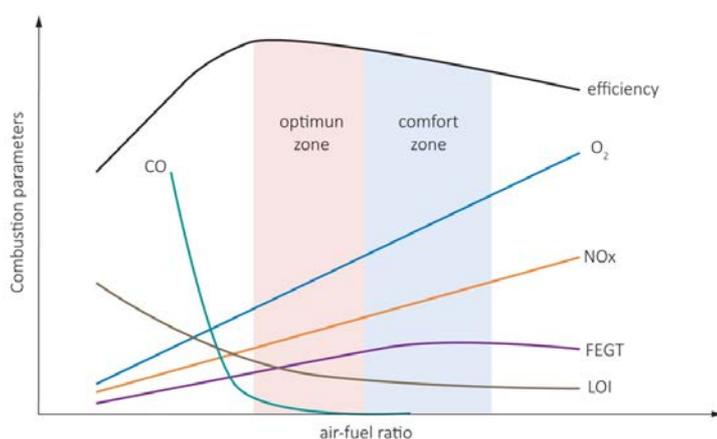


Advanced sensors and smart controls for coal-fired power plant

Coal-fired power plant is under growing pressure to operate with higher efficiency, cleaner emissions, and sufficient flexibility to provide rapid back-up to intermittent renewable energy sources. With significant recent advances in both the sensor hardware and control software available to plants, control system upgrades have become an increasingly effective means of meeting these demands. More accurate, real time data can be generated by online sensors which are located closer to the processes they monitor, and more advanced algorithms have been developed for determination of the optimum control response. However, sensors for combustion processes in particular are still limited by their reliability in the harsh environments in which they operate. Emerging concepts for high-efficiency coal power such as advanced ultra-supercritical and integrated gasification combined cycle plants will require sensor technologies which are even more resilient to high temperatures and corrosive atmospheres. The development of sensors for both monitoring and control in these environments is consequently an area which is attracting increasing research interest.

For pulverised coal plant, optimisation of the combustion process is the primary driver for the development of new sensor and control technologies. To ensure complete coal combustion and maintain low CO levels, furnaces are frequently operated with an unnecessarily high proportion of excess air which represents an efficiency penalty and promotes NO_x formation – potentially requiring costly downstream abatement. Such practice is usually the result of the limited information available on the distribution of air, fuel, and combustion products within the furnace, allowing localised regions of poor combustion to arise. Newer technologies such as tunable diode laser absorption spectroscopy and advanced acoustic pyrometry are allowing the temperature and composition of flue gas to be mapped out over a furnace cross-section. At the same time, devices for online monitoring of the coal and air flow distribution to individual burners enable combustion stoichiometry to be precisely controlled in real time. These additional data allow the control system to balance combustion and reduce excess air to optimum levels, improving efficiency and NO_x emissions, whilst better control of furnace exit gas temperatures corresponds to improved steam temperature control and reduced slagging.



The variation in key combustion parameters with air-fuel ratio, showing the performance improvements possible when the plant control system can confine operation to the optimum zone

Even where sensor data remain limited, coal plant is able to draw on a growing range of advanced process control software for maintaining an optimum state. These systems usually make use of complex algorithms such as neural networks which can be trained on operational data to build up an empirical model of the plant system. In contrast to conventional control, which relies on a series of discrete feedback loops, these model-based approaches are able to continuously identify the optimum combination of control actions for a given set of demands on the plant. Model

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predictive control is one such technique which is seeing increasing adoption due to its ability to deal with highly dynamic systems, although non-linear models such as neural networks and fuzzy logic are often also incorporated. Comparable to sensor-based optimisation, state-of-the-art process control software can typically demonstrate efficiency improvements of up to 1%, around 20% lower NO_x emissions, and improved load dynamics and steam temperatures – generally resulting in rapid payback times for the plant. In cooperation with intelligent soot blowing systems which replace fixed interval boiler cleaning with more targeted actions, slagging and material damage are also minimised. Advanced control systems can become particularly effective when combined with online sensor technologies which are able to supply them with more useful data, and such systems may indeed be best-placed to make use of this growing influx of information.

Research into combustion sensors has focused primarily on developing more robust, miniaturised devices which can operate reliably in the challenging environments of furnaces, gas turbines, and gasifiers. Of particular interest are devices based on optical fibres which encode and transmit sensory data as some property of light, offering higher signal fidelity and better immunity to electromagnetic noise than electronic sensors. Individual fibres can be modified with structures such as Fabry-Pérot interferometers and Bragg gratings which display sensitivity to temperature, pressure, or strain, whilst chemically sensitive fibre coatings can provide gas sensing functionality. Although conventional silica fibres become unstable at temperatures much over 800°C, new techniques have been developed to incorporate these sensors into sapphire fibres which are viable to nearly 2000°C. With appropriate interrogation signals, optical fibres also offer the additional capability of distributed sensing, in which variation in a physical parameter is mapped along the entire fibre length. Several of these optical device concepts have undergone testing in full-scale gasifiers or gas turbine test facilities and demonstrated significantly extended lifetimes over conventional sensors. For additional protection, optical fibres can be embedded in power plant components such as steam pipes using additive manufacturing techniques, introducing the possibility of ‘smart parts’ which are able to report on their own condition.

Microelectronic devices have also attracted interest for their potential as low cost and robust sensing platforms, benefitting from the availability of mass production techniques and developments in high temperature electronic materials. Following the model of the widespread zirconia-based oxygen sensor, related solid electrolyte sensors have also been designed for detection of NO_x, CO, and SO₂. Even simpler gas sensors can be based on chemiresistive metal oxide films, although achieving sufficient gas selectivity remains a significant challenge. Whilst conventional microelectronics based on silicon are not viable at temperatures greater than 350°C, equivalent devices based on higher temperature silicon alloys have demonstrated their use as sensors, as well as providing integrated high-temperature electronics for signal processing or even miniaturised radio transceivers for wireless devices.

The capability for wireless communication is itself a key technology for miniaturised sensors, avoiding the cost and vulnerability of wiring and granting access to previously inaccessible locations such as turbine blades. Whilst new networking protocols have already been introduced to meet the growing trend towards plant monitoring with wireless networks, self-powered devices are needed to maximise the potential of wireless sensor networks for control applications. Radio frequency-powered devices based on dielectric resonators or surface acoustic wave sensors are amongst the most promising concepts, with thermal energy-harvesting sensors also under investigation. Optimisation of the data quality and energy consumption of such dense networks may benefit from collective control of individual sensor activity by self-organising algorithms.

Growing interest in developing new sensors and controls for the fossil fuel sector can partly be seen as a consequence of rapid advances in a number of technologies which have outpaced their adoption as commercial devices, despite the increasing need to optimise coal plant. The US Department of Energy have calculated that the incremental improvements in plant efficiency and reliability provided by control system upgrades could represent yearly savings of US\$ 358 million and 14.4 MtCO₂ if applied to the country’s entire coal fleet, and is consequently funding an extensive research programme in this field. As more complex, higher efficiency plant is deployed, potentially incorporating carbon capture systems, the application of these emerging technologies for optimising plant control is likely to become increasingly necessary.