Chapter 14
Oxy-fuel Combustion for Carbon Capture and Sequestration (CCS) from a Coal/Biomass Power Plant: Experimental and Simulation Studies

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Abstract Oxy-fuel combustion is a promising and relatively new technology to facilitate CO_2 capture and sequestration (CCS) for power plants utilising hydrocarbon fuels. In this research experimental oxy-combustion trials and simulation are carried out by firing pulverised coal and biomass and co-firing a mixture of them in a 100 kW retrofitted oxy-combustor at Cranfield University. The parent fuels are coal (Daw Mill) and biomass cereal co-product (CCP) and experimental work was done for 100 % coal (w/w), 100 % biomass (w/w) and a blend of coal 50 % (w/w) and biomass 50 % (w/w). The recirculation flue gas (RFG) rate was set at 52 % of the total flue gas. The maximum percentage of CO_2 observed was 56.7 % wet basis (73.6 % on a dry basis) when 100 % Daw Mill coal was fired. Major and minor emission species and gas temperature profiles were obtained and analysed for different fuel mixtures. A drop in the maximum temperature of more than 200 K was observed when changing the fuel from 100 % Daw Mill coal to 100 % cereal co-product biomass. Deposits formed on the ash deposition probes were also collected and analysed using the environmental scanning electron microscopy (ESEM) with energy-dispersive X-ray (EDX) technique. The high sulphur, potassium and chlorine contents detected in the ash generated using 100 % cereal co-product biomass are expected to increase the corrosion potential of these deposits. In addition, a rate-based simulation model has been developed using Aspen Plus® and experimentally validated. It is concluded that the model provides an adequate prediction for the gas composition of the flue gas.

Keywords Oxy-fuel combustion • Carbon capture and sequestration (CCS) • Co-firing coal and biomass • Process modelling

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List of Abbreviations

CCP	Cereal co-product
CCS	CO_2 capture and sequestration
db	Dry basis
EDX	Energy-dispersive X-ray
ESEM	Environmental scanning electron microscopy
FB	Fluidised bed
FTIR	Fourier transform infrared
NO	Nitric oxide
NO_x	Nitrogen oxides
PF	Pulverised fuel
RFG	Recirculation flue gas
SO_x	Sulphur oxide
w/w	Weight ratio
wb	Wet basis

14.1 Introduction

There are three major carbon capture technologies that could reduce emissions from fossil fuel power plants: pre-combustion capture, post-combustion capture, and oxy-fuel combustion capture. Oxy-fuel combustion has several features which makes it a very attractive technology for implementation in both existing air-firing and new power plants. These features include generation of a flue gas with a high percentage of CO_2 which is more easily captured, reduction in the size of the flue gas conditioning equipment, no additional space required for the post-combustion capture equipment, and also reduced environmental impacts compared with the other carbon capture technologies [1].

The main disadvantage of oxy-fuel combustion technology is the efficiency loss and cost associated with generating high-purity O_2 by cryogenic separation. Nonetheless, oxy-firing remains an extremely promising option as it requires minimal modification of existing coal-fired plants, and for coal firing at least it can already be considered to be near commercial technology. This is, however, not the case for co-firing with biomass. Such studies that have been done on co-firing of coal and biomass have noted that the ignition temperature decreases as the proportion of biomass in the fuel increases [2, 3]. It is found that the fuel burnout improves when oxy-firing blends of coal and biomass [2, 4, 5]. Recycling the flue gas to the oxy-combustor decreases or returns the nitric oxide (NO) content and sulphur oxide (SO_x) emissions (sulphur is retained in the ashes) per energy unit of fuel combusted. It has been suggested that boiler corrosion problems are likely to appear as the acid gases increase in the flue gases, as compared with the air-firing case [6, 3]. It has been also pointed out that some problems are likely to appear during the utilisation of the cement or concrete fabricated with the fly ashes generated in the oxy-combustion process, due to the higher content of SO_x retained by them [3]. It is, therefore, clear that while much is known, more research is required on a wide range of biomass fuels co-fired with coal in oxy-fuel systems. Ideally, experimental programs should be supported by process modelling, so the results of such tests can be generalised and used to provide data on scale-up.

Typical commercial packages used to support experimental studies or model full-scale systems include Fluent, Chemkin Pro, Aspen Plus or Hysys®, gPROMS® or Thermoflex®. However, prior to the use of this software to study combustion processes, such as conventional combustion, fluidised circulating bed combustion and oxy-firing, rigorous research was undertaken on the characterisation of char combustion [7, 8]. Researchers have investigated the oxy-firing process using Aspen Plus® [9], and circulating fluidised bed using coal as fuel in air-firing conditions [10, 11], both using coal as fuel in oxy-firing assuming equilibrium conditions. However, to date few authors have performed simulations on oxy-firing for co-firing using Aspen Plus®. The work endeavours to fill this gap, by providing such an experimental study using a 100 kW unit, together with a simulation of co-firing coal and biomass blends. The rate-based simulation model was designed to predict the gas composition and temperatures reached in the oxy-combustion mode, although with the simplifying assumptions proposed [12].

14.2 Experimental Approach

Air-firing of the fossil fuels results in relatively low concentration of CO_2 in flue gases which make the capture of CO_2 difficult and expensive. Oxy-firing combustion is a novel method of using enriched oxygen for coal/biomass combustion with recycled flue gases (RFG) to control the adiabatic flame temperature and to increase the CO_2 concentration of the off-gases up to 60–70 % in oxy-firing mode (compared to air-fired mode, around 12–14 %). This new technology is being applied at Cranfield University to retrofit an existing 100 kWth air-firing down-fired multi-fuel combustor to the oxy-firing mode. The retrofitting process of this combustor consisted of several phases and during that the following modifications and measurement systems have been implemented on the rig (see Fig. 14.1):

- Installation of flue gas recirculation line (recycle mode)
- Installation of the primary and secondary lines of the oxygen feedings
- Fitting an axial swirler in the air inlet port of the burner to improve mixing
- Installation of a gas-tight fan for recirculation of the flue gases
- Employing a gas-tight and CO_2 purged fuel feeder facility
- Water and SO_x removal facilities (in general acidic species)
- Gas analyser, thermocouples for measurement of the process environment
- Collection and analysis of the ash deposits

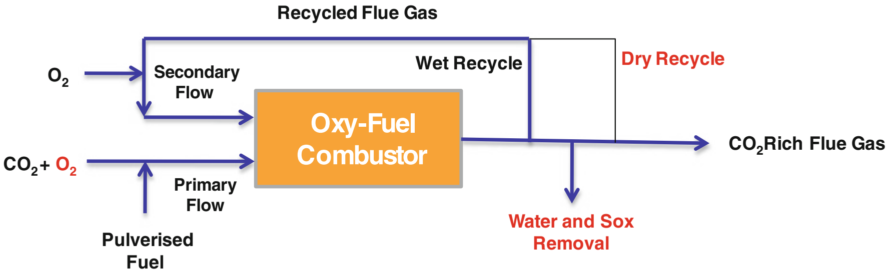

Fig. 14.1 Simple flow diagram of Cranfield University oxy-fuel combustor (*red*: recent modifications)

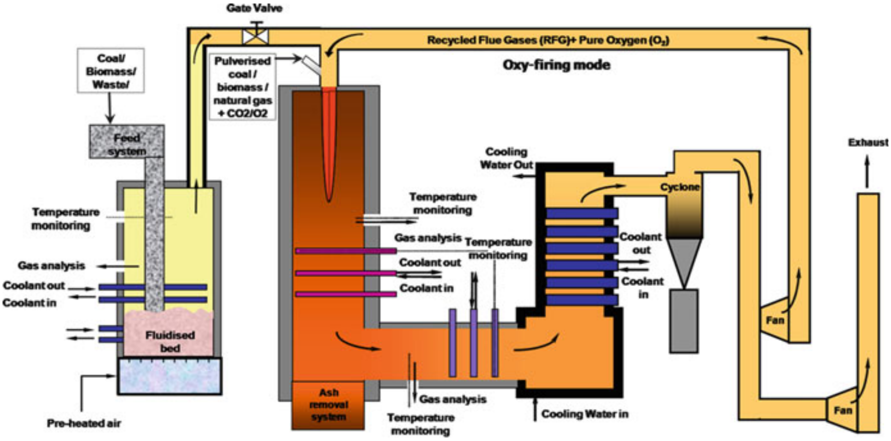

Fig. 14.2 Diagram of multi-fuel combustion rig at Cranfield University including the RFG pipe for the oxy-firing mode

Figure 14.2 illustrates a schematic of the multi-fuel combustor rig at Cranfield University. This rig, which has been retrofitted for the oxy-fuel combustion experiments, comprises both a fluidised bed (50 kWth) and a down-fired pulverised fuel combustor (100 kWth). For the oxy-combustion tests here, only the pulverised fuel (PF) combustor was used, with the gate valve, placed between the fluidised bed (FB) and the PF, closed to isolate the fluidised bed section of the reactor.

The pulverised fuel is fed to the oxy-combustor at a constant rate using a fuel feeder provided by a metering screw, a vibratory tray and a venturi eductor. Additionally, the feeder has three purge points located at the main storage hopper, at the feeding hopper and at the end of the vibratory tray feeder. CO_2 is injected through these purge points to keep a positive pressure inside the pulverised fuel feeding system so as to avoid air ingress once the pulverised fuel reaches the venturi eductor; it is fluidised and conveyed to the burner by a stream of pure CO_2 gas coming from CO_2 cylinders. Prior to this stream being fed to the burner, the primary O_2, coming from O_2 cylinders, is also injected into the primary stream.

The combustor is equipped with a down-fired burner, provided with a pilot flame port and a flame detector. The pulverised fuel is combusted in the vertical zone of the combustor (3.7 m height). The combustor has a square cross section with sides of 650 mm and thermal isolation with thickness of 175 mm. The vertical zone has four view ports and ports where sensors are used to measure wall temperatures (six type K thermocouples). The data acquisition system is a Pico Logger Unit-TC-08. More thermocouples are installed along the rig monitoring: inlet and outlet temperature of the water used in the refrigeration system, at the heat exchanger section, temperature after the cyclone and six more thermocouples to measure the temperature along the recirculation line. These sensors are sampled using the data logger, with 24 sampling ports distributed along the vertical and horizontal sections of the chamber. Three of these ports, placed at the bottom part of the vertical section, are used by the deposition probes. To collect the deposits, it was necessary to allow the chamber to cool down for 18–24 h, and then the ash deposited on the probes was sampled and analysed using ESEM/EDX. An online high-resolution multi-component Fourier transform infrared (FTIR) gas analyser is connected to one of the aforementioned sampling ports located at the vertical section of the chamber to measure the composition of the oxy-combustion gas.

The exhaust gas goes through two water-cooled heat exchangers, one in the horizontal and one in the vertical section, before exiting the oxy-combustor. Finally, after leaving the chamber, the gas enters a cyclone where the suspended particles are removed. Then part of the gas is recirculated to the combustion chamber and the rest is sent to the stack. The pipelines that convey the recycled flue gas are thermally isolated with a trace heating system to avoid a temperature drop below the acid dew point of the flue gas. The secondary O_2 is injected into this stream prior to feeding it to the oxy-combustor.

The PF oxy-combustor at Cranfield University is based on a retrofit to the existing air-firing combustor. The retrofitting process involved the installation of the recirculation line including setting up the recirculation fan, the O_2 injection to the recycle flue gas (secondary O_2) and trace heating wiring to prevent condensation in the flue gas recirculation lines. Additionally, a line to supply the CO_2 was installed to convey the pulverised fuel from the hopper to the burner itself. The second phase covered the design and fitting of an axial swirler in the air inlet port of the burner; the implementation of a gas-tight fan to recirculate the flue gas; the primary O_2 injection, added to the stream conveying the fuel to the combustor; installation of the gas-tight fuel-feed hopper and the design and replacement of a new CO_2 supply line, to respond to the design requirements of the new fuel feeder.

For these tests 100 % coal (w/w), 100 % biomass (w/w) and blend of coal 50 % (w/w) and biomass 50 % (w/w) were used. The coal used was Daw Mill and the biomass was cereal co-product (CCP), the analyses of which are shown in Table 14.1.

The experiments have been carried out with recirculation of 52 % (v/v) flue gas to the oxy-combustor. Calculations have been carried out for the cases in which the

Table 14.1 Analysis of Daw Mill and cereal co-product (CCP)

Properties	Daw Mill	CCP
CV, kJ/kg (as received)		
– Gross	25,260	17,610
– Net	24,107	16,340
Proximate analysis (% (w/w))		
– Moisture	4.6	8.1
– Fixed carbon	62.78	18.39
– Volatile matter	32.8	77.04
– Ash	4.4	4.57
Ultimate analysis (% (w/w))		
– C	77.7	47.22
– H	4.5	6.46
– N	1.2	3
– Cl	0.2	0.18
– S	1.3	0.17
– O	10.9	38.4
Sulphur analysis (% (w/w))		
– Pyritic	0.2	0.06
– Sulphate	0	0.05
– Organic	1.1	0.06

O_2 would be fed to the process at a 5 %, 10 % and 21 % (v/v) excess. To ensure safe conditions for the oxygen injection, the oxygen percentage in the primary stream must not exceed 21 % (v/v). For the secondary stream, which mainly comprises the recycled flue gas, the upper limit for the oxygen content is 28 %. These limits are selected to ensure that the oxygen leaving the combustor varies between 3 and 5 % (v/v). The operating pressure in the combustor must be below atmospheric pressure due to design conditions. However, to minimise the air ingress into the chamber, the pressure during the experimental tests was kept as close as possible to atmospheric pressure.

14.3 Simulation Approach

Limited publications are available giving the results of oxy-combustion of blends of coal and biomass considering the kinetics for the char combustion, and this chapter seeks to explore these issues further. In the model suggested here, a number of reactors have been defined to recreate as faithfully as possible the experimental process. The main effort has been focused on providing a mathematical model of the reactor where the char particles are oxy-fired. Furthermore, an equation has been proposed to provide the kinetics in the oxy-combustor. Additional reactors have been included in the model to simulate the gas treatments (particle removal and desulphurisation) before the recirculation of the flue gas to the combustor or its proceeding to the next stage of the carbon capture process (CO_2 purification and compression).

The implementation of the model presented in this chapter has been carried out using Aspen Plus® V7.3 and has taken place in two stages. A model based on the equilibrium of the reactions was first defined. The aim of this stage was to perform an initial analysis of the resulting mass and energy balances, providing an assessment of the contribution of different inputs including: percentage of oxygen excess; percentage of recycled flue gas (RFG); heat loss in the RFG stream and air ingress into the process. The equilibrium model was developed taking into account the published works [10, 11], as well as Aspen Plus® tutorials/guidelines. In the second stage, a kinetic model was developed. The additional output of this model provides a more realistic approach to the process than the equilibrium one. The criterion adopted here is to ensure the same heat transfer as in the air-firing case [13]. However, this chapter focuses on the explanation of the kinetic simulations.

The oxy-combustor is simulated using five reactors: the first one serves to convert the fuel, which is regarded as a nonconventional solid, to a conventional one; then there is a reactor to perform the combustion of the volatile species of the fuel; a reactor to simulate the combustion of the char; a reactor where the thermal nitrogen oxides (NO_x) are generated and, lastly, a reactor to simulate the generation of NO_x from the N of the fuel. A variation of the previous case study was considered, in which an additional block was implemented to simulate the partial condensation of H_2O vapour during recirculation of the flue gas to the oxy-combustor. This set of simulations was necessary so as to have a kinetic model with operating conditions as similar as possible to the experimental tests performed in the pilot plant. The box plot for the rate-based case is presented in Fig. 14.3.

In the next stage a rate-based model with partial condensation will be developed for dry recirculation modelling. To define the amount of H_2O vapour that condenses in this reactor, the vapour pressure of the H_2O at the minimum temperature reached in the flue gas will be considered. This value established the maximum concentration in the gaseous phase that the H_2O vapour could have. Thus, if the H_2O vapour concentration is higher, it will condense.

The methodology adopted to compare results from simulations and experimental data was, first, to set up operating conditions as similar as possible to the experiments, and, second, to perform the simulations comparing the results generated by the model in Aspen Plus® regarding gas composition and temperatures reached.

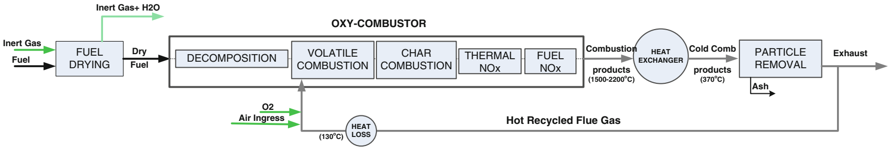

Fig. 14.3 Box plot of the rate-based model

For the first step (establish similar operating conditions), it was necessary to find out the amount of air ingress into the process which occurred during the experiments. This was accomplished using mass balances based on the experimental data. In addition air ingress was varied in the model, until analogous values generated by the simulations to the empirical gas composition were obtained. Although the air ingress is an unknown variable that needed to be characterised, other operating parameters were changed in the simulations to find out the combination that best represented the experimental conditions during the tests. These parameters were percentage of RFG, excess of oxygen fed and amount of water vapour condensed.

14.4 Results and Discussion

14.4.1 Experimental Results

Major emission species (CO_2, O_2, H_2O) and minor emission species (SO_2, CO, NO, NO_2, N_2O, HCl, CH_4) and gas temperature profiles were obtained and analysed for different fuel mixtures. Figure 14.4 shows the typical emission profiles of gaseous species using different fuels (100 % Daw Mill coal, 100 % CCP biomass and 50 % Daw Mill coal-50 % CCP biomass).

As expected, the highest percentage of CO_2 in the flue gas is achieved when 100 % Daw Mill is burned. A summary of the maximum values for CO_2 and average values for H_2O, O_2, SO_2 and CO achieved is given in Table 14.2. These data are in qualitative agreement with typical gas compositions obtained in different facilities by other authors [14–16] as shown in Table 14.2. The quantitative effect of the amount of air ingress on decreasing of the CO_2 concentration follows the trend suggested by [14]. In the graph proposed by these authors an increment in the air ingress into the process of 1 % causes a drop in the CO_2 content of around 3.5 %. The main points where the air leakage takes place are believed to be in the recirculation fan and along the oxy-combustor. In reality, the same type of issues would be faced in retrofitting an existing power plant, so it is necessary to explore the effect of such leakage. In addition, such data are relevant to hybrid concepts, where oxy-fuel is combined with amine scrubbing [17].

The content of H_2O vapour measured in the flue gas increases when the content of biomass in the fuel as expected is higher. Problems related to the performance of the FTIR analyser were observed during the test where 100 % CCP was used and in the future a condenser will be placed between the cyclone and the recirculation fan as conditioning equipment for the RFG.

The measured SO_2 concentration follows the trend of decreasing when the content of biomass in the fuel is higher. This was expected given that the biomass used here has one-eighth the sulphur present in the coal used. However, while the case where co-firing 50 % coal-50 % biomass shows a content of SO_2 in the flue gas in agreement (same order of magnitude) with the theoretical prediction (1,217 ppm

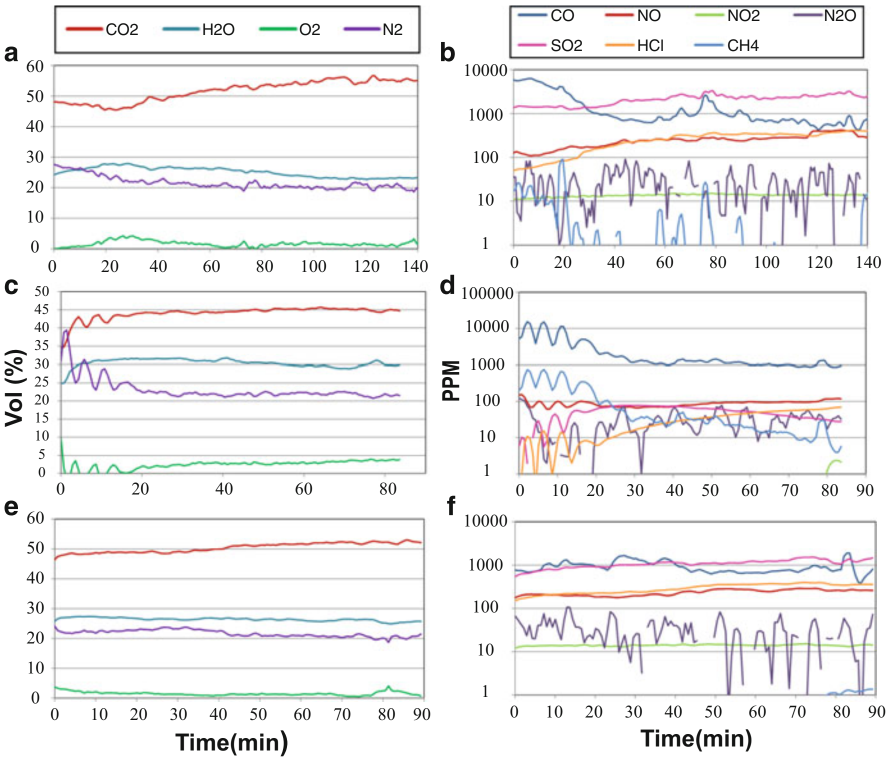

Fig. 14.4 Gas composition of the flue gases from the experimental work. (**a**) Main species 100 % Daw Mill. (**b**) Minor species 100 % Daw Mill. (**c**) Main species 100 % CCP. (**d**) Minor species 100 % CCP. (**e**) Main species 50 % Daw Mill-50 % CCP. (**f**) Minor species 50% Daw Mill-50 % CCP

measured against 1,450 ppm predicted), that is not the case for the test where 100 % of biomass was oxy-fired. The decrease in the SO_2 content when burning 100 % cereal co-product is higher than expected (47 ppm measured against 320 ppm predicted). The most likely reason is that the FTIR analyser results were affected by the very high concentration of H_2O vapour. An additional explanation for the SO_2 content not following the expected trend may be that part of the SO_2 was oxidised to SO_3 and condensed together with the H_2O vapour as H_2SO_4. This may also be a consequence of the temperature dropping below the acid dew point in a particular location of the RFG pipeline.

The CO presence is very high (around 10,000 ppm) during the initial stage of the tests using either 100 % Daw Mill or 100 % cereal co-product. But once the steady operation regime is reached, it drops down to around 850 ppm, on average (800 ppm for 100 % Daw Mill coal; 1,000 ppm for 100 % cereal co-product; 700 ppm for 50 % coal-50 % biomass). It is possible that part of the explanation for this result is that the gaseous species are sampled inside the combustor and are

Table 14.2 Experimental values for gas compositions with comparisons from the literature [14–16]

	Cranfield University						[14]		[15]		[16]	
	100 % Daw Mill coal		100 % CCP biomass		50 % Daw Mill-50 % CCP blend		100 % Coal (10 % air ingress)		Blends of coal and biomass		100 % coal	
	wb	db	wb	db	wb	db	wb	db	wb	db	wb	db
CO_2 (%)	56.7	73.6	45.7	65.3	53	72	62.4	–	55–65	96	68	90
H_2O(%)	23	–	30	–	26.4		4.2	–	–	–	20	–
O_2(%)	1.5	–	3	–	1.5		3	–	–	–	–	–
SO_2 (ppm)	2,000	–	100	–	1,500		–	–	–	–	–	–
CO (ppm)	1,000	–	1,200	–	900		–	–	–	–	–	–

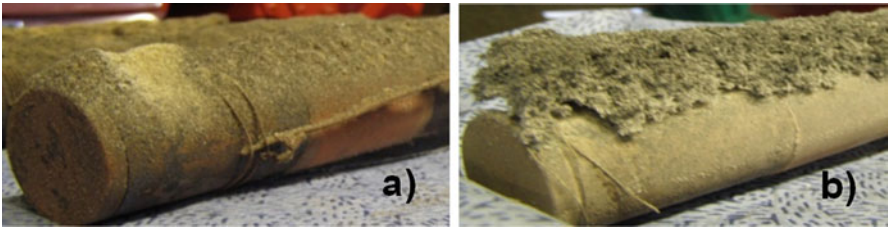

Fig. 14.5 Close-up view of the deposits formed from oxy-firing (**a**) Daw Mill:CCP(50:50 %,wt), (**b**) CCP(100 %,wt)

relatively close to the flame. As such the equilibrium of the exothermic reaction, $CO + 0.5O_2 \leftrightarrow CO_2$, would be shifted towards the generation of CO instead of CO_2, due to the high temperatures and elevated CO_2 [18]. The maximum flue gas temperatures reached during the experimental tests were achieved when oxy-firing 100 % Daw Mill coal (1,100 °C). The temperatures decrease as the content of biomass in the fuel increases, due to the lower heat value of this fuel. The HCl and NO contents decrease in the flue gas when there is more biomass in the fuel.

In terms of ash sampling data, the appearance of the deposits generated using different types of fuel indicates that when using 100 % CCP the structure of the deposit is more fibrous and porous than when oxy-firing 100 % Daw Mill coal or the blend of 50 % Daw Mill-50 % CCP (see Fig. 14.5). Additionally, from the SEM images the larger size of the particles of the 100 % CCP case is observed.

Figure 14.6 shows the elemental concentration (%wt) of the ash generated during the oxy-combustion of different fuels (100 % Daw Mill coal, 100 % cereal co-product biomass and 50 % Daw Mill coal-50 % cereal co-product biomass).

For elements such as K, Mg, Fe and Ti, the trend followed agrees with the previous analysis. It is worth mentioning that K and Mg increase with the percentage of biomass, and Fe and Ti rise with the percentage of coal. Other elements (O, Si) do not show a clear pattern and Ca content increases as the share of biomass increases, showing the opposite behaviour to that expected. The S content in ash increases with the share of biomass in the fuel fired, contrary to expectations given the elemental analysis of the parent fuels shown in Table 14.1 (the S content in coal is eight times higher than in biomass). This may be due to the higher content of K in deposits generated from 100 % CCP, as higher K in the fuel means more K_2SO_4 is likely to form. In addition, the lower temperatures experienced in the reactor may possibly have increased the conversion from SO_2 to SO_3 compared to cases using coal or co-firing [19]. However, the resulting trend for the S content in ash is not very different from the one shown by Stanger and Wall [20], where coals with low S content (0.24 %, db) generated ash with similar SO_3 content to the ash from oxy-firing higher S-content coals (0.88 %, db).

Cl content was only detected in the deposits generated when oxy-firing 100 % CCP biomass. This, together with the higher concentration of HCl in the flue gas

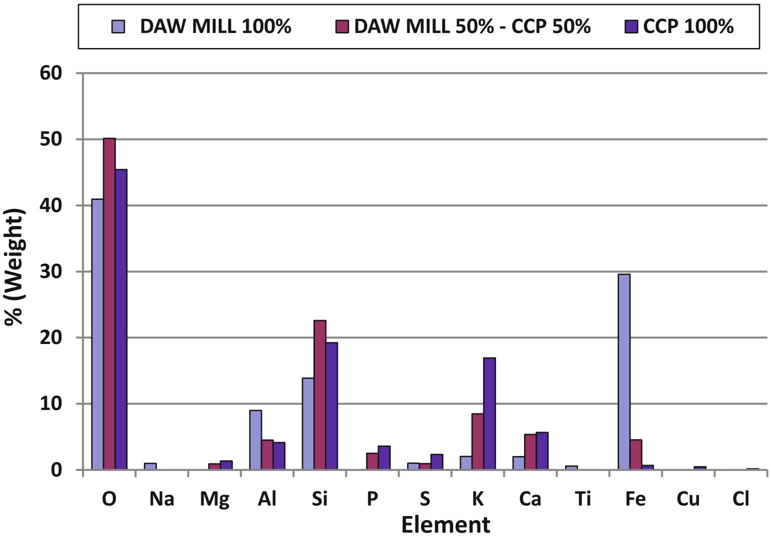

Fig. 14.6 Elemental concentrations of the top ash deposits from oxy-firing different blends of the fuels

generated by 100 % coal and 50 % coal-50 % biomass (also reported by Khodier and Simms [21], indicates that Cl tends to be in the gaseous phase and not retained in the ash deposit when there is a low share of biomass in the fuel.

14.4.2 Simulation Results (with Comparison with the Experimental Data)

To carry out the comparison between the simulation and the experimental data, key parameters such as amount of air ingress into the process, % RFG and % O_2 excess in the combustion stream have been varied within a range to recreate the same operating conditions as in the experimental tests. The experimental data used to validate the rate-based simulation model were generated at the retrofitted Cranfield University oxy-combustor. Each of the parameters varied for the simulations was changed while keeping a fixed value for the rest. The first phase of the rate-based simulations was focused on the study of the effects when the percentage of air ingress varied (2 %, 10 % and 18 % of the total flow rate fed to the oxy-combustor), and the selection of the amount of air ingress that better represented the experimental conditions during the operation of the pilot plant. Figure 14.7 shows the comparison between the experimental data and the results from the intermediate rate-based simulation model (box plot shown in Fig. 14.3).

For these simulations 55 % RFG was used, and two different excess O_2 feed values (0 and 5 %). The CO_2 percentage is better predicted by the simulations that

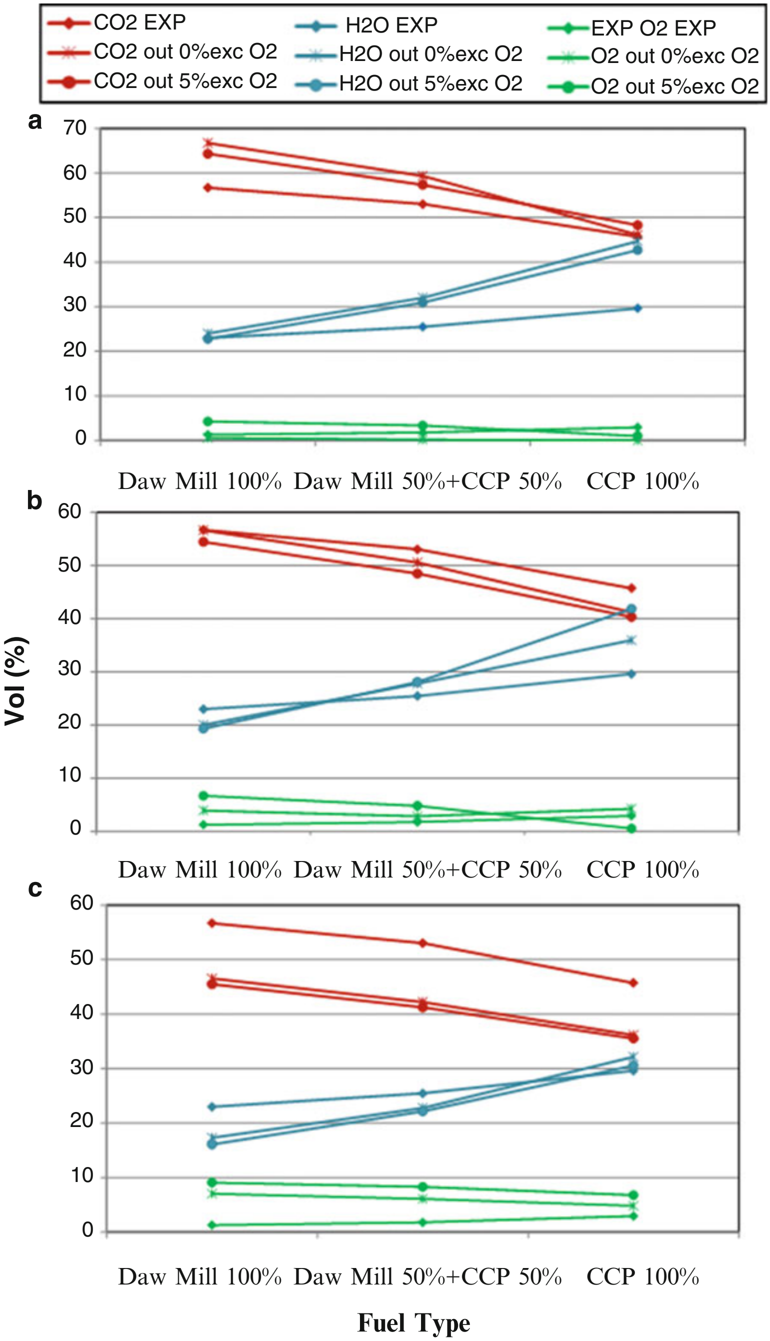

Fig. 14.7 Comparison between experimental results and rate-based simulation data burning different blends of fuel considering different percentages of air ingress. (**a**) 2 % Air ingress. (**b**) 10 % Air ingress. (**c**) 18 % Air ingress

used 2 and 10 % of air ingress. For the simulation case for 18 % of air ingress, the flue gas appears to be more diluted than in the experimental cases. Regarding the H_2O vapour content, the best estimation for the 18 % air ingress case is obtained using 100 % CCP as fuel. For the O_2 percentage at the exit of the oxy-combustor, the simulations using 2 and 10 % of air ingress give a good approximation in comparison with the experimental data. Consequently, supplementary simulations to improve the rate-based model will be done using 10 % air ingress.

The temperature estimation given by the model is in good agreement with the measurements of Smart et al. [6], for a 500 MWth test rig. Likewise, these calculations were checked using the FACT program, allowing for flame dissociation, and gave very similar results to the ASPEN calculation (T-Aspen:1,940 °C against T-FACT:1,944 °C). These results are generated using 100 % Daw Mill coal as fuel, feeding 5 % of excess of oxygen over the stoichiometric and recirculating 55 % of the flue gas to the oxy-combustor block. It should be noted that given that temperatures are at or below 2,000 K, dissociation has been ignored in the ASPEN simulation.

14.5 Conclusions

This chapter summarises the retrofitting experience and the experimental results in a 100 kW oxy-combustor located at Cranfield University in the UK, as well as the rate-based simulation results using Aspen Plus®. The fuel blends used for this study are 100 % Daw Mill coal, 50 % Daw Mill coal-50 % cereal co-product (biomass) and 100 % cereal co-product. The performance of the combustor was explored, keeping recirculation of the flue gas around 52 %, and the maximum percentage of CO_2 achieved was 56.7 %, wb (73.6 %, db) when 100 % Daw Mill coal was fired. The high content of H_2O vapour in the flue gas when firing 100 % cereal co-product biomass caused operational complications. Thus a water condenser will be installed as part of the flue gas conditioning equipment with the aim of avoiding these difficulties in forthcoming tests.

The ash deposition was evaluated taking into account different fuels and it appears that similar sulphate contents existed in deposits generated using 100 % Daw Mill coal and 100 % cereal co-product, even though the biomass has much lower S content in its elemental analysis. The higher K content in the deposits generated by oxy-firing of 100 % cereal co-product biomass was also noticeable. Consequently, operational problems, related to material corrosion, are likely to occur. In general the oxy-fuel environment appears to be more "corrosive" in comparison to the air-firing environment due to higher levels of K_2SO_4 formation in the deposits as well as the higher SO_x content in the flue gas generated in the oxy-combustion process. Also higher concentrations of K and Cl in the deposits generated by 100 % cereal co-product biomass suggest the formation of KCl, which would contribute to more corrosion problems as it is a highly fouling compound. Further corrosion research is required to study this effect in more detail.

A kinetic simulation model was developed and validated to determine the amount of air ingress in comparison with the experimental data. It was estimated that the air ingress into the reactor is 10 % of the total gas fed to the combustor. Simulation results using different values for % RFG and % O_2 excess fed to the oxy-combustor are achieved. In the second stage a rate-based model with partial condensation in the RFG is under development.

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