Characterization and Quantification of Deposit Build-up and Removal in Straw Suspension-Fired Boilers - Ph.d. thesis Muhammad Shafique Bashir - DTU Orbit (07/01/2019)

An increased use of biomass in large suspension-red power plants can be a relatively economic and potentially also efficient way to utilize biomass for heat and power production. However, large deposit formation problems limit the electrical efficiency by limiting the maximum applicable superheater temperature, and the deposits may also cause boiler stoppages where different parts of the boiler have to be cleaned. This project aims at providing scientifically based knowledge on understanding of ash deposit formation and shedding in biomass suspension-red boilers. Deposit probe measurements have been conducted in different biomass suspension-red boilers by using advanced ash deposition probes. Two kinds of ash deposition probes have been used. A horizontal probe that has been developed further, which can register probe temperature, deposit mass uptake, heat uptake and video monitoring. First steps have also been taken for the development of a vertical probe that was employed for ash deposit formation measurements on a boiler furnace wall.

In the first series of probe measurements, the influence of straw ring technology (grate and suspension) on ash transformation, deposit formation rate and deposit characteristics has been investigated. Full-scale probe measurements were conducted at a 250 MWth suspension boiler, ring straw and wood in suspension, and the results were compared with measurements conducted at a 105 MWth straw-red grate boiler. Bulk elemental analysis of fly ashes revealed that fly ash from suspension ring of straw has high contents of Si, K and Ca, while fly ash from straw grate ring was rich in the volatile elements, K, Cl and S. SEM-EDS analysis showed that the fly ash from suspension ring consists of three kinds of particles: 1) flake type Si rich particles, 2) molten or partially molten particles (> 20 m) rich in Si, K and Ca with small amounts of Mg, P, and potassium salts on the outer surface, and 3) small particles rich in K, Cl and S (aerosols, between 0.1 and 5 m). Ash deposition data were compared with data from previously conducted deposit probe measurements in biomass-red grate boilers. The comparison showed an increasing trend in deposit formation rate with increase in fuel gas temperature. At a fuel gas temperature of 650 °C, the deposit formation rate is typically from 5 to 30 g/m2/h and at 900 °C, the deposit formation rate is typically 20 to 110 g/m2/h. At higher fuel alkali contents (K > 0.9 wt.%), the increase in deposit formation rate with fuel gas temperature was more significant, compared to the increase in deposit formation rate at lower fuel alkali contents (K 0.9 wt.%). An increased fuel gas temperature probably increases the fraction of molten ash as well as provides an increased content of gaseous phase alkali species, and both will lead to an increased deposit formation rate. The deposit formation rates during diffusion suspension ring and straw grate ring were on similar levels. This was observed even though the concentration of fly ash in the fuel gas was higher during suspension straw ring.

The objective of the second probe measuring series was to investigate the influence of fuel type (straw share in wood), probe exposure time, probe surface temperature (500 °C, 550 °C and 600 °C), and fuel gas temperature (600-1050 °C) on the transient deposit build-up and shedding in a 350 MWth suspension boiler, ring straw and wood. Two different measures of deposit formation rate are used in the analysis of the data. The first is the integral deposit formation rate (IDF-rate) found by dividing the integral mass change over integral time intervals (order of several hours) by the time interval. The IDF-rate is then the result of both the deposit formation rate and shedding events in a given period. In this work IDF-rates were determined using 12 h intervals. The IDF-rate is similar to deposit formation rates determined from previous full-scale measuring data. A second measure, the derivative-based deposit formation rate (DDF-rate), was determined by calculating the local values of the time derivative of the deposit mass uptake, removing large negative values signifying major shedding events, and finally time smoothing the derivatives to remove excessive noise. The DDF-rate excludes the major shedding events. The overall DDF-rates were measured to be between 234 and 3105 g/m2/h. The IDF-rates were measured between 1 and 95 g/m2/h. The results showed that the DDF-rate was influenced by fuel gas temperature and straw share, while changes in probe surface temperature had no significant influence. The IDF-rate, qualitatively related to the ratio between the time-integrated DDF-rate and the integration time, followed the same trends. Quantification of naturally occurring deposit shedding and deposit shedding during plant sootblowing was made via deposit mass uptake signals obtained from the deposit probe. The deposit shedding process was characterized by calculation of the amount of deposit removed at a shedding event [g/m2] and the frequency of the shedding events [h⁻¹]. The results showed that the shedding process is stochastic and the amount of deposit removed varies even at constant local conditions. However, the deposit shedding rates showed an increasing trend with increase in fuel gas temperatures and probe deposit mass loads. The deposit shedding rate was in most of the cases higher at a probe temperature of 500 °C than at a probe temperature of 600 °C. A possible reason for this is partial melting and/or sintering of the innermost deposit layer (rich in K, Cl and S) at higher probe surface temperature. This could cause the adhesion strength of the deposit to the probe to increase at the higher probe temperature. Quantification of the necessary Peak Impact Pressure (PIP) needed to remove the deposit was also made by use of a sootblowing probe in conjunction with the deposit probe. Results of deposit removal by artificial sootblowing showed that the deposits formed on a 500 °C probe temperature and at exposure less than 91 h can be removed with a PIP of less than 55 kPa. However, an increase in exposure time and/or probe surface temperature (to 600 °C) significantly increases the PIP needed to remove the deposits.

As a part of the third probe measurement series, full-scale probe measurements of deposit build-up and shedding were conducted at a 800 MWth suspension boiler, ring wood and natural gas, with the addition of coal fly ash. The results showed that the addition of coal fly ash can significantly affect the ash deposition behaviors and the deposit properties. At the location of the probe measurements with fuel gas temperature of 1250-1300 °C, although the addition of coal fly ash increases the DDF-rate and the ash deposition propensity, the deposits formed during coal ash addition seem to shed frequently, suggesting that they are easily removable. On the other hand, the amount of K2SO4 in the deposits was significantly reduced when coal fly ash was added, which is favorable from corrosion point of view. At the location with
ue gas temperature of 750-800 °C, the deposits formed without coal ash addition were dominated by small particles rich in K, Ca, S and Cl. With the addition of coal fly, the Cl disappeared in the deposits, which were dominated by calcium-alumina-silicates rich particles, supplemented by a small amount of K2SO4 particles. The ash deposition propensity was decreased when coal ash was added.

A mechanistic model of ash deposit build-up and heat uptake was used to simulate the deposit formation process. The model describes the deposit related processes as a function of the local parameters as fuel gas temperature, probe surface temperature and fuel changes. Simulation results showed that the model over predicts the DDF-rate quantitatively but the qualitative behavior was in accordance with the experimental findings. The model predictions regarding probe heat uptake were satisfactory both quantitatively and qualitatively.