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PRE-TREATMENT OF COAL FOR EFFICIENCY AND EMISSIONS IMPROVEMENTS

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ACRONYMS AND ABBREVIATIONS

CFBC	circulating fluidised bed combustion
CV	calorific value
FGD	flue gas desulphurisation
LOI	loss on ignition
PCC	pulverised coal combustion
SCR	selective catalytic reduction
SDG	Sustainable Development Goal

UNITS

g	gramme
kg	kilogramme
kWth	kilowatt-thermal
mg/m^3	miligrammes per cubic metre

CHEMICALS

CO	carbon monoxide
CO_2	carbon dioxide
HCN	hydrogen cyanide
NO_2	nitrogen dioxide
NOx	nitrogen oxides
SO_2	sulphur dioxide

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ABSTRACT

Various fuel additives have been developed for the pretreatment of coal. The aim of the additives is to improve the combustion performance of coal and reduce the emissions of pollutants. The status of four additives is reviewed: Sootaway, CETALYST™ A, Addicoal and Silanite™. Three developers, Johnsen Chemicals AS Norway, Combustion and Emissions Technologies, LLC, in the USA, and MEA CAPITAL Ltd's subdivision COALTECH appear to remain active in the area. The main market is likely to be smaller, inefficient boilers and furnaces.

1 INTRODUCTION

Globally, coal provides the largest single proportion of power generation, at around 38%, and is likely to retain prominence for some time during the energy transition towards net zero CO_2 emissions, particularly in emerging economies (IEA, 2020). Coal is also still important in industrial heat and steam production in various countries including some of eastern Europe (Mills, 2022). Energy policies are moving generally towards the eventual elimination of coal, but the Russia-Ukraine conflict has contributed to an increase in the global use of coal for power generation in 2022. Thus, policy drivers to reduce further the impact of coal on the environment continue to feature.

The use of any major energy resource such as coal requires minimising the associated emissions of pollutants to safe levels. Emissions of sulphur dioxide (SO_2) have been reduced dramatically over recent years through the deployment of flue gas desulphurisation (FGD), which commonly uses liquid scrubbing of the flue gas systems. Nitrogen oxides (NOx) are reduced by careful control of air/fuel mixing before and during combustion by applying selective catalytic reduction (SCR) to the hot product gases. Such processes are mandated on modern, large combustion plants almost everywhere, but they may be difficult to apply on some older, smaller plants due to the capital costs.

Fuel additives that aim to provide more modest improvements in coal combustion performance in coal-fired plants have been proposed at intervals over the years. The use of such technologies may reduce emissions from coal combustion to the extent that the more resource-intensive or costly alternatives such as flue gas clean-up systems are not required. Some recent examples which aim to achieve reduced emissions and greater combustion efficiency are summarised in this paper. They are based on application of spray or powder additives to the coal before firing.

Tests up to pilot scale, and, in some cases, at medium-sized power generation plants were reported up to 2019-20, shortly before the Covid-19 pandemic. At that time developers were seeking to attract more industrial collaborators and sponsors in efforts to move towards commercialisation at utility pulverised coal combustion (PCC) units. There have been changes in the intervening period, and the current position is summarised (August 2022). Brief descriptions of the technologies are provided with comments on their likely applicability and potential to contribute to UN Sustainable Development Goals (SDGs).

2 TECHNOLOGIES

The technologies described in this chapter are Sootaway, CETALYST™ A, Addicoal and Silanite™.

2.1 SOOTAWAY

2.1.1 Description

Sootaway has been described by its developers, Johnsen Chemicals AS Norway, as a combustion catalyst that acts by attracting oxygen to the surface of the fuel. The additive is also described as an oxygen scavenger. It contains manganese acetate hydrate, acetic acid and dimethylaminoethanol (Wrocław University of Technology, 2015). The additive is applied as a liquid spray to the coal at the rate of one gramme per kilogramme of fuel.

Reduction of emissions of NOx and SO_2 have been shown to be achievable (ADK GreenTech LLC, 2022). The reported emissions savings are described as coming from the catalyst enabling the boiler to operate satisfactorily at reduced levels of oxygen (Vebenstad, 2022). Although Sootaway was not designed specifically to reduce emissions of CO_2, some of the trials have reported lower emissions of this greenhouse gas.

2.1.2 Status

Laboratory tests (thermogravimetric analyses) were carried out in 2014 on treated and untreated samples of a hard coal from the Wieczorek mine, Poland (Pawlak-Kruczek and Zgóra, 2014). They showed an increased combustion rate and greater heat release on using the catalyst, with the effect greatest when the coal had been freshly treated.

Domestic scale (home heating) boiler tests at 15 kWth were carried out in 2016. An Orlignio 400 boiler was used to burn pinewood sawdust in pelleted form. Both untreated pellets and those that had been treated with two versions of the Sootaway catalyst were fired. The treated pellets showed a reported 30% lower specific fuel consumption and increased boiler output. NOx emissions were lower with the catalyst-treated fuel, but carbon monoxide (CO) emissions were higher. The commercially marketed wood pellet-burning stove was clearly operating at a low combustion efficiency without the additive.

Trials were also carried out in 2015 at a grate-fired boiler, dating from the 1960s but modernised at intervals, in Jelcz, Poland. The boiler, with a 10 kg/s coal feed rate, is used for industrial hot water production and district heating. The trials showed a reduction in emissions of CO, SO_2, NOx and hydrogen cyanide (HCN) (Wrocław University of Technology, 2015).

The tests confirmed that the catalyst increased the speed of the combustion reaction, allowing a more rapid and intense combustion with a slightly higher burn-out. This was shown by a reduction in loss on ignition (LOI) of the ash discharge from around 1% to about 0.8%, although with large variations.

The calorific content of the ash was reduced by 62%, indicating an improved fuel combustion efficiency (ADK GreenTech LLC, 2022). At a constant airflow the level of oxygen in the combustion gases was reduced by 18%. The reduction in emissions of NOx and SO_2 were attributed to the reduced availability of oxygen in the boiler.

The tests at Jelcz showed emissions reduction in nitrogen dioxide (NO_2) of 88% and 34% for SO_2, but increasing or decreasing the air supply could reduce or increase these values markedly (Vebenstad, 2022). An observed reduction in slagging (up to 85% reduction in deposition potential) was also reported (Vebenstad, 2022). This could be most relevant for cofiring biomass with coal and, as one of the reports on the tests says, there may be benefits to using the catalyst for lower calorific value (CV) coals (Wrocław University of Technology, 2015).

Three-week duration tests, described on the ADK GreenTech website (ADK GreenTech LLC, 2022), were carried out at a newer waste-to-energy power plant, built in 2009. These showed a 58% reduction of NOx emissions to 15.3 mg/m^3, a 67% reduction of SO_2 emissions to 2.8 mg/m^3, and an 84% reduction of CO emissions to 0.5 mg/m^3.

Trials at a power plant in Nowa Sol, Poland, were reported to reduce the consumption of coal by 35%, attributed to increased fuel burnout and reduced deposition. At a power plant in Opole, Poland, it was reported that the usage of the calorific value in coal without treatment was 65% and it increased to 85% with treatment, while fuel efficiency increased by 31% from its previous low value (ADK GreenTech LLC, 2022).

Trials were conducted in India aimed at increasing fuel efficiency on a 135 MW circulating fluidised bed combustion (CFBC) unit at the Dongamouhua Captive Power Plant in Reigarth (Vebenstad, 2019). The 4 x 135 MW CFBC captive power plant, dating from 2009, fires a low-quality Indian coal with 45% ash and a CV of around 11 MJ/kg. The trials showed that specific fuel consumption, corrected for variations of calorific content, was reduced by 10% (Vebenstad, 2022), but details of the measured effect on SO_2 emissions were not given.

2.1.3 Economics

The cost of installation on a commercial power unit in pump, piping and nozzles is given as approximately $1000 (Vebenstad, 2022). The economics of the operation depend on the cost of the catalyst and the value of the reduction in fuel consumption. An example quoted was that, at current coal prices (around 400 $/t of coal), the value of a 10% reduction in fuel consumption was $40. The price of the catalyst would be negotiated with the customer but would be substantially lower than $40 per litre (one litre treats one tonne of solid fuel) (Vebenstad, 2022).

2.1.4 Comments

The system is simple, low-cost to install and can result in reductions in emissions of NOx and SO_2 that have varied at different installations. The reductions in NOx and SO_2 emissions appear to come from reduced oxidation due to reduced oxygen levels, so the sulphur content in the ash will be increased.

Sootaway appears to be primarily aimed at poorly performing systems, which are less likely to have SO_2 scrubbers fitted and are likely to benefit most from the combustion efficiency and emissions improvements.

It is possible that the system may increase the types of usable coals or wastes.

2.2 CETALYST™ A

2.2.1 Description

CETALYST™ A, from Combustion and Emissions Technologies, LLC., in the USA, is a combustion catalyst designed to improve efficiency in coal-fired power generating units by promoting the complete oxidation of the coal in the combustor. As well as reducing carbon losses to ash, it is also stated to reduce the quantity of excess air required and so reduce flue gas and fan power energy losses. An improvement in heat rate of up to 4% is said to be achievable. The formulation of the material is varied according to the characteristics of the coal fired to enable the quantity added to be optimised. The material is added to the coal as a dry powder or can be introduced with some of the primary air (CET, 2022).

NOx reductions of 3–15% are said to come from the reduced excess air required and SO_2 and mercury emission reductions would arise from the reduced specific coal consumption (2–4%) (CET, 2019). Additional reduction in mercury emissions would be due to the increased capture of oxidised mercury in the FGD unit.

The developers have not declared the composition of CETALYST™ A, but it is described to act by increasing the burn rate of the char formed on devolatilisation under reduced excess oxygen levels, providing both the reduction in NOx as well as the heat rate improvement. The developers have not reported the effect on the various forms of mercury but expected a substantial increase in oxidation of the mercury, rendering it more easily removable by the scrubbers (Kollin (2020).

2.2.2 Status

Initial experiments showed a reduction of total carbon-in-ash of up to 90%, while large pilot tests at the Energy & Environmental Research Center (EERC) in the USA showed a decrease in carbon-in-ash from 22.5% to 10%. The excess air rate reduces flue gas losses and fan power giving a further overall heat rate improvement. A 3% efficiency gain was reported from the EERC pilot tests, and it is stated that optimising the formulation to suit the coal would have given further gains while reducing the rate of additive needed. Fly ash LOI was reduced by more than 50% while reducing the excess oxygen levels from 3.25% to 2.75% with a Northern Appalachian bituminous coal (CET, 2022).

Demonstration tests on commercial plants are the next stage required to confirm the additive's effectiveness. The company was reported to be working with one of the largest energy providers in the USA running bituminous coal-fired power plants and hoped to have a field trial completed within 3–5 months, as of April 2020 (Kollin, 2020). The main aims of the trial would be to reduce carbon-in-ash losses, to render the fly ash marketable, and to reduce NOx and mercury emissions. In response to an article published in India in 2021, the company reported that they were still looking for strategic partners for further testing and additional investment (Kollin, 2022).

2.2.3 Economics

The process is described as cost beneficial, with a suggested negative cost of compliance under the 2019 planned regulations in the USA. For a US coal-fired plant, a low (described as 'negligible') installation cost is shown on the website for a 3% heat rate improvement (CET, 2022).

2.2.4 Comments

The system is simple to implement and could give some efficiency gains and emissions reductions in older power plants in the USA. However, there is limited information on the levels of emissions reduction achievable. A modern bituminous coal PCC plant operating optimally would probably have less potential to benefit from such an additive than older, less efficient units with limited environmental controls, and these would probably be best for such a demonstration. Costs are low.

2.3 ADDiCOAL

2.3.1 Description

COALTECH, a subdivision of MEA CAPITAL Ltd is s a start-up project based in Latvia, which involves another additive (AddiCoal) giving efficiency and emissions benefits. Efficiency is raised by 5–15%, while emissions of SOx and NOx are reduced by what are described as several percentage points. Claimed additional benefits are reduced boiler slag deposits and less dust from coal milling improving the safety of power plant operations. The spray-applied additive (mixed on site) is applied at a rate of 1–10 litres per tonne of coal to the pulverised coal at the power plant (in the pulveriser), or to a belt feeder, or it can be added to a coal cargo before leaving the mining area, or at port coal handling areas. The composition is adjusted according to the type of coal and other site-specific factors. The material can also act as a dust suppressant for transport (MEA CAPITAL, 2022).

2.3.2 Status

Laboratory tests were completed in 2020, and a collaborating power plant operator is being sought for testing at a plant. A previous relationship based in Ukraine had to be terminated because of the Russia-Ukraine conflict of 2022.

2.3.3 Economics

There are no detailed cost data available, but the developers estimate that the operating cost should not exceed 2.5% of the cost of coal (Grotuss, 2022). Spray systems generally involve low capital costs and low pumping energy requirements. The economics will depend on the price at which the additive is supplied to site.

2.3.4 Comments

This is a business start-up so there is little detail on which to comment. The source of the product is not stated. There are no operating performance data from test rigs available at the time of writing (August 2022). An industrial testing partnership is being sought.

2.4 SILANITE™

2.4.1 Description

The Silanite™ Fuel Enrichment System was being developed by IIT UK Ltd with the Universities of Leeds and Sheffield in the UK. It entailed the addition of 3–4% of a dry, finely ground multi-oxide additive, based on the slag from copper or nickel smelting, to the fuel feed of a pulverised coal-fired plant. However, the technology has now been dropped, and IIT UK Ltd has been dissolved. Published papers include that by Daood and others (2017). The system was shown to be capable of increasing carbon burnout (by about 1%), reducing NOx emissions by 8–10%, and reducing corrosion and deposition in the boiler.

2.4.2 Status

Combustion tests were carried out on a 100 kWth coal combustion test rig. These tests, and full-scale tests carried out at the 230 MWth Wilton Power Station in the UK in 2016 demonstrated a reduction of NOx emissions of more than 8%.

2.4.3 Economics

There were no details available on costs, although the system would have been expected to be comparatively low-cost in comparison with conventional NOx emission control systems.

2.4.4 Comments

The expected modest emissions reductions and combustion efficiency gains would have restricted the application of the technology to plants where greater emissions reductions were not required.

3 CONTRIBUTION TO ACHIEVING UN SUSTAINABLE DEVELOPMENT GOALS

All the technologies discussed could be described as helping achieve SDG3 – good health and well-being, as they reduce harmful emissions of air pollutants including greenhouse gases. Meeting SDG7 – affordable and clean energy and SDG 13 – climate action would be aided by fuel savings and emissions reductions. Benefits would be most worthwhile from application to regions with poorly performing coal-fired plants.

4 ENERGY POLICY IMPLICATIONS

Whilst many energy policies are generally aimed at the eventual elimination of unabated coal, during the interim, regulatory measures to reduce further its impact on the environment and human health have to be maintained. These technologies fit within this approach, but they will have greatest relevance to countries where there are currently large numbers of poorly performing coal-fired installations.

5 CONCLUSIONS

Globally, coal still provides much of the world's energy and will do for decades. Thus methods to reduce further its impact on the environment remain essential.

Combustion additives have been investigated as a means to improve coal combustion in power and industrial plants for some years. They work by promoting the ease of oxygen take-up by the coal carbon. The aim has been to achieve reductions in emissions of sulphur dioxide and nitrogen oxides and improvements in combustion efficiency at a lower cost than the established, capital-intensive, flue gas treatment systems. Three developers, Johnsen Chemicals AS Norway, Combustion and Emissions Technologies, LLC, in the USA, and MEA CAPITAL Ltd's subdivision COALTECH appear to remain active in the area.

Although some systems have shown useful improvements in tests at large plants (hundreds of megawatts electrical), the main market appears to lie with smaller boilers and furnaces that operate inefficiently at present. Whilst the low capital and operating costs would be a feature, the degree of emissions reduction would depend on the particular boiler installation, varying from the order of 10% to over 50%. It is possible that the firing of lower calorific value fuels could be facilitated from these systems. Reductions of specific emissions of CO_2 would only be major at very inefficient plants. On plants and in countries where the strictest abatement requirements apply, there is little prospect of these technologies being required, and this will be the main reason behind the limited application.

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