Institution: University of South Wales

Unit of Assessment: B15

Title of case study: Industrial modelling and monitoring

1. Summary of the impact

This case study is an example of the impact of the ERC, which specialises in furnace and utility boiler modelling and monitoring through research in collaboration with European Industrial partners. Modelling work primarily based around the zone method and physical acid-alkali modelling has led to significant NOx reductions (50%+) for the glass melting process and this work is currently being demonstrated on the furnaces of Owens Illinois and SiseCam. The monitoring work has demonstrated that by monitoring spectral information from individual flames it is possible to reduce NOx emissions from utility power station burners by as much as 40%.

2. Underpinning research

Wilcox, Chong and Tan have worked closely with significant industrial stakeholders, such as, Tata Steel, Doosan Power Systems, EDF, EON and GDF Suez on long term projects that have been funded over, in general, more than one grant. It is this long term view to collaboration with key industrial partners that has been at the core of the ERC since its inception. Our extensive research focuses on two main aspects:

a) The application of modelling techniques to better understand industrial combustion and heat transfer problems so as to be able to improve efficiency and reduce emissions.

b) The development of flame monitoring techniques to be able to individually assess the combustion at an individual burner level by the use of relatively inexpensive instrumentation. This work is aimed at detecting burner instabilities and burner control for emissions and combustion efficiency.

The ERC specialises in both mathematical modelling of the heat transfer within a furnace using the zone modelling technique first expounded by Hottel in 1958 and acid-alkali modelling of the transient phenomena of furnaces. Examples of this collaborative work include two Carbon Trust supported projects (2002-6-8 & 2004-6-1330), in collaboration with Gaz de France (now GDF Suez) and Global Combustion Systems, a leading UK supplier of combustion equipment to the glass industry on the development of alternative firing techniques for glass melting furnaces. This research has resulted in reductions in NOx emissions of more than 60%, without adverse effects on heat transfer, in experimental tests on a 1 MW pilot furnace. GDF Suez has taken out patent protection (French Registration Number 06 55 571) and (PCT/FR2007052518) on behalf of all three partners and licensing arrangements have been agreed for exploitation of the technology. Patent cover has subsequently been extended to Europe and the USA as well as other key territories world-wide. The University of South Wales and its team of inventors will be beneficiaries from net royalties generated. This work is currently being demonstrated as part of an FP7 project (296042) in collaboration with two leading glass manufacturers Owens Illinois (France) and Sise Cam (Turkey).

Industrial monitoring includes European Coal & Steel Community programmes (7220-PR/047 & 7220-PR/076) concerned with monitoring and control of combustion plant using low cost sensors coupled with neural networks. These techniques were used to maintain the excess air levels and NOx emissions within acceptable limits for large pulverised coal-fired burners. The changes in flame characteristics detected by the sensors were used to monitor the formation of large near burner slag deposits in coal-fired test facilities at the UK Coal Research Establishment and RWE npower. The success of this work has resulted in the European Research Fund for Coal and Steel (RFCS) sponsoring further work (RFSR-CT-2005-00009) on intelligent monitoring and control of gas-fired burners with Corus UK and partners in the Netherlands, Germany, Spain and Sweden. Pilot scale trials have been successful and full-scale tests on large production steel furnaces have been undertaken in the UK and at Arcelor in Spain. In further work, Wilcox has coordinated (7220-

PR/081 match funded by BCURA B51) an ECSC programme on control of stoker-fired boilers and fluidised beds with INETI in Portugal and James Proctor Ltd. in the UK.

3. References to the research

1. Tucker, R. and Ward, J. 'Identifying and quantifying energy savings on fired plant using low cost modelling techniques', *Applied Energy*, **89**(1):127-132, January 2012

2. Ward, J., Tucker, R.J., Correia, S.A.C. and Rhine, J. 'The use of permeable refractory linings for enhancement of the thermal performance of a high-temperature furnace', *Journal of the Energy Institute*, **78**(1):11-17, April 2005
   This work took place in collaboration with Hotwork Combustion Technology Ltd.

3. Alves e Sousa, João, Correia, S.C., Ward, J., Nogueira, M. 'Modélisation de zone multidimensionnelle et transitoire d'un four à rouleaux', *Industrie Ceramique et Verriere,* **986**, 44-54, April 2003 Language: French

4. Tan, Chee-Keong, Jenkins, J., Ward, J., Broughton, J. Heeley, A. 'Zone modelling of the thermal performances of a large-scale bloom reheating furnace' *Applied Thermal Engineering*, **50**(1):1111-1118, 2013
   This work took place in collaboration with Tata Steel Swinden Laboratories.

5. Chong A.Z.S., Wilcox S.J. and Ward J. 'Application of a Neural-Network Based Controller on an Industrial Chain Grate Stoker Fired Boiler'. *Journal of the Institute of Energy*, **73**, 208-214, 2000.
   This work was funded by the British Coal Utilisation Association and led to further work funded by the European Coal and Steel Community.

6. Tan C.K., Wilcox S.J., Ward J. and Lewitt M. 'Monitoring Near Burner Slag Deposition with a Hybrid Neural Network System'. *Measurement Science and Technology*, **14**(2003), 1137-1145.
   This work was funded by the European Coal and Steel Community and took place in collaboration with RWE npower and Gas Natural fenosa.

4. Details of the impact

The impact of the work of the ERC can be seen in the demonstration of developed techniques at the industrial scale in collaboration with EU industry. It has made an impact in the glass melting, power generation and steel manufacturing industries.

In collaboration with GDF Suez and Global Combustion Systems Ltd. an alternative firing technique for use during the manufacture of glass is now being demonstrated through an European 7th Framework demonstration grant that GDF Suez is coordinating with Global Combustion Systems and the University of South Wales, the original research partners, and with the additional glass manufacturer partners of Sise Cam in Turkey and Owens Illinois in France. The original research was funded through two Carbon Trust grants in collaboration with GDF Suez and GCS in 2002 and 2004. The new firing method has been demonstrated successfully at pilot scale. The patented technique (patent held by GDF SUEZ on behalf of the University of South Wales and Global Combustion Systems with royalties being shared via a collaboration agreement) uses auxiliary injection of part of the fuel to yield significant NOx reductions (60%+) and efficiency improvements (2-5%) with no adverse impact on the furnace crown temperature or heat transfer to the glass. The impact and contribution of the University of South Wales has been through its modelling work. Zone modelling as a computationally efficient technique enables parametric studies to be undertaken of a large number of interesting scenarios, in a way that would not be possible with computational fluid dynamic modelling. This modelling is used by the consortium to identify likely locations for the auxiliary injection and then complementary modelling with a Perspex scaled model of the glass melting furnace, using the acid-alkali technique, is used to enable the

temporal dynamics of the furnace to be simulated. This has enabled the ERC to advise the consortium as to which furnace configurations to discount due to instabilities in the furnace, again something that is extremely difficult to accomplish with CFD. Similar modelling work in collaboration with Tata Steel in the UK (that has developed over two CASE PhD awards and earlier work with Wyman-Gordon, USA, has yielded a 3D model of the heat transfer characteristics of a real industrial steel reheating furnace that is able to operate in near real time. These rapid simulation times make the modelling technique suitable for use in process control and to undertake parametric studies of different furnace scheduling configurations. Recently the ERC has been successful in obtaining a RFCS research project, coordinated by VDEh-Betriebs-forschungsinstitut GmbH in Germany with Tata in the UK and Gerdau Sidenor in Spain and Swerea MEFOS in Sweden, that will further develop these modelling techniques for a range of industrial reheating furnaces in the EU to enable advanced scheduling of steel reheating.

Another example of the impact of the work of the ERC is the demonstration of burner monitoring techniques to control coal/biomass combustion on a utility power station (Dolna Oldra, Poland) in a Research Fund for Coal and Steel sponsored project (RFCR-CT-2008-00009). Partners on the project were the Institute of Power Engineering (Poland), University of Zaragoza (Spain), Gas Natural Fenosa (Spain) and Indra Systems (Spain). The project was coordinated by Wilcox and successfully demonstrated a developed intelligent monitoring system able to reduce emissions and increase the combustion efficiency of full-scale industrial burners co-firing various coals and straw. The technique uses relatively inexpensive sensors to monitor the individual flame and from the information recorded it is possible to extract salient features in the joint time-frequency domain and then use artificial neural networks to detect burner instabilities and correlate with the individual burner emissions. This information was then used to demonstrate individual burner control for NOx and excess air. Wilcox is coordinating a FP7 project under the Energy programme (FP7-ENERGY-2010-2 268191 RELCOM “Reliable and Efficient Combustion of Oxygen/Coal/Recycled Flue Gas Mixtures”) that is undertaking a systematic and focused series of applied research, development and demonstration activities involving both experimental studies and combustion modelling work to enable full-scale early demonstration oxyfuel plant to be designed and specified with greater confidence as well as providing improved assessment of the commercial risks and opportunities. The monitoring of flames under these conditions is crucial to ensuring flame stability (www.relcomeu.com).

5. Sources to corroborate the impact

Confidential letters from industrial collaborators

1. Letter from Tata Steel Swinden Technology Centre, Rotherham, South Yorkshire. S60 3AR
2. Letter from GDF SUEZ, Research and Innovation, Saint-Denis La Plaine, Paris, France. 93211
3. Letter from Global Combustion Systems, Edinburgh
4. Letter from Institute of Power Engineering, Warsaw, Poland.

Reports in the public domain

1. SMARTBURN final public report (http://bookshop.europa.eu/en/the-intelligent-control-and-optimisation-of-power-station-boilers-firing-pulverised-coal-and-coal-biomass-blends-smartburn--pbKINA25860/)
2. SMARTFIRE final public report (http://bookshop.europa.eu/en/smartfire-pbKINA24174/)