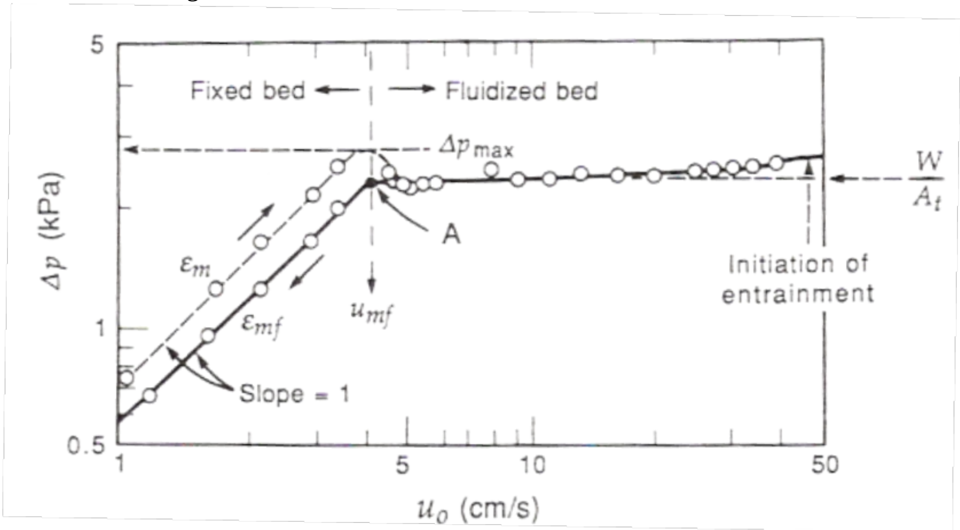

Fig. 1 Pressure drop of layer of solids related to velocity of fluidization medium stream [1]

The Figure 1 shows an increase of pressure drop of the solid particles layer until when this pressure drop does not grow any further and is constant with increasing velocity. This corresponding velocity, marked as umf, is called minimum fluidization velocity. At this velocity, the particles become lifted up – fluidized. Second specific velocity is terminal particle velocity ut (in the Figure 1 shown as “initiation of entrainment”), when the fluidization regime changes into the regime of pneumatic transport of particles. According to these two characteristic velocities we distinguish between two types of fluidized bed boilers. A stationary/bubbling fluidized bed (BFB) boiler operates with fluidization velocities between umf and ut. A circulating fluidized bed (CFB) boiler operates at velocities above ut. In this case, the solid particles are carried away from the combustor and returned back to the combustion zone using a gas-solid separator. In fact, the particles circulate in the system [2]. In the case of BFB, there are two key aspects. The first is that the fluidized bed should be operated at least on a multiple of the minimum fluidization velocity. The reason is that the particles do not have uniform size, but a certain distribution of sizes. Typically, the size distribution curve can be described by log-normal distribution. Furthermore should be mentioned that the umf is usually calculated for mode or median of the particle size distribution. In the particle set are therefore such particles, that are not fluidized yet at umf as well as particles already far above the umf and the fluidized bed tends to segregate. The second aspect concerns fluidization properties of fuel particles that should fall within the fluidization range of the bed material.

4 OPERATION OF THE FLUIDIZED BED BOILER AND ASPECTS OF ITS CONTROL

Already during the design process as well as during the operation, it is necessary to put together two particular requirements – the requirement for fluidization, determined by the umf of particles/fuel and bed pressure drop, and the requirement for supplying sufficient amount of oxygen for complete burnout of the fuel. Next requirement is keeping the mean bed temperature within acceptable range and keeping area and volumetric thermal load under limiting values. Generally, practical experiences set the volumetric thermal load of the bed not above 2 MW/m3 and surface thermal load below 3 – 4 MW/m2. Low boundary of the fluidized bed temperature is around 780 – 800°C. Below this temperature, carbon monoxide oxidation is too slow. High boundary is usually determined by deformation temperatures of inert bed material and ash of the fuel. In some cases, this boundary is as low as 1000°C. Upper boundary can be also in some cases limited by application of direct SO2 capture technology, which significantly loses its efficiency above 900°C. General control priorities are following:

1) ensuring required thermal power output – by fuel feeding rate

2) ensuring fluidization by controlling flow of primary air

3) controlling overall balance of combustion air

4) keeping fluidized bed temperature between 800 and 900°C

These four points are crucial for controlling the boiler. However, it is always of the highest importance to ensure bed fluidization. The current status of fluidization is determined by measurement of pressure drop across the bed and it is important ti follow the line shown in Figure 1. It means that with increasing fluidization velocity (i.e. increasing flow rate of primary air) the pressure drop should remain almost constant. However, always grows pressure drop of the air distributor. It is therefor essential to measure both pressure drops – on the distributor nozzles as well as across the bed. The amount of fluidization (primary) air cannot be increased up to the nominal (maximum) air flow, since it is necessary to keep the terminal particle velocity ut for both bed material and fuel with enough reserve according to the particle size distribution.

Considering the bed temperature control, it is important to distinguish between adiabatic design and design with immersed heat exchanger loops (usually serving as evaporator). In practice can be found both designs. In the case of adiabatic (uncooled) bed, it is partially possible to control the bed temperature by changing the air-fuel ratio, but this control is limited and has several restrictions, for example significant decrease of power load operation range of the boiler and decrease of its efficiency. One of the effective tools for this case is using a flue gas recirculation, which means extraction of cooled clean flue gas and its blending with the primary air. This allows keeping constant volumetric flow of the fluidization stream, but it has lower fraction of oxygen compared to air. This results in lower heat release in the bed, which causes cooling down the fluidized bed. On the other hand, it means a partial shift of the combustion zone to the freeboard, which requires higher flow of secondary air. This option must be used according to actual concentration of oxygen in the flue gas. It is effective only in such a case, when this concentration is quite low, usually below 6 % vol. An alternative temperature control option is the so-called re-injecting of the bed material. This control principle is based on feeding cold (ambient temperature) inert bed material from an external storage. The effect is firstly in quick cooling of the fluidized bed, secondly in increasing volume of the bed material and thus lowering the volumetric thermal load of the bed. In the case of submerged heat exchanger (evaporator) design, there is one more control option based on controlling power load of this evaporator. It is possible to realize it since such evaporator is typically constructed with forced circulation, i.e. there is a feeding pump that can, in some extent, control the flow through the heat exchanger.

5 FLUIDIZED BED BOILER IN OXYFUEL MODE

Recently, a new emerging technology, concerning fluidized bed boiler control, is oxyfuel combustion, which means a replacement of combustion air by oxygen. This meas completely different combustion conditions connected with significant change of flue gas flow and its composition, which is further reflected in change of its material properties and conditions affecting heat transfer process. Significant is also change of the combustion temperature and in consequence flue gas temperature that affects distribution of thermal fluxes in the combustion chamber and to the heat exchanging surfaces. Replacing combustion air by oxygen reduces volume of the flue gas and rapid growth of combustion temperature. It is even more important here to keep the bed temperature in the desired range. The only possible solution is using extensive flue gas recirculation (in multiples of nominal flow) with the aim to reach similar conditions as in air combustion. The oxyfuel mode also changes fluidization conditions, one of the most important impact is lowering of the umf. This is illustrated in Figure 2.

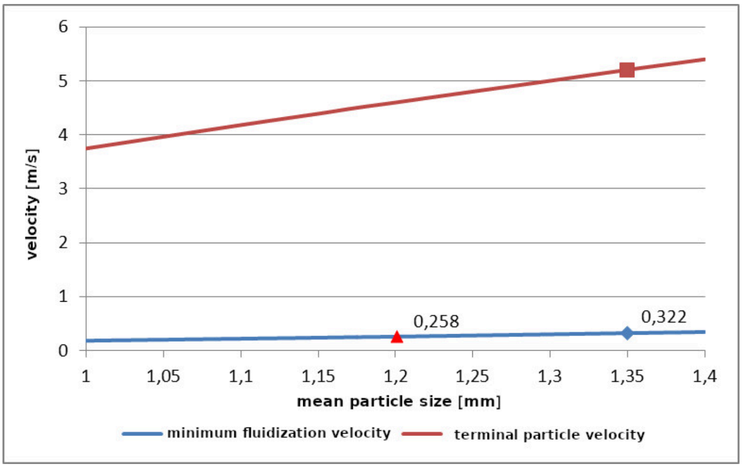

Fig. 2 Correlation of minimum fluidization velocity and terminal particle velocity with particle size

The Figure 2 shows two points on the blue line. The blue point corresponds to the umf in air combustion mode for selected particle size. If the flow of the fluidization medium would decrease by 20 %, which is an expected level when changing from air to oxygen with recirculated flue gas, similar fluidization conditions in the bed would be reached at umf of 20 % lower (0,258 m/s for this specific case), which corresponds to median of the particle size 1.2 mm. It implies that the control of oxyfuel fluidization mode can also be based on changing the particle size distribution of the bed.

6 CONCLUSIONS

The paper has shown the main aspects of controlling boilers with bubbling/stationary fluidized bed. It points out mainly interconnection between the respective parameters, particularly fluidized bed temperature, fluidization parameters and requirement for complete burnout of the fuel. The issue with converting the fluidized bed combustion into oxyfuel mode is connected particularly with change of the composition of fluidization medium that significantly changes conditions for bed temperature and fluidization control.

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