Institution: University of Kent

Unit of Assessment: 12: Engineering

Title of case study: Improving Combustion Efficiency in Power Generation Internationally through Novel Instrumentation Technology

Period when the underpinning research was undertaken: 2004-2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Yong Yan	Professor of Electronic Instrumentation	2004-present
Gang Lu	Reader in Electronic Instrumentation	2006-present
Md. Moinul Hossain	Lecturer in Electronic Engineering	2018-present

Period when the claimed impact occurred: 2014-2020

Is this case study continued from a case study submitted in 2014? Yes

1. Summary of the impact (indicative maximum 100 words)

The University of Kent's Instrumentation team, led by Professor Yan, has developed two novel instrumentation technologies that improve combustion efficiency and reduce pollutant emissions. The first, pulverised fuel flow metering, has been adopted by 23 coal-fired power stations across China; the second, burner-flame imaging, has been applied to power stations across Europe and Asia, and to industrial-scale combustion test facilities in the UK and China. Leading industrial partners and users of the technologies, including RWE npower, EDF Energy, Moneypoint Power Station, and Doosan Babcock, have benefited significantly from optimised combustion performance, increased process efficiency, and reduced greenhouse gas emissions. In addition, Yan and his team have advanced knowledge, competitiveness, and practice of combustion instrumentation technologies throughout the industry, through technical consultancy, staff training, and industrial collaborations with RJM International (UK), Enlandar Instrumentation and Control (China), and Walsn Energy (China).

2. Underpinning research (indicative maximum 500 words)

Since **2004**, Kent's Instrumentation team (Gang Lu, Moinul Hossain, Jan Krabicka and Duo Sun, led by Yong Yan) has been developing technologies for pulverised fuel flow metering and burner-flame imaging to enhance the combustion efficiency, performance, and environmental impact of coal- and biomass-fired power stations. The team works in close collaboration with a range of industry partners, and has provided consultancy and training on best practice across the UK, Ireland, China, and Vietnam.

Pulverised fuel flow metering: background and underpinning research

In many Asian countries, energy supply is dominated by fossil-fuel-fired power stations. In China, for instance, coal-fired power stations make up 70% of the energy market, supplying energy to almost a billion people. Global fluctuations in coal price and logistic uncertainties mean that many power plants burn a diverse range of fuels, and, without an effective online fuel monitoring system, pulverising mills and burners may not be optimally configured for the type and quality of the fuel. The resulting imbalance in fuel supply leads to low thermal efficiency and increased pollutant emissions.

Since **2012**, Kent's Instrumentation team, in collaboration with North China Electric Power University, has developed a novel acoustic emission detection technology incorporating electrostatic sensor arrays that measures the mass flow rate and size distribution of coal

particles in an online, continuous manner **[R1, R2]**. As such, this technology avoids the need for power-station operators to take periodic, manual samples and analysis of pulverised fuel. The novel design of the system is such that mass flow rate and velocity of particles are determined from the outputs from electrostatic sensor arrays **[R1]**, but particle size distribution is measured from an acoustic sensor **[R2]**. The design makes the best use of the advantages of each sensing technology, as the electrostatic sensing technology is ideal for particle velocity and mass flow metering, but unsuitable for particle size distribution measurement. At the same time, between **2014** and **2017**, novel signal-processing algorithms **[R1, R2]** were also developed and incorporated by the Kent team to enhance the performance, reliability, and accessibility of the measurement system.

Burner flame imaging: background and underpinning research

Over the last decade, Kent's Instrumentation team has made significant advances in burner flame imaging technology that can measure flame stability for a range of fuels under a diverse range of combustion conditions. The team has deployed novel image-processing algorithms, along with imaging devices, spectroscopic modules, and image fibre bundles, to measure a range of flame characteristics, including temperature distribution, oscillation frequency, and radiative profiles of free radicals **[R3, R4, R5]**. The team established, for the first time, the concept of flame stability index and a method for its quantitative determination **[R5]**. Such comprehensive information about flame characteristics and flame stability is important to power-plant operators and combustion practitioners for plant optimisation and emissions reduction.

Soft computing algorithms have been incorporated in the flame imaging system to enhance monitoring and to enable prognosis and optimisation of a combustion process **[R6]**. Quantitative information about flames for a range of fuels and conversion conditions, such as high-moisture coal, oxy-fuel combustion, co-firing of biomass with coal, and direct wood pellet combustion, has been acquired with the flame imaging system and disseminated to the power industry **[R3, R5, R6]**.

3. References to the research (indicative maximum of six references)

Since 2004, the Kent Instrumentation team has comprised several academic staff and Research Associates and PGRs led by Yong Yan. Of that team, those listed on the publications (below) from Kent include: Gang Lu, Lingjun Gao (PGR, 2010-13), Moinul Hossain (RA, 2017-18), Jan Krabicka (RA, 2010-11), and Duo Sun (RA, 2013-15). All other authors represent the team's industrial and international collaborators.

[R1] Qian, X. C., **Yan, Y.**, Huang, X. B., and Hu, Y. H. (**2017**). 'Measurement of the mass flow and velocity distributions of pulverised fuel in primary air pipes using electrostatic sensing techniques'. *IEEE Transactions on Instrumentation and Measurement* 66(5): 944-952. doi: 10.1109/TIM.2016.2627246.

[R2] Hu, Y., Qian, X. C., Huang, X. B., **Gao, L.**, and **Yan, Y.** (**2014**). 'Online continuous measurement of the size distribution of pneumatically conveyed particles by acoustic emission methods'. *Flow Measurement and Instrumentation* 40(12): 163-168. doi: 10.1016/j.flowmeasinst.2014.07.002.

[R3] Smart, J., **Lu, G.**, **Yan, Y.**, and Riley, G. (**2010**). 'Characterisation of an oxy-coal flame through digital imaging'. *Combustion and Flame* 157(6): 1132–1139. doi: 10.1016/j.combustflame.2009.10.017.

[R4] Krabicka, J., **Lu, G.**, and **Yan, Y.** (**2011**). 'Profiling and characterization of flame radicals by combining spectroscopic imaging and neural network techniques'. *IEEE Transactions on Instrumentation and Measurement* 60(5): 1854-1860. doi: 10.1109/TIM.2010.2102411.

[R5] Sun, D., **Lu, G.**, Zhou, H., **Yan, Y.**, and Liu, S. (**2015**). 'Quantitative assessment of flame

stability through image processing and spectral analysis'. *IEEE Transactions on Instrumentation and Measurement* 64(12): 3323-3333. doi: 10.1109/TIM.2015.2444262.

[R6] Bai, X. J., **Lu, G.**, **Hossain, M. M.**, Szuhánszki, J., Daood, S. S., Nimmo, W., **Yan, Y.**, and Pourkashanian, M. (**2017**). 'Multi-mode combustion process monitoring on a pulverised fuel combustion test facility based on flame imaging and random weight network techniques'. *Fuel* 202: 656-664. doi: 10.1016/j.fuel.2017.03.091.

Grants and Awards

Between **2005** and **2020**, the underpinning research was supported by 14 externally funded grants and industrial contracts, with a total value of £2.5 million, from EPSRC, Innovate UK, European Union, the Royal Academy of Engineering, and the Royal Society, as well as industrial partners. These include four key grants with a total of £1.2 million from EPSRC (EP/F061307, EP/G002398, EP/G002398 and EP/G062153).

Kent's pulverised fuel flow metering technology was recognised by the Best Paper Award (1st Place) at the IEEE International Instrumentation and Measurement Technology Conference in **2016** and the Best Application Prize by the IEEE Instrumentation and Measurement Society in **2017**.

4. Details of the impact (indicative maximum 750 words)

Since **2014**, Professor Yan and his team's research in the area of combustion instrumentation and their extensive industry collaboration have led to the implementation of fuel flow metering and burner flame imaging applications in more than 20 coal-fired power plants across Europe and Asia. The research and technology have also been used for the diagnosis of full-scale power generation units and the basis of best practice consultancy for several leading industrial partners, including RJM International (UK, **2014-present**), Doosan Babcock Energy (UK, **2017-19**), EDF Energy (UK, **2019-present**), British Sugar (UK, **2015-19**), Enlandar Instrumentation and Control (China, **2014-present**), and Walsn Energy (China, **2019-present**).

Through this widespread adoption, Yan's research has achieved significant commercial impact for industrial partners in the UK and internationally, in the form of improved technology competitiveness, fuel conversion efficiency, best engineering practice, and increased productivity. Additionally, the technologies have enabled improvements in process efficiency, leading to a significant reduction in environmental emissions.

Pulverised fuel flow metering: commercial and environmental impact

Commercial pulverised fuel flow metering systems operating on the electrostatic sensing principle developed by Yan and his team have been installed on 23 coal-fired power stations across China since **2014**, in collaboration with Enlandar Instrumentation and Control **[a]**. In addition, the latest commercial prototypes that combine electrostatic sensing and acoustic emission techniques were demonstrated on three coal-fired stations in China between January and October **2020 [b]**.

The deployment of the systems has helped the plant operators to measure and subsequently control the fuel milling and injection processes. The commercial impact has been significant. For example, the Director of the Production Technology Department at Luyang (1000 MW) Power Station in Henan Province states that: 'We have estimated that the deployment of the fuel flow measurement system and the optimization control system has brought a reduction of coal consumption by 2.81 g/kWh and increased boiler efficiency by 0.9%. This savings in fuel and higher boiler efficiency are equivalent to US$0.93 million extra profit per year. I understand the fuel flow metering and the optimization control technology has been deployed at over 20 coal-fired power stations in China since 2014. The overall extra profit of such power stations due to fuel savings is estimated to be around US$40 million' **[a].**

Lowering carbon emissions from coal-fired power generation not only benefits the countries where the instrumentation systems are installed but also has a positive impact on the global environment. The Deputy Director of the Institute for Thermal Power Engineering at Zhejiang University explains that: 'The environmental benefits of [Yan's] research are enormous in terms of efficient use of fossil and renewable fuels and reduction of pollutant emissions from power stations' **[c]**.

In addition to these direct commercial and environmental impacts, the technology has wider benefits. The resulting efficient utilisation of coal for power generation means that electricity can be produced more cheaply, leading to lower electricity costs for consumers. Moreover, the fuel flow measurement technology has enabled power plants to fire low-ranking coals, and thus to reduce their dependence on high-quality fossil fuels, with a significant implication for energy security **[a, b]**.

Burner flame imaging: consultancy and professional impact

Since **2014**, Kent's Instrumentation team has been commissioned by a number of industrial partners for collaborative projects and consultancy on the use of the flame imaging technology. These include British Sugar (UK, **2015-19**), Doosan Babcock Energy (UK, **2017-19**), EDF Energy (UK, **2019-present)**, Jimah Power Station (Malaysia, **2020-present**), Moneypoint Power Station (Ireland, **2017-18**), Mong Duong II Power Station (Vietnam, **2019-20**), and RJM International (UK, **2014-present**). These partners have applied the team's expertise in flame imaging to observations of difficult and unstable burner flames of a range of fuels, and gained first-hand knowledge of the fuels, burners, and the combustion conditions from the practical flame imaging data provided. Such data has also provided scientific evidence for flame quality and stability assessment for low-quality fuels on full-scale power stations. Examples of the direct impact of this technology include:

1. The Kent team has collaborated extensively with RJM International, one of the world's leading combustion and emission specialist companies. RJM used the flame imaging technology on Moneypoint, the largest coal-fired electricity generation station in Ireland (**2017-18**) and Mong Duong II Power Station in Vietnam (**2019-20**), with planned future applications at Jimah Power Station in Malaysia in 2021 **[d]**. RJM International's Process Engineer explains that: 'The practical flame imaging data provided first-hand knowledge of the fuels, burners and the combustion conditions, and proved critical for the optimisation of existing power stations and in the design of new power plants' **[d]**. They also state that: 'Optimising the plant settings with the use of the Kent technology has been shown to "free up" typically 19 kg/s air and thus prevent carbon monoxide (CO) breakaway on the generation unit. On the basis of 1000ppm CO production equating to 3.77 MJ/s loss, this gives an annual benefit of £91.5k per unit' **[d].** Yan's work with RJM International also has a direct environmental impact: 'The technology pioneered by you and your Kent team is especially important to us, our business practice and thinking as we move towards conversion of existing coal fired power stations to 100% biomass firing in order to reduce the United Kingdom's carbon dioxide emissions' **[d]**.

2. Doosan Babcock has benefited from an in-depth understanding and subsequent optimisation of high-moisture coal (a special type of coal) combustion, as the flame imaging technology enabled them to gain substantial practical flame data from their 40 MWth test plant in Glasgow **[e]**. Doosan Babcock's Specialist Engineer confirms: 'The practical flame imaging data had provided first-hand knowledge of the fuels, burners and the combustion conditions, and the information was analysed and used in the design and test of new burners at Doosan Babcock' **[e].**

3. A dedicated flame imaging system employing the Kent technology was installed on the UKCCSRC PACT Facilities near Sheffield in **2017**, and has been used routinely for a range of industrial scale test purposes **[f]**. The PACT business development manager

has described how 'The in-flame measurements were significantly complemented by the flame imaging technology developed by the Kent team to provide a comprehensive understanding of the air- and oxy-biomass flames. The work was considered to be the step forward of applying flame imaging techniques in realistic industrial environments, and thus providing valuable data and experience for transferring the techniques to full-scale industrial applications' **[f].**

Instrumentation technologies: impact on professional practice

Alongside these direct industrial, commercial, and environmental impacts, the power generation industry as a whole has gained indirect benefits from the instrumentation technologies, through the Kent team's ongoing collaborations, consultancy, training, and technical presentations. The team's work on pulverised fuel flow measurement and burner flame monitoring has influenced engineering practice across the sector. This includes the methodologies and procedures that are now widely adopted in the automated acquisition and analysis of fuel flow and flame data. The concept and quantification of flame stability index is a good example, demonstrating the influence of Yan and his team's work on engineering practice in the power and related industries, specifically on how flame stability is measured and utilised for comparison and optimisation of different burners.

Yan and Lu were invited to deliver keynote lectures at several international conferences (CCT2014, SCOReD2016, ISCTE-IUL2018, CICS2019 and ISTM2019), many of which were attended by power-plant operators and combustion engineers. The research outputs from the Kent team have been widely referenced by industrial practitioners **[c, d, e, f]**. As evidence of their professional esteem, Yan was a Distinguished Lecturer at the IEEE Instrumentation and Measurement Society (**2012-18**) and was elected as a Fellow of the Royal Academy of Engineering in **2020**, whilst Lu has been an active member of the Energy Institute since 2009.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[a] Letter from the Director of Production Technology Department, Luyang Power Station in China, confirming the impact of Kent's pulverised fuel flow metering technology on the operation of coal-fired power stations in China.

[b] Letter from the Technical Director of Walsn Energy in China, confirming the impact of Kent's pulverised fuel flow metering and online particle sizing technologies on the operation of coal-fired power stations in China.

[c] Letter from the Deputy Director of the Institute of Thermal Power Engineering at Zhejiang University, P.R. China, confirming how Kent's flame imaging technology is applied in the power industry.

[d] Letter from the Corporate Engineer at RJM International, confirming the application of Kent's flame imaging technology in the operation of their business to resolve a range of problems at coal- and biomass-fired power stations.

[e] Letter from the Specialist Engineer at Doosan Babcock, confirming the application of Kent's flame imaging technology in their industrial combustion test facility to quantify new fuels and burner design.

[f] Letter from the Business Development Manager at UKCCSRC PACT Facilities, confirming the routine usage of the flame imaging system on the PACT.