MOBILE FACILITY FOR ON-LINE FLUE GAS CHARACTERISATION

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Abstract: Eskom Holdings and Tswane University of Technology (TUT) initiated a research project for the mitigation of coal burning power station flue gas pollutants. It was decided to carry out pulsed corona flue gas characterisation on-line in this project on a side-stream at an operating pulverised fuel burning power station. In this, removal energies against removal percentages would be determined for NO_x and SO_x to furnish design information for an all-solid state driven pilot De-NO_x and De-SO_x pulsed corona unit. A mobile laboratory unit was constructed for this purpose and has been used to evaluate the effectiveness of the solid-state pulser equipment and on the flue gas characterisation. This paper reports on the layout of the mobile facility and on the flue gas measurements. A separate paper reports on the design, modelling and operation of the pulser equipment itself.

Keywords: Pulse power, voltage inversion, pulser, electromagnetic pulse compressor, air pollution.

1. INTRODUCTION

As part of Eskom's Emissions Research Portfolio, various alternatives to Flue Gas Desulphurisation (FGD) by wet scrubbing and Flue Gas Denitrification by Selective Catalytic Reduction (SCR) have been researched. Although there is presently no legislation in South Africa governing this, Eskom believes it prudent to be proactive in identifying technologies appropriate to the South African environment for possible future use. Previous studies had investigated Electron Beam Dry Scrubbing as a possible alternative and this research aims to develop and demonstrate Solid State Pulsed Corona technology as a means to cost effectively reduce gaseous emissions.

A scaled down all solid-state pulsed corona facility, by means of which separation efficiencies and the input energy requirements can be established for NO, NO_x and SO_2 in coal burning power stations, were reported at ISESP 8[1]. At that time, this facility was housed in the laboratory and the flue gas characterisation for energy input and separation efficiency of removal for the three gasses were to be carried out on simulated bottled flue gas. It was realised, however, that others have already carried out this work and that no essential new knowledge would accrue from laboratory measurements. A decision was therefore taken to accommodate the pulsed corona equipment on a trailer along with other supporting services and to carry out the required testing live on a flue-gas side stream at an operating power station.

The Duvha 3 600 MW power station near Witbank in Mpumalanga was chosen for the task. Duvha employs six generation units of 600 MW each. Units 1 to 3 employ pulse jet fabric filters whilst units 4 to 6 are equipped with Electrostatic Precipitators (ESP's) for fly ash removal. Unit 3 was chosen on which to initiate the tests because the gas was relatively free of fly ash in the bag filter stream and the layout of the plant furnished a convenient location for parking and operating the mobile facility. It was planned to move to Unit 4 after completing the tests on Unit 3, to also expose the system to a larger content of fly ash.

2. MOBILE LABORATORY LAYOUT

The photograph in Figure 1 shows the layout of the equipment on the mobile laboratory.

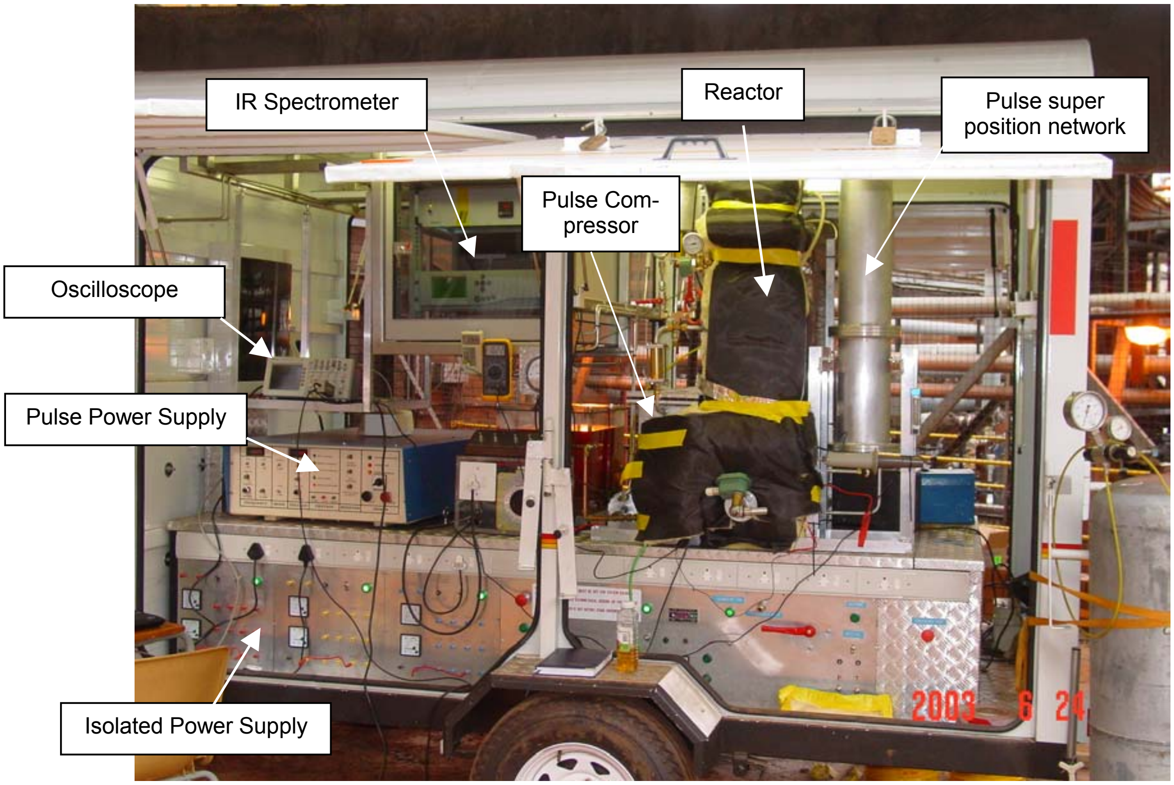


Figure 1 – Layout of pulsed corona mobile laboratory

The equipment is permanently installed in the trailer and the latter is towed to wherever measurements have to be carried out. The pulser subsystems consist of the following:

- The Resonant Inversion Pulse power supply (RIP), responsible for generating the initial pulses[2] for further processing. The output of the RIP supplies electrical pulses at up to 2J, 33kV and with half-sinusoidal transfer times of 1.7μs.
- The output of the RIP is supplied to a three-stage series electromagnetic pulse compressor (Melville Line)[7] that resonantly compresses the pulses down in time to a half sinusoidal pulse width of about 70ns.
- The output of the pulse compressor is then supplied to a pulse superposition network in which the output pulses are superimposed on a DC bias voltage that can be adjusted from zero to 20 kV.
- The DC high voltage supply is capable of delivering 20mA and supplies the Bias on which the pulses are superimposed. A typical form of the reactor voltage and current is shown in the oscillogram in Figure 5.
- The reactor is supplied with an adjustable DC bias, just below the corona threshold voltage, on which the pulses are superimposed. A coaxial reactor has been used to date, comprising of 16 of 40mm x 500mm tubes with 2mm electrode wires.

The scheme referred to above is shown in block-diagrammatic form in Figure 2.

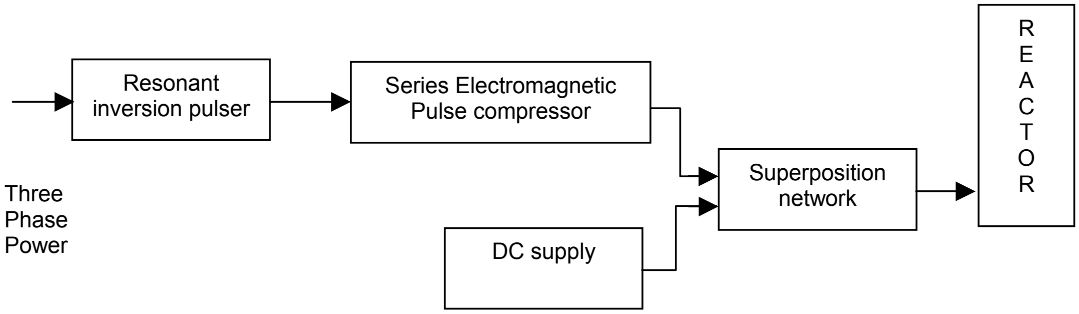


Figure 2 – Pulser subsystems in block-diagrammatic form

The photographs in Figure 3 show a view of the Resonant Inversion Pulser with its cover removed on the left and the assembled compressor, out of its shell, on the right.

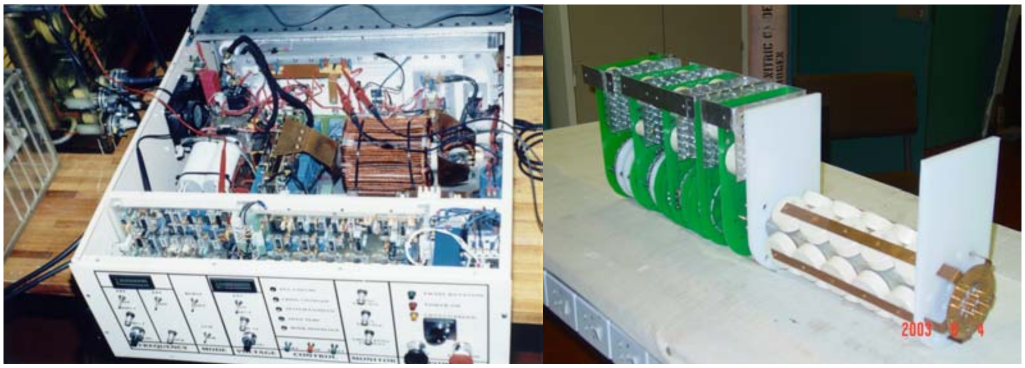


Figure 3 – Photographs of the RIP on the left and pulse compressor assembly on the right

Figure 4, left photograph, shows the reactor (centre), pulse compressor shell (left) and assembled pulse superposition unit (right). The photograph on the right in Figure 4 shows a top view into the open reactor.

The largest advantage of the mobile laboratory is that it can be taken to the site where measurements have to be carried out by towing and that it can be set up with minimum effort. To enable the testing to be carried out with minimum assistance from the site itself, it has been constructed as a self-contained unit requiring only the following services from the site where testing is to be conducted:

1. A clean water supply for cooling purposes and for steam generation;
2. A compressed air supply for drying and cleaning the reactor when necessary;
3. A 380V 20A three phase power supply.

The following facilities are incorporated into the equipment on the trailer to make it self contained and to enhance operation and analysis procedures:

1. The incoming three-phase power is supplied through three single-phase isolation transformers with an unearthed neutral. That makes it possible to have a floating power supply of which any point can be ground referenced. This feature simplifies the use of grounded oscilloscopes and other instrumentation to examine any circuit in the equipment. A special ground-potential voltage-measuring scheme has been installed with which accidental electrical ground-faults can be monitored.
2. In order to maintain a controllable temperature between 60°C to 200°C of the flue gas delivered to the reactor, the flue gas sampling pipe, a high temperature resistant, spiral wire armoured, rubber pipe of 80mm diameter, is heated by passing a controlled current through the spiral wire reinforcing. The Reactor is also equipped with separately controlled Calrod elements for heating.

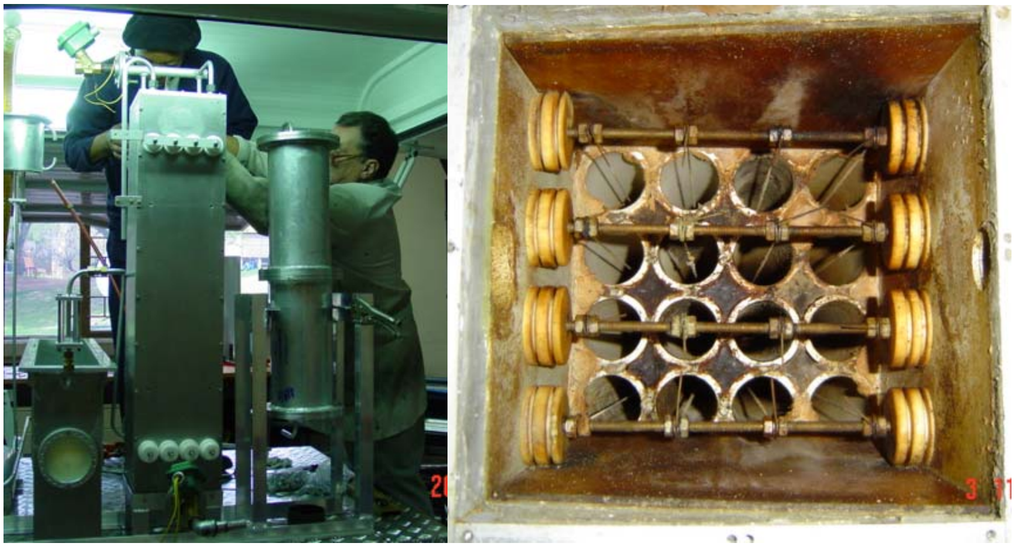


Figure 4 – Composite picture on the left show the pulse compressor shell, reactor and pulse forming network F.L.T.R. Picture on the right show top view into the reactor.

3. Gas flow is controlled by employing a single-phase centrifugal fan to furnish suction on the outlet end of the reactor through a continuously adjustable butterfly valve. Normally, the flue gas pressure in the ducting between the station induced draft fan and the stack is only slightly above atmospheric pressure and it is necessary to assist it with this fan to obtain the flow magnitudes necessary for operation. Treated flue gasses are vented at a point about 15m from the trailer.
4. The gas flow is measured by pressure differential transducers supplied from an adjustable diameter orifice meter.
5. Cooling water is circulated through the Resonant Inversion Pulser, and through two heat exchangers that serve to cool the insulating oil in the compressor, DC supply and superposition network.
6. Because the insulating quality of the oil in the compressor and RIP high voltage section must be free of air bubbles and maintained in a clean and dry condition, a closed, dedicated oil system is installed in the trailer. Two separate pumps are employed. The first, to circulate the oil through the pulser subsystems and heat exchangers for cooling. The second, a self-priming centrifugal pump, enables fast evacuation and filling for each of the pulser subsystems when modifications or repairs have to be made on

site. A second function of the second pump is to draw a high vacuum on the compressor to evacuate air bubbles that may lodge in the small dielectric gaps in the inductor windings. Such air bubbles present low dielectric strength and will cause failure to insulation during operation.

7. To ensure the absence of potential air bubbles further, the system is also equipped with an SF_6 gas filling system that can be used before initial oil filling in the compressor to completely displace the air.
8. The NO, NO_x and SO_2 concentrations in the input and reactor-delivered flue gas are measured continuously by Chemiluminescent (NO, NO_x) cells and Infrared Spectrometer modules built into the trailer. Only one IR spectrometer is installed presently and its input is switched between the upstream and downstream sides of the reactor by electrically controlled solenoid valve. The equipment distinguishes between NO and NO_x by employing a NO_x converter by means of which all the NO_x compounds present in the sample are converted to NO.
9. The reactor voltage and current are measured respectively by means of a Tektronix 35kV type P0015 high voltage probe and a custom designed PEM Rogowski coil, connected to a Tektronix 2024 12 giga-samples per second oscilloscope. The oscilloscope waveform digitised data is then transferred to a laptop through RS232 port. A Wavestar program package is employed on the laptop to furnish oscillograms like the one in Figure 5 which is then digitised and presented for processing. An MS Excel spreadsheet package is used to calculate the pulse energy from the digitised data furnished by Wavestar.
10. The trailer contains compartments for spares, components and tools. In addition it also carries the different gasses needed for the purging and calibration of the IR spectrometer.

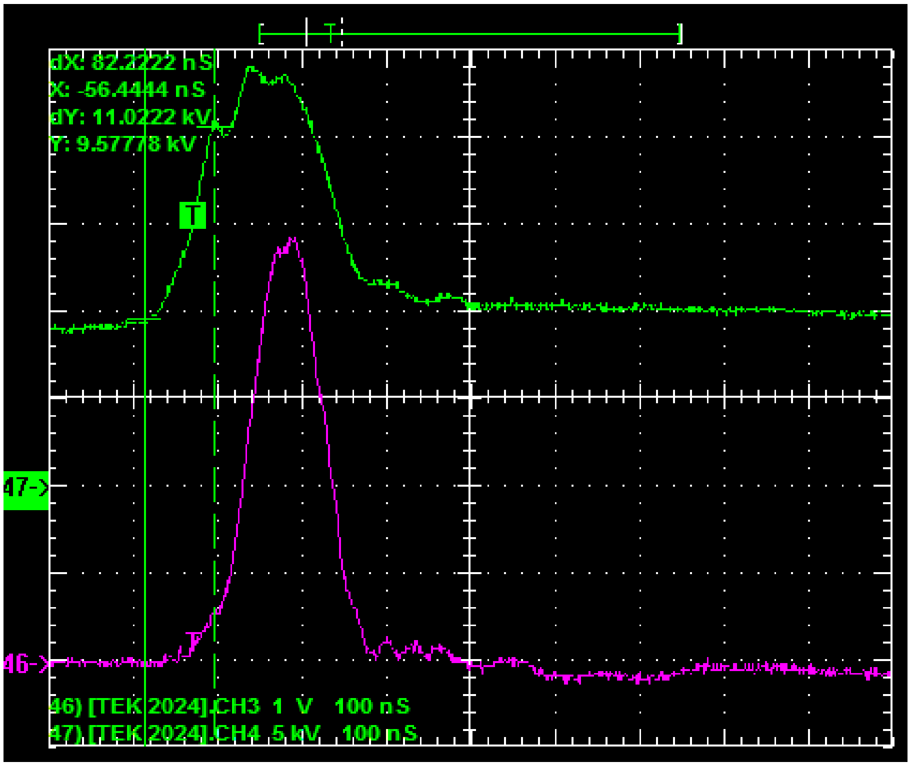


Figure 5 – Typical reactor voltage (green trace) and current (magenta trace) oscillograms as obtained during flue gas characterisation measurements

As far as the on-site testing is concerned, the four photographs in Figure 6 show the placement of the trailer underneath the flue gas duct. Shown from top left to bottom right in Figure 6: (a) Parked Pulsed Corona mobile laboratory; (b) Characterisation measurements in progress; (c) Flue gas sampling line from Generator Number 3 flue gas duct; (d) Flue gas sampling line entry into trailer.

3. FLUE GAS CHARACTERISATION

The main objective of "flue gas characterisation" is to determine the input energy requirement into the gas against specified removal rates in percentage of the NO, the NO_x and the SO_2, against variations in the following parameters:

- Pulse Repetition Rate;
- DC bias voltage;
- Pulse peak voltage;
- Wire-cylinder and wire-plate electrode spacing; gap field strength;
- Pulse voltage rise time;
- Pulse half sinusoidal transfer time (energy transfer time to reactor);
- Incoming gas temperature;
- Incoming NO, NO_x and SO_2 concentration;
- Gas flow rate; Reactor Residence time; Reactor flow velocity;
- Ammonia feed concentration.

Figure 6 – Mobile laboratory measurements position

The measurements made during the testing are the following:

- Flow rate, from orifice diameter, differential pressure, absolute pressure, temperature;
- Oscillograms of reactor voltage and current for pulse energy calculation;
- Reactor voltage rise time;
- Incoming gas temperature;
- NO, NO_x and SO_2 input concentrations; and
- NO, NO_x and SO_2 output (after the reactor) concentrations.

From these measurements, the following are calculated:

- Electrode Gap electric field intensity, as the sum of the pulse voltage and the DC bias, divided by the electrode spacing;
- The reactor voltage rise time, before corona conduction commences, from the reactor voltage oscillogram shown in Figure 5;
- Peak reactor pulse voltage achieved, from the reactor voltage oscillogram;
- Pulse half sinusoidal transfer time, inferred from the reactor voltage and reactor current profiles in the oscillograms, in a manner that will be explained below;
- The total energy transferred to the gas in each pulse, collectively from the reactor voltage and current waveforms, as explained in greater detail later;
- The pulse power supplied to the reactor, as the product of the rep-rate and the pulse energy;
- The removal rates for NO, NO_x and SO_2;
- Specific gas energy density in the reactor;
- Equivalent Station Efficiency.

Of the above measurement results, the Specific Gas Energy Density, the molecular input energy (energy required for destruction of one molecule), the removal rates for the three different pollutants and the Equivalent Station Efficiency are the most important.

Station Efficiency

Although the projected capital cost of Pulsed Corona mitigation through all solid-state pulse power generation will be high, as the result of the high cost of specialised magnetics and dielectrics maintenance cost will be a minimum. However, the cost of the energy used in the pulse generation will present the dominating operating cost component and the major objective of the present study is to minimise energy input as far as possible. The "*Station Efficiency*" furnishes a convenient parameter against which the energy efficiency of removal of the NO, NO_x and SO_2 against pre-determined levels can be compared. Station Efficiency is defined as the ratio of the required input power to the pulsed corona reactor, to the equivalent electrical power generation level that could be obtained by burning the fuel of which the combustion products are passed through the reactor. If the pulsed corona process is able to furnish a station efficiency of 6% in a 600 MWE plant, for example, the electrical energy input into the gas would have to be 600 x 0.06 or 36 MW .

Other researchers have found[3] that a 50% to 60% NO_x removal rate can be achieved in the case where the incoming gas contains between 350 and 400 ppm of NO_x. In the measurements, carried out at the Marghera Power Station near Venice in Italy, the pulses used had "rise fronts" in the order of 400ns and the input energy supplied to the gas ranged between 12 and 14 Wh/Nm^3 of gas. Subsequent studies by others[4] have introduced the expectation that the minimum energy input against the given removal rates for NO, NO_x and SO_2 are based on a station efficiency of 5 per cent, for removal of 80% NO_x. The dominating aim in our own work is therefore to bring our equipment performance into line with, or to improve on this energy input.

4. INITIAL MEASUREMENT RESULTS

Flue gas characterisation has been carried out on-line at the power station under actual operating conditions and the results are therefore representative of the actual field conditions. Employing a spreadsheet for the accumulating and computation of the data, the following preliminary results were obtained.

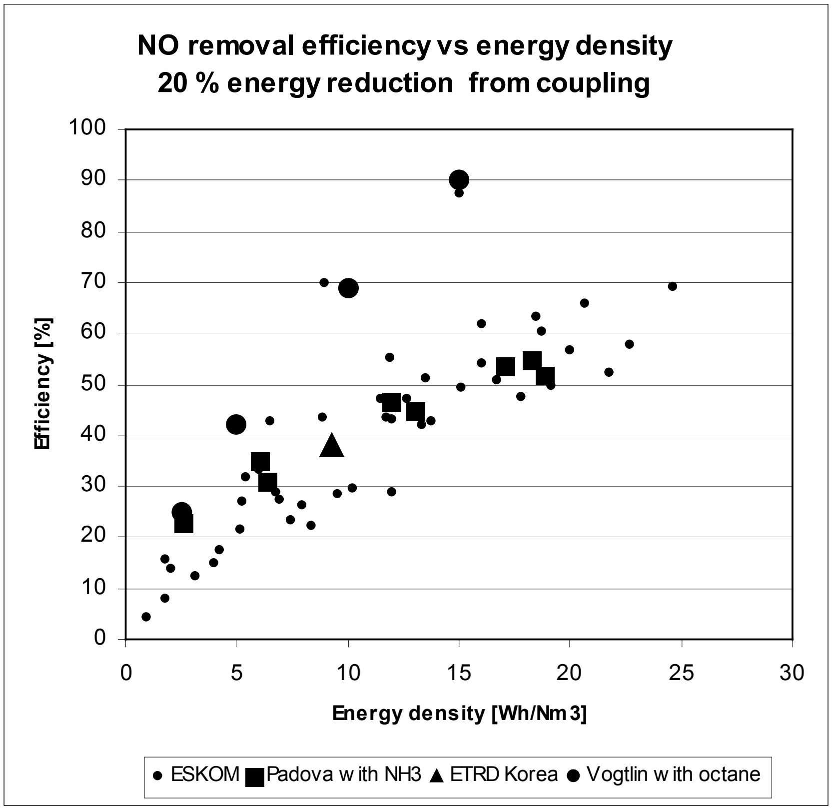
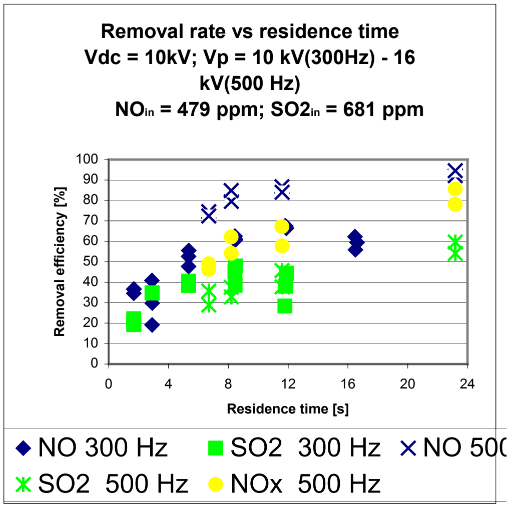


Figure 7 – Removal Efficiency vs. residence time in the reactor

These following results represent the data obtained after the initial series of measurements. Figure 7 shows removal efficiency vs residence time in the reactor at voltages close to the maximum peak voltage value (DC bias plus pulse height). NO removal of up to 85%, NO_x removal up to 68% and SO_2 removal up to 45% were obtained at a residence time of 12s. The SO_2 value is surprisingly high, since other researchers have shown values not exceeding 20%. The results will be corroborated, but may be due to heterogeneous state reactions in the aerosol phase, e.g. effects of fly ash particles.

Figure 8 shows the removal efficiency obtained with the addition of NH_3 at a residence time of 6 seconds. As expected, SO_2 removal is close to 99%. NO and NO_x removal efficiencies were not improved above those without NH_3. This result conforms to that reported in literature.



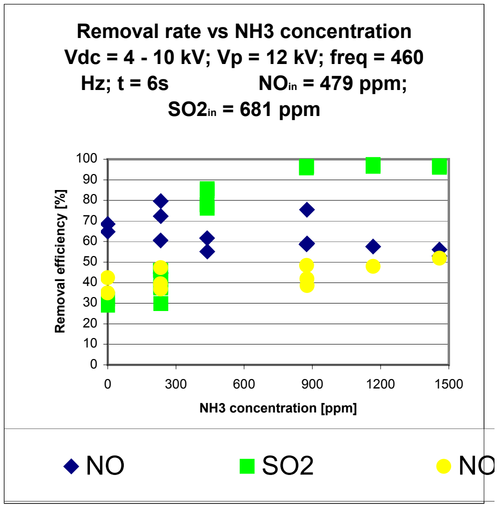


Figure 8 – Removal efficiency with addition of NH_3

Figure 9 - Removal efficiency of NO vs. energy density input into gas

Figure 8 – Removal efficiency with addition of NH_3

Figure 9 - Removal efficiency of NO vs. energy density input into gas

shows the removal efficiency of NO vs. energy density input into the gas. Results from other researchers are also presented. The present results are comparable to those found by others. It should be noted that energy values were corrected downwards by 20% to compensate for losses in the coupling between the pulser and the reactor.

A large number of measurements have been completed since, but interpretation and refinement are still ongoing. Generally, it is found that the higher concentrations of NO found in the flue gas, compared to the values mentioned in Section 3, require higher energy input.

5. CONCLUSIONS

The objective of this research is to develop commercial Pulsed Corona De-SO_x and De-NO_x equipment for installation in coal burning power stations. Rather than repeating experimentation under laboratory conditions, Eskom TSI required that the Gas Characterisation testing be conducted on site, under actual operating conditions, on operating power stations. This paper reports on the methods, apparatus and results achieved with these tests.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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