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Estimating hovering of a mobile sensor in combustion boiler environment

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A B S T R A C T

Our research group is investigating possibilities of developing a mobile sensor for short-term measurement work inside large industrial boilers. The aim of the sensor is to aid researchers modelling and simulating combustion processes in big boilers to test and verify their models. To that action a short-term, active mobile sensor is an extra-ordinary and unique tool, because it offers measurements in locations which cannot be reached with other traditional measurement methods in large boilers.

There are many technical challenges to overcome before the active mobile sensor is ready for service. One is to know the balance between gravity forces, buoyancy and drag of the fluids from the bottom to upper parts of the boiler, in order to get the sensor ball floating and moving freely with the flows. This paper concentrates on estimating the conditions for hovering of the sensor ball.

1. Introduction

Industrial energy and recovery boilers are ever increasing in size. The largest of them can produce up to 1500–1800 MW of thermal energy. Large energy capacities demand vast surfaces to collect the heat flow. Consequently the boilers are very big in size. The bottom area of boilers can be hundreds of square meters and the height of the combustion chamber can reach 50–90 m. [1–5]. The largest kraft recovery boiler has a bottom area of 480 m^2 [1].

In order to measure inside the large boilers, new measurement methods are needed. Methods used today are unable to get information from the inner parts of the combustion chamber. In addition, new requirements for pollution control and monitoring demand new measurement methods [6,7].

Ordinary pressure, temperature and flow sensors measure only at areas near the walls. When they are traversed some meters towards the middle part of the chamber, water cooled probes must be used. These are cumbersome and uneconomic. The probe structures are heavy and demand much space outside the boiler during assembly and operation.

These problems, among others, in traditional measurement techniques have led to the idea of utilizing an active, mobile sensor propagating in combustion chamber.

Fig. 1 shows the opened sensor ball prototype opened developed in our research project.

The sensor ball contains simple electronics. The processor board is ARDUINO Nano™ board based on ARM ATmega328 processor and Arduino compatible radio module HC-12 operating at 433 MHz frequency. In addition, there is MAX6675 electronic board for connecting K-type thermo-element for external temperature measurements. Internal temperature measurements are done by PT-1000 thermistor, type DM-507. The ball has no active-cooling mechanism, but it is protected by the thermally insulating enclosure. The ball diameter was about 95 mm. The wall thickness was about 20 mm and weight varied from about 65 g to 150 g depending the enclosure material. According to first tests, the lifetime of the sensor or the time before the sensor became damaged, varied from 4 to 10 min, depending on the enclosure material. During the operational period, the sensors were able to do a series of measurements and transmit the results in real time to the base station outside the combustion chamber.

In this paper we concentrate on the hovering issues of the ball. If the ball hovers in the combustion chamber, it can move to almost anywhere measuring and transmitting information from positions not reached before for measurements.

The paper is arranged as follows. First boiler types and conditions inside boilers are briefly introduced. Next the basic forces affecting the sensor ball in flows and fluids are studied. Thirdly, the calculations for floating in different conditions are presented. And lastly, some conclusions are drawn.

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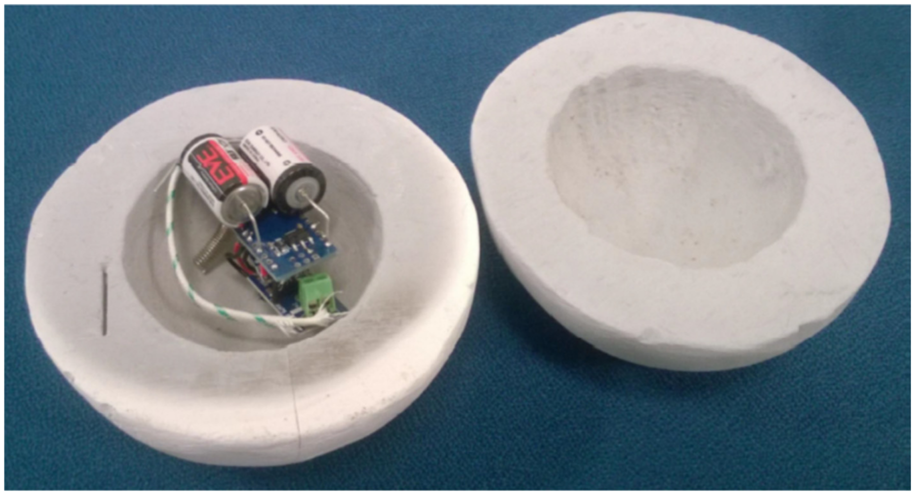

Fig. 1. The opened mobile sensor prototype for combustion measurements. The two halves of the enclosure are fabricated from Skamol-1100E insulator board.

2. Conditions inside the boiler furnaces

The combustion chamber is the volume in boiler work, in which the chemical energy of fuels is converted to thermal energy. The energy is collected through water and steam cooled walls and transported in steam form to turbines and heat exchangers. The turbines generate electricity. The rest of the heat from the heat exchangers can be delivered to industrial processes and district heating. There are a variety of burning processes and boiler types. Main types of boilers are circulating fluidized bed (CFB), show in Fig. 2, bubbling fluidized bed (BFB), grate boilers and kraft recovery boilers (KRB). While all are used for energy production, the KRB is used also for chemical recovery from black liquor [4].

In BFB and CFB boilers there is a large quantity, up to tens of tons, of sand inside the boiler, which is used as fluidized bed material. In bubbling fluidized bed sand fluidizes and form bubbles that are about one to two meters in diameter over the gas distributor grid. In the CFB boiler, the sand is fluidized and it circulates from grid up to upper parts of the boiler and through cyclone and back-loop back to the grid. In both boiler types, sand evens out the burning process and temperatures. CFB boilers operate at a relatively higher riser gas velocity. In the CFB boiler, the sand transports the heat energy to heat exchange surfaces. The floating conditions in CFB boilers differ a lot from the conditions in other boiler types [2].

The boilers differ from each other in suspension densities inside the combustion chamber. Some researchers have classified circulating fluidized beds into low density (LDCFB) and high density (HDCFB) boilers [8]. In LDCFB boilers, at bottom level of the bed the sand suspension densities are hundreds of kilograms/m^3 [2]. The density decreases gradually upwards in the region of bed and continues to decrease in riser as a function of distance above the grid to 10–20 kg/m^3, see Fig. 3 [9]. Near the walls, extending to some tens of centimeters from the walls, there are sand streams flowing down [2]. These must be taken into account in practical hovering situations.

In BFB boilers, the bed density is significantly greater than in CFB boilers, up to 1000–2500 kg/m^3 [2]. Above the bubbling bed, in the splash zone area, the density decreases precipitously, see Fig. 4. In the upper parts of the combustion chamber, suspension

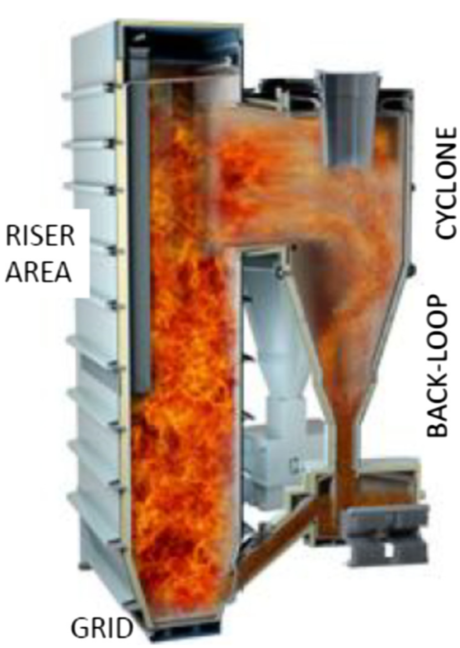

Fig. 2. Cross section of a CFB boiler.

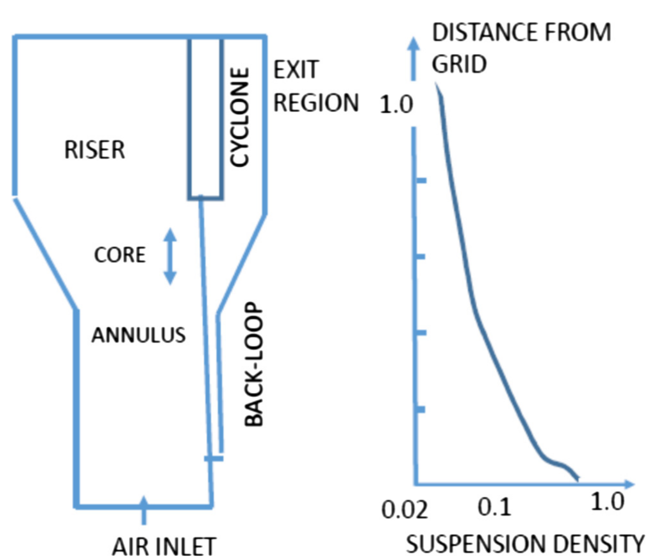

Fig. 3. Suspension density as a function of distance from grid in CFB boiler.