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Waste tyre rubber as a secondary fuel for power plants

S. Singh, W. Nimmo *, B.M. Gibbs, P.T. Williams

Energy and Resources Research Institute, Houldsworth Building, The University of Leeds, Leeds LS2 9JT, UK

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ABSTRACT

Approximately 1 billion waste tyres are generated worldwide each year, with the US producing 300 million and the EU 260 million tyres, representing an enormous waste management problem. At the same time, increasingly stringent emission control targets are being imposed on electric power generating plants. The development of science and technology for clean coal combustion is crucial for a sustainable environment which is dependent on a mix of energy production systems. In this pilot scale study we have shown that tyre rubber can be fired with pulverised coal and may have a role to play in co-firing configurations in full scale power plant boilers as wastes are beginning to feature in 'fuel switching' scenarios for CO_2 mitigation. Utilisation of waste tyres in a coal combustion plant can, in one step, reduce NO emissions and recover energy from waste tyres, efficiently. Therefore, through this process, a problem waste stream is effectively utilised to help solve a major environmental pollution problem. We present data demonstrating reburning and co-firing configurations utilising waste tyre rubber. Low levels of NO emission (up to 80% reduction at reburning fuel fractions <12%th) can be achieved, when using a lower volatile South African coal as the primary fuel. The results for tyre reburning are compared with the performance of a suite of reburning fuels with differing volatile hydrocarbon contents. Direct co-firing of tyre with coal can also reduce NO levels but the degree of reduction is dependent on the reactivity of the coal and the prevailing combustion conditions in the primary zone of the mixed fuel flame.

1. Introduction

The world's reliance on rubber derived products, particularly tyres, has come at a huge environmental cost. Worldwide generation of waste tyres amounts to 5 million tonnes per year, representing 2% of total annual solid waste. The US discarded around 290 million tyres in 2003, in the same year the European Union (EU) generated ~260 million waste tyres [1]. The disposal of tyres has proved to be extremely difficult due to their highly resistant chemical, biological and physical properties. Waste tyres represent a serious fire hazard that can result in the exposure of soil, atmosphere and water to high levels of pollution [2]. Previously, the main route of disposal for waste tyres in Europe was landfill (40%). However, since the implementation of the EC Waste Landfill Directive in 2006, tyres can no longer be sent to landfill. The Landfill Directive 1999/31/EC, the End-of-Life Vehicle Directive 2000/53/EC, and the Waste Incineration Directive 2000/76/EC have been designed to ensure that the 40% of waste tyres sent to landfill are recycled by alternative technologies [1].

Fossil fuels in the form of coal, oil and gas currently provide 80% of the global energy demands [3]. Oxides of nitrogen (NO_x) and sulphur (SO_x) produced by the combustion of coal are a cause of significant environmental harm and responsible for the production of acid rain (HNO_3, H_2SO_4), high ground level ozone (O_3) concentrations, and elevated levels of fine particulates [4,5].

Increasingly stringent emission control targets are being imposed as a result of the Kyoto protocol and in Europe by the Large Combustion Plant Directive (LCPD) (2001/80/EC), which sets limits for the emission of SO_2 and NO_x from combustion plants greater than 50 MW. In the UK this will be implemented under the National Emission Reductions Plan (NERP). These targets may be achieved by combustion modification, burner control, over-fire air and the fitting of low-NO_x burners [6,7]. Power stations will also be required to implement additional measures, such as selective catalytic reduction. However, development of reburning and selective non-catalytic reduction (SNCR) methods may provide alternatives in meeting the targets when they become technologically and economically proven at full scale. Novel applications of reburning and co-firing technologies of alternative fuels such as waste tyres may provide a potential energy source at the same time lowering NO_x emissions as well as reducing the burden on coal [8,9].

Reburning is a fuel staging process for the reduction of NO_x emissions by using an auxiliary fuel. The technology involves adjusting the levels of combustion air and fuel stoichiometries in the burner area and injecting the reburn fuel downstream of the burner followed by the injection of over-fire air (OFA) below the reburn zone for completion of the combustion process. Co-firing is another fuel combustion process whereby a part of the primary fuel supplied to the boiler or furnace is substituted for a secondary

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* Corresponding author. Tel.: +44 01133432513.
E-mail address: w.nimmo@leeds.ac.uk (W. Nimmo).

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fuel. The introduction of a secondary fuel along with the primary fuel feed to the burner is again performed under carefully controlled air and fuel stoichiometries.

An essential parameter of the primary or secondary fuel for the lowering of NO_x emissions by utilisation of fuel staging processes is the release of volatile hydrocarbons. Waste tyres are an ideal source of hydrocarbon radicals (CH_i) [10,11]. Thermal treatment studies of waste tyres reveal they are a rich source of volatile hydrocarbons readily producing CH_i radicals that are required in the reburning zone for the destruction of NO_x, further favouring tyres as an excellent reburn fuel. Waste shredded tyres also have low nitrogen content, low chlorine content, and a high calorific value [12–14].

The objective of this present study is to evaluate the NO_x reduction and particle burnout performance of tyre rubber as a reburn and co-fired fuel. A lower volatile South African coal and a higher volatile South American coal were used as primary fuels for the reburning and co-firing studies.

2. Experimental

Reburning and co-firing tests using pulverised tyre rubber were performed in a down-fired combustion test facility (CTF) operating at about 80kWth. The overall length of the furnace is 4.5 m consisting of square box sections with internal dimensions 350 mm × 350 mm. Each section is equipped with access ports to accommodate thermocouple and injection installation points (Fig. 1). Either pulverised coal or propane (this study) could be used as the primary combustion fuel. Calibrated screw feeders (Rospen Industries Ltd.) were used for the primary coal feed and the reburn tyre feed. A smaller feeder was used for co-firing tyres with the lower and higher volatile coals. The waste tyre rubber was supplied by SRC Ltd., (Cheshire, UK) in pre-sieved size ranges (<250 µm). The method used was of ambient shredding which involves chopping the tyre rubber by rotating knives followed by sieving to get the required range for our experiments. The lower volatile South African coal (<100 µm) and the higher volatile South American coal (<100 µm) were both supplied by E. On (Nottingham, UK).

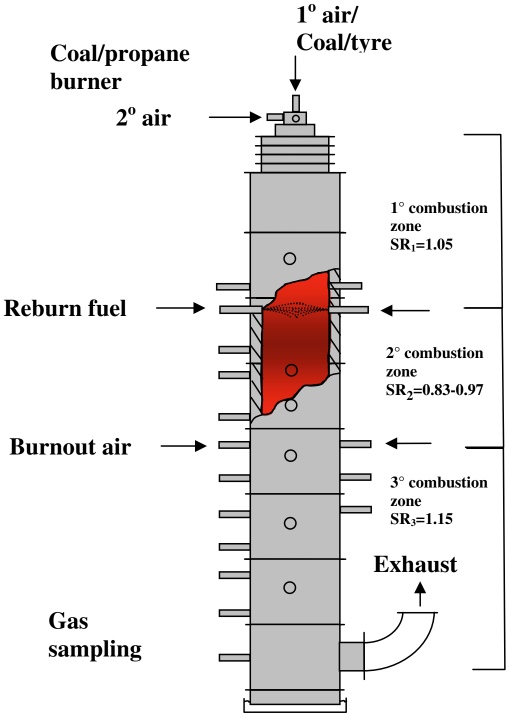

Fig. 1. Schematic diagram of the 80 kW down-fired furnace, showing primary, reburn and burnout combustion zones.

Table 1
Relationship between R_{ff} and reburn zone stoichiometry SR_2. $*SR_1$ = primary zone stoichiometry.

$SR_2 = SR_1(1 - R_{ff}/100)$	R_{ff} %		
0	5	15	20
$SR_1 = 1.05$	$SR_2 = 0.99$	$SR_2 = 0.89$	$SR_2 = 0.84$

2.1. Reburning experiments

Primary combustion zone air to fuel stoichiometry for all reburn experiments was set at $SR_1 = 1.05$ (1% excess O_2 in the flue gas). Reburn fuel fractions (R_{ff}) up to 25% were studied. The reburn zone stoichiometry (SR_2) was set by controlling the feed rate of waste shredded tyres, coal and the primary zone oxygen levels (Table 1). The reburn zone residence time was set to 0.8 seconds to match our historical data which had previously optimised the process on our facility at this condition. This was essential so that we could make a direct comparison of tyre as a NO_x reburn fuel with a large body of data that we have accumulated on the same combustion test facilities. NO reduction with tyre as the reburn fuel was compared with the performance of a South African (lower volatile) and South American (higher volatile) coal for furnace conditions coal was used as the primary fuel. The pulverised tyre was fed pneumatically through two opposing water-cooled injectors. The carrier gas was nitrogen and the gas temperature at the injection point was in excess of 1100 °C. Where propane was used as the primary fuel, initial NO levels were set by doping with NH_3 so that comparable levels can be achieved with low-NO_x burner systems.

The secondary fuel feed systems used for the coal and the pulverised tyre were calibrated prior to the test runs and had a variation of around ±7% of the feed setting. This equates to an uncertainty in the thermal fraction of tyre fed (FF) ranging from ±0.1 to 1.2%.

2.2. Co-firing experiments

The air to fuel stoichiometry was set at $SR_1 = 1.16 \ = 1.16$ (3% excess O_2 in the flue gas) for co-firing experiments of waste shredded tyre with South African coal and South American coal by controlling the co-firing feed rates of the waste shredded tyre and coals. The waste shredded tyre was metered via a small screw feeder and mixed with the coal flow on the spreader tray then transported pneumatically to the burner.

Flue gas analysis was performed by drawing sample gas through appropriate sample conditioning lines to on-line gas analysis systems for O_2 (Servomex, paramagnetic), NO_x (Signal, Chemiluminescence) and CO_2 and CO (ADC, NDIR). SO_2 (Signal) sampling was through heated sample lines (180 °C), coalescing filters and driers to avoid SO_2 losses. Data from the analysers and thermocouples were collected by a data-logging system (Iotech Multiscan) and stored on a PC for post-run processing and analysis. Ash particles were collected by cyclone in the flue of the combustor.

2.3. Carbon burnout calculations

Ash from the combustion process under co-firing, reburning or single firing conditions was collected using an in-line cyclone separator with a replaceable catch-pot. As was collected over a period of about 30 min for each stable operating condition. The carbon and ash contents of the samples were obtained by standard furnace ashing methods. Calculation of carbon burnout was obtained by the ash tracer method knowing the ash content of the initial fuel