METHOD AND INSTRUMENTATION FOR DIRECT MEASUREMENT OF CORROSIVE SPECIES FROM COMBUSTION

One of the key elements of battling climate change is the drive to reduce dependence on fossil fuels. This progression can be seen in transport, industry, and energy production sectors. One approach for the energy sector is to replace coal-based solid fuels with renewable or semi-renewable fuels such as biomass and waste (IPCC working group III, 2022). While this approach is beneficial in terms of greatly reduced "new" CO_2 emissions into the atmosphere, it presents some challenges for the combustion plants. Biomass and waste have a lower energy density compared to coal so the flue gas cleaning systems need to deal with an increased amount of dust when firing biomass or waste with same power output. Another more difficult problem is the increased potential for the generation of corrosive species during combustion (Berlanga et al., 2013). Corrosive species are in vapor form in the combustion chamber but as the flue gas cools down the vapor molecules nucleate forming new particles or grow existing particles by condensing on them.

These newly formed particles cause fouling of the heat exchanger surfaces and boiler walls where they deposit due to the large temperature gradient between the flue gas and wall. This again reduces the overall efficiency of the plant and shortens the plant operational time between maintenance operations that require shutting down the combustion unit. It is known that formation of corrosive species can be mitigated with for example reducing combustion temperature, by using additives or a small fraction of coal in the fuel(Aho et al, 2004, 2005). There are issues with each of these mitigation techniques; reduction of combustion temperature reduces the overall efficiency of the plant while the use of additives or coal in the combustion increases the operation costs of the plant. The most beneficial approach is to find an operation point for the boiler where the combustion temperature is as high as possible and corrosive species are kept at minimum through optimized use of additives or coal co-firing. Thermal NOx formation must be also considered especially in plants operating without an SCR (Selective Catalytic Reduction System). This approach has been hindered in the past by the difficulty to optimize additive usage or co-firing as there hasn't been a way to assess formation of corrosive species in real-time. In this study, we will present a new aerosol/gas conditioning instrument specifically developed to characterize corrosive species into aerosol form.

Methods

Sample conditioning

High temperature sampling probe prototypes have previously been used by the Technical Research Centre of Finland (VTT) to study corrosion in biomass and waste firing plants (Aho et al., 2008). Dekati Ltd. acquired this technology through a collaboration project with VTT to commercialize the probe and integrate it into an existing sample conditioning and measurement systems. This High Temperature Sampling Probe is an air-cooled dilution probe made of high temperature steel to allow direct sampling from combustion zone in up to 1200 °C . The tip of the probe incorporates a perforated dilution stage which drops the temperature of the sample to ~300 °C (Figure 1.). This temperature decrease is similar to what happens near the boiler walls and especially the heat exchanger surfaces. As the temperature drop is caused by the dilution process, any vapor form compounds in the sample are forced to nucleate or condense onto existing aerosols instead of condensing on the probe walls. The resulting aerosol is transferred into further dilution and subsequent measurement with instruments. High Temperature Sampling Probe also incorporates a heater to keep the temperature at a minimum of 200 °C to eliminate any thermophoretic losses subsequent to the dilution. Dekati® High Temperature Sampling Probe schematic is shown in Figure 1. The High Temperature Sampling Probe is connected to the Dekati® eDiluter™ Pro that is an automatically controlled two stage dilution system. eDiluter™ Pro regulates dilution air flow into the heated probe and as it is an ejector dilution-based system it also pumps the sample from the probe and further dilutes it. As the eDiluter™ Pro automatically keeps the dilution factor constant regardless of inlet pressure, it is especially well suited to sample from turbulent firing zone conditions. eDiluter™ Pro operation has

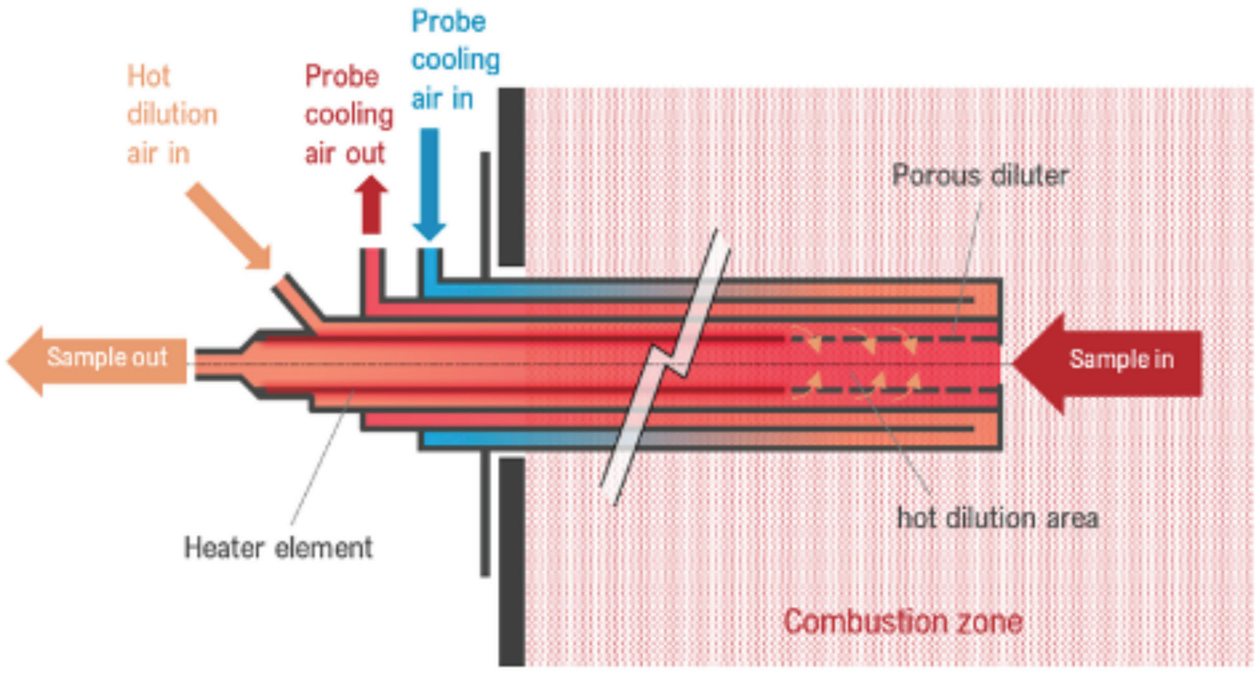

Figure 1. Dekati® High temperature sampling probe operation principle

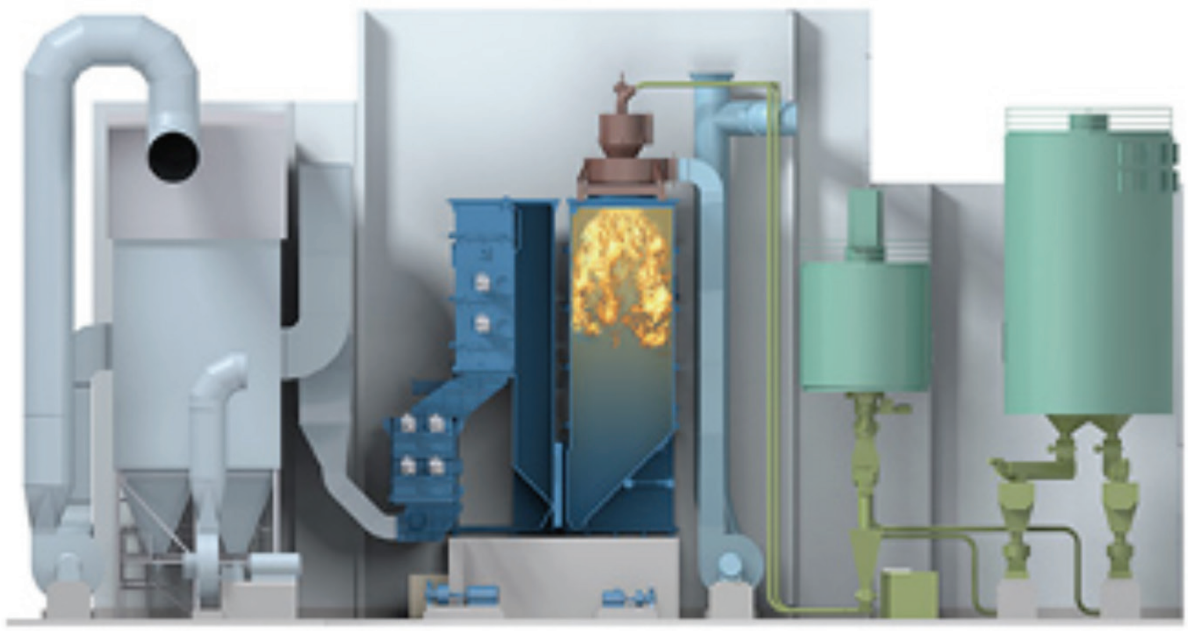

Figure 2. Salmisaari pellet power plant sampling locations

been previously described in detail in (Niemela et al., 2019). It is recommended to use a ~ 10 µm cutpoint cyclone between the high temperature probe and eDiluter Pro unit to remove coarse flyash and potential unburned fuel from the sample flow.

Aerosol measurements

Dekati® Electrical Low Pressure Impactor+ (ELPI®+) was used for particle detection due to its wide concentration and size range Wide size range is needed as corrosive species are formed is ultrafine particle size range, while most of other produced aerosol mass is in supermicrometer range. In addition, as the ELPI®+ measured particles in real-time it can detect quick changes in a dynamic combustion process. ELPI®+ characteristics and operation have been previously presented by (Järvinen et al., 2014) It is also recommended to take collect the aerosol samples for subsequent chemical analysis to confirm the presence of corrosive species. This can also be done with the ELPI®+ using analysis collection plates or by using a parallel cascade impactor such as the Dekati® Low Pressure Impactor (DLPI+).

Experimental work

Dekati® High temperature sampling probe was used in combination with eDiluter™ Pro and ELPI®+ to measure combustion zone aerosols in Salmisaari 100MW pellet firing biomass power plant. Measurements were made in two locations, right before heat exchangers and directly from the combustion zone (Figure 2). The aim of the measurements was to study the potential formation of corrosive species in different combustion conditions. Power plant was running at 100 MW (optimal), 60 MW and 40 MW loads simulating different load levels during summer, winter and intermediate conditions respectively. High temperature sampling probe was installed in the facility for more than two weeks with 6 full measurement days. Compared with "typical" aerosol measurements from power plant processes, specific safety precautions need to be considered when using the the High temperature Sampling Probe. It is important to ensure continuous availability of cooling air for the probe, and a safe location for the used cooling air output need to be arranged.

Sufficient space should also be reserved around the measurement area to allow safe handling and cooling of the probe after the measurements.

Results

Number size distribution results showed a repeatable accumulation mode peak @ 100nm with all plant output levels. High number concentrations (10^8#/cc - 10^9#/cc) suggest that the aerosol subsequently agglomerates into larger particles in the flue gas stream. Potential corrosive species were detected around 20-30 nm especially during high load and during unstable combustion conditions. This peak was highly dependent on power plant load with significantly lower concentrations during lower loads and lower combustion temperatures. Effect of load on particle concentration and size is shown in Figure 3. Cyclone was found to have collected a significant amount of flyash from the process (Figure 4).

Conclusions

Aerosol concentration measured from the combustion chamber of a pellet fired biomass plant was found to correlate directly with plant load with highest concentrations detected with highest plant load. There was no adverse effect on emissions even at only 40% of optimal load which shows that this plant type can be used without emission penalty at partial loads. Potential corrosive species were found to form mainly during high combustion temperatures under full load conditions and especially when plant load was changing. This information can effectively be used to control additive or coal co-combustion to mitigate corrosion, and to lengthen the periods between mandatory maintenance operations. High temperature probe and other instruments were found to be suitable for these types of measurements as they operated without issues or need for maintenance operations throughout the measurement campaign.

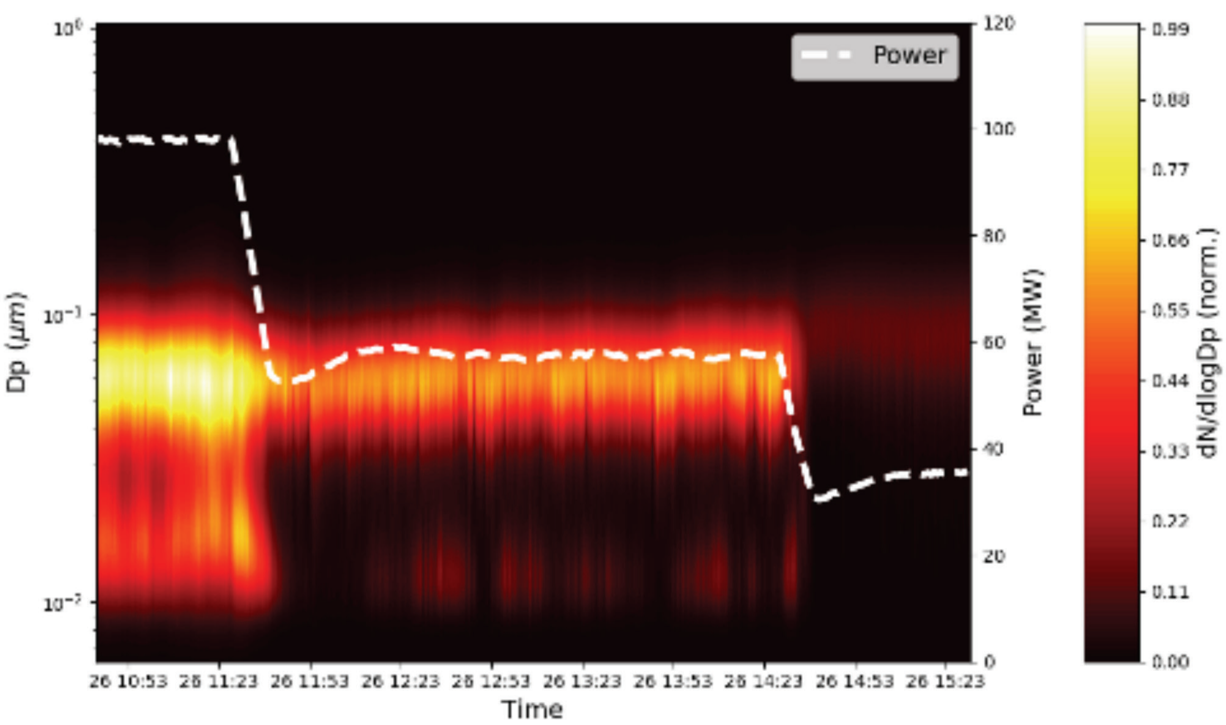

Figure 3. Particle size and concentration with different plant loads

Figure 4. Coarse fly ash in cyclone collection cup

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