THE PERFORMANCE OF A PILOT-SCALE ELECTROSTATIC PRECIPITATOR USING CONTINUOUS, INTERMITTENT AND PULSED ENERGISATION

C.A.J. Paulson
A.J. Prokopiuk
CSIRO, Division of Coal and Energy Technology
PO Box 136
North Ryde
NSW 2113, Australia

R. Morrow
CSIRO, Division of Applied Physics
PO Box 218
Lindfield
NSW 2070, Australia

Abstract

A single stage, single duct electrostatic precipitator has been used to collect fresh flyash generated from the combustion of an Australian bituminous coal in a pilot-scale pulverised-coal-fired furnace. The precipitator, which represents the first stage of a multi-stage precipitator, was operated with continuous, intermittent and pulsed energisation. The performance of the precipitator has been investigated for all three modes of energisation over a complete range of operating voltages from zero to breakdown. Furthermore the intermittent energisation was operated over a range of on/off ratios varying from 1:10 to 1:400 and the pulsed energisation over a range of 10 to 200 pulses per second.

The results of these tests show that with continuous energisation a precipitator collecting this flyash would require a specific collecting area of 80 square metres of collecting plate area per kilogram of gas per second (m^2/kgs^{-1}) for an outlet dust loading of 100 mgm^{-3}. With intermittent energisation this precipitator size is reduced to 44 m^2/kgs^{-1}, whilst with pulsed voltage it is further reduced to 33 m^2/kgs^{-1}. Thus there appears to be a considerable advantage with intermittent and pulsed voltage. The tests also showed that for intermittent energisation the precipitator performance fell away rapidly as the on/off ratio was increased. However for the pulsed mode it was found that the precipitator performance was not effected by pulse frequency at pulse rates greater then 50 pulses per second but deteriorated at pulse rates lower than this.

1. Introduction

For more than 20 years the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia has had an ongoing project researching the performance of electrostatic precipitators collecting the flyash from the combustion of pulverised coal in power stations. The work has been based on a pilot-scale pulverised-coal-fired furnace and its attached tubular and plate-type electrostatic precipitators. The test rig generates flue gas and flyash in the proportions typical of full-scale operation and simulates as closely as possible the conditions prevailing in a power station.

The testing has been used as a research tool to study the process of electrostatic precipitation, particularly in relation to low sulphur Australian coals. The effect of operating parameters such as volumetric flow, temperature, applied voltage, flue gas additives, coal sulphur content and coal mineral matter composition on electrostatic precipitator performance has been determined.

Recently transformer-rectifier power supplies have been included to allow precipitator operation with either continuous, intermittent or pulsed energisation. These power supplies have been applied in a series of experiments operating one of the pilot precipitators at a constant set of conditions in order to investigate the performance of the precipitator under all three modes of energisation.

2. Equipment

2.1 Combustion rig

The pilot-scale pulverised-coal-fired furnace used to generate the flyash for these tests has been fully described elsewhere[1]. In principle, it consists of a horizontal refractory-lined cylindrical furnace, burning up to 50 kgh^{-1} of pulverised coal, which corresponds to a heat release rate of 1.7×10^5 Wm^{-3}, comparable to that in a power station boiler furnace.

The flue gas temperature is reduced to the required precipitator temperature using a fire-tube boiler and a series of six shell and tube heat exchangers. The cooling medium for the first two exchangers is the combustion air and for the remaining four is water. The exchangers are constructed so that up to four heat exchangers can be by-passed if required.

The coal was pulverised so that 75% passed through a 75 μm (200 mesh) sieve. This is a common size for pulverised coal in full-scale boiler plant and in this furnace this size allows complete combustion of the coal, with less than 3% of the carbon being retained in the ash. Samples of flyash from these tests were submitted for carbon-in-ash analysis, and the results showed that the carbon-in-ash was less than 2%.

2.2 Electrostatic precipitator

The laboratory scale electrostatic precipitator used in these experiments is shown in Figure 1. It consists of a single stage plate-precipitator which represents the first stage of a multi-stage precipitator. It has a single duct with collecting plates 1m high and 2.4 m long, spaced 200 mm apart. There are twelve equally-spaced discharge wires placed between the collecting plates. These discharge wires are made from 3 mm diameter plain wire and are all connected to a common busbar. The inlet duct of the precipitator is fitted with vanes and the outlet with a perforated plate to assist in uniform gas distribution.

The collecting plates are rapped with a pneumatic hammer and the rapped off dust is collected in a hopper beneath the precipitator. The rapping intensity and interval can both be varied. The discharge wires are not rapped but are cleaned regularly so that there is no dust build-up on them.

The collecting efficiency of the precipitator is measured by taking an isokinetic sample of the gas and suspended dust at the entry and exit of the precipitator. From the dust weight and the gas volume the dust loading into and out of the precipitator can be calculated and hence the gravimetric efficiency.

2.3 Power supplies

Three different power supplies are available for this precipitator. They have been supplied by Research-Cottrell. Inc. (Cottrell-ette), Lurgi GmbH (Coromatic) and Masuda Research. Inc. (Eldyne Pulser). All three power supplies can be operated with either positive or negative voltage outputs.

2.3.1 Research-Cottrell, Inc. This Cottrell-ette power supply is a solid state transformer-rectifier with a maximum output of 45 kV and 5 mA. Silicon rectifiers are used to give full-wave rectification. Power to the precipitator is manually controlled by means of variac controllers on the primary power supply, allowing continuous variation in precipitator operating voltage from zero to breakdown voltage. Secondary current and voltage are measured directly, the latter by means of an oil immersed 500 MΩ resistor between the high tension terminal and the voltmeter.

2.3.2 Lurgi GmbH The Lurgi Coromatic power supply can be operated in either the continuous or the variopulsing (intermittent) mode. The maximum output is 70 kV and 500 mA. In both the continuous and intermittent modes the supply can be set to either maximise its operation or to operate at any specific output voltage between zero and maximum. At the maximum operating condition the power supply checks every 15 minutes to make sure the optimum is being sustained.

In the variopulsing mode the 'on-time' can be varied between 1 and 250 half waves (0.01 and 2.5 seconds) and the interval between 10 and 500 half waves (0.1 and 5 seconds). If the supply is in its optimising mode the on/off ratio is automatically decided by the software in the operating system and this is commonly 1:10.

2.3.3 Masuda Research. Inc. The pulsing mechanism of the Eldyne Pulser T-5S consists of a series of condensers which are charged up and then allowed to discharge via a variable speed rotary spark-gap. It has a maximum pulse voltage of 100 kV. The pulse voltage can be set between zero and breakdown by controlling the primary voltage, which has a maximum value of 220 volts. The pulse frequency can be continuously adjusted between 0 and 200 pulses per second. The pulse rise time is 100 ns and the pulse width is about 200 ns. Measuring circuits for the secondary voltage and current are still being developed.

The pulser has a total of five condensers in series and the number of condensers being used is varied according to the load being applied. With all five condensers in the circuit the maximum corona load, in terms of total precipitator collecting plate area, is 5 m^2 with a plate spacing of 200 mm.

3. Experimental

3.1 Combustion rig

The pulverised-coal-fired furnace was operated at a coal feed rate of 45 kgh^{-1} throughout the precipitator tests. The same coal, which is an Australian bituminous coal burnt in both domestic and overseas power stations, was burnt in all the tests. The flue gas temperature was reduced to 120°C in the heat exchanger system before entering the precipitator. Thus all the precipitator tests were all carried out under similar conditions.

3.2 Electrostatic precipitator

The electrostatic precipitator was operated at the same gas flow conditions for all the tests. The precipitator operating temperature was maintained at 120°C and the volumetric flow rate was controlled to give a velocity of 1 ms^{-1}. This gas flow rate gives an operating specific collecting area (SCA) of about 35 m^2 of collecting plate area for each kgs^{-1} of flue gas passing through the precipitator. This SCA is very low compared with conventional precipitators which would normally have SCAs as high as 100 m^2/kgs^{-1} or more. However it has already been pointed out that this precipitator only represents the first stage of a multi-stage precipitator.

3.2.1 Continuous energisation. Precipitator tests were carried out with continuous energisation using both the Cottrell-ette and Coromatic power supplies. Both power supplies were operated over a range of voltages between zero and breakdown.

3.2.2 Intermittent energisation. Using the Coromatic power supply in it's 'Variopulsing' mode the precipitator operating voltage was varied between zero and maximum. In this case the maximum voltage was achieved when the power supply was operating in self-optimising mode and under these conditions the on/off ratio is normally 1:10. Therefore during the manually controlled tests the on/off ratio was maintained at 1:10. A series of test was also carried out at constant voltage controlling the on/off ratio at 1:50, 1:100, 1:200 and 1:400 in order to determine the effect of this ratio on precipitator performance.

3.2.3 Pulsed energisation. The Eldyne Pulser was operated over a range of primary voltages between 50 and 200 volts with pulse frequencies of 10, 50, 100, 150 and 200 pulses per second. A matrix of tests was carried out with enough combinations of these voltages and pulse frequencies to give a strong indication of the response of the precipitator to this type of energisation.

4. Results

4.1 Efficiency tests

The results of the precipitator tests for all three modes of energisation are shown in Figures 2, 3, and 5. The diagrams equate the slip (ie. the percentage of dust escaping from the precipitator) against the product of the SCA (α in m^2/kgs^{-1}) and the square of the operating voltage (V in kilovolts). This performance line plotting technique, using the modified Deutsch Equation developed by CSIRO, is fully discussed elsewhere[2]. The modified Deutsch Equation is:

$$\log(1-\varepsilon) = \log(1-\varepsilon_s) + k\alpha V^2$$

where ε = fractional collecting efficiency
ε_s = fractional collecting efficiency at the corona starting voltage
k = constant
α = specific collecting area
V = applied voltage

Thus a plot of log(1-ε), which is log(slip), against αV^2 should result in straight line with slope k once a corona has been established and the particles are fully charged. The line between corona onset and mechanical efficiency (when voltage, and hence αV^2, is zero) will have a lower slope. This is because, at these low voltages, the corona is not yet formed or is not fully established and therefore, at best, the particles are only partially charged.

The performance of the precipitator under continuous energisation with both the Cottrell-ette and Coromatic power supplies is shown in Figure 2. From the graph it can be seen that the straight line relationship occurs but the lowest slip obtained was still about 13%. Furthermore the diagram shows the expected trend of power supply independence. To achieve the commonly required outlet dust loading of 100 mgm^{-3} whilst collecting flyash from this coal requires a slip of only 0.6% (99.4% efficiency), so a much larger precipitator than this would be required. The maximum operating voltage obtained during these tests was 35 kV and, by extrapolating the performance line to obtain the αV^2 value needed for an outlet of 100 mgm^{-3} (9.8×10^4) the required precipitator size is calculated to be 80 m^2/kgs^{-1}. The graph also shows that at low values of αV^2 (ie. at low voltages) as expected the slope of the line is lower. At an αV^2 value of 0 (ie. when the precipitator is electrically inert) the slip is about 90%. Thus the mechanical efficiency of the precipitator is about 10%.

Figure 3 shows the performance of the precipitator with intermittent energisation in the optimising mode. In this case both the peak and mean operating voltages were measured during the period when the power supply was operating (ie. during the 'on' time) and the voltage used to calculate the values of αV^2 was the mean. From the diagram it can be seen that the results again give a straight line relationship of log(slip) against αV^2. This time the slope of the line is low at mean voltages up to about 41 kV ($\alpha V^2 = 6 \times 10^4$) and the slip at comparative values of αV^2 is considerably higher than that for continuous energisation. This low slope is similar to that in Figure 2 when the particles are not properly charged and points to the conclusion that, with intermittent energisation, only at high operating voltages are the particles properly charged. At voltages greater than 41 kV the slope increases considerably and the lowest slip measured was about 4%. This is a much better performance than with continuous energisation once the operating voltage is high enough to properly charge the particles. By extrapolating the performance line and allowing for the measured maximum mean operating voltage, which was 45 kV, the precipitator size required for 100 mgm^{-3} is found to be reduced to 44 m^2/kgs^{-1}, a more than 40% reduction in size. Thus there is both a capital financial saving with intermittent voltage and also an operating saving in power used.

The effect of changing the on/off ratio of the intermittent power supply at a constant voltage of 45 kV is shown in Figure 4. From the graph it can be seen that the slip increases dramatically with ratio increase. As the ratio is changed from 1:10 to 1:50 the slip is tripled and it doubles again as the ratio goes to 1:100. By the time the on/off ratio is increased to 1:400 the slip is almost fifteen times that for a ratio of 1:10. Thus although the effect of intermittent voltage is to improve the precipitator performance it appears that this will only occur at low on/off ratios. However it is interesting to note that even with an on/off ratio of 1:400 the slip is lower than the value when the voltage is turned off (shown in Figures 2, 3 and 5 when αV^2 is zero).

The effect of pulsing the voltage is shown in Figure 5. The αV^2 values for this graph cannot be compared directly with those in Figures 2 and 3 because the voltage used in this case is the primary voltage applied to the pulser. This is because, at the time of writing, no reliable readings of the secondary voltage for the pulser have been made. If the secondary, or output, voltage is proportional to the primary (input) voltage then again a straight line relationship should occur. It can be seen from the figure that this is the case providing the pulse rate was greater than 50 pulses per second (pps) and that a there is a common performance line for all pulse rates between 50 and 200 pps. Again at low voltages the slope is lower showing that the particles are not fully charged. Furthermore if this line is extrapolated it passes close to the 10 pps points showing that, at this pulse rate, the particles are not adequately charged. It can be seen that at high voltages the slip is less than 1% and calculations showed that at a primary voltage of 200 V, which was the maximum used, a precipitator with an SCA of only 33 m^2/kgs^{-1} would be required to achieve an outlet dust loading of 100 mgm^{-3}. In future experiments it may be possible to increase this primary voltage further and thus reduce the required size even more.

Therefore these tests have demonstrated that both intermittent and pulsed voltages improve the performance of this precipitator considerably whilst collecting this particular dust at an operating temperature of 120°C. However more tests will be required to find out whether this effect is general for a range of different particles and precipitator operating conditions.

5. Conclusions

1. Tests carried out on the CSIRO pulverised-coal-fired furnace/electrostatic precipitator test rig have shown that, whilst collecting flyash from an Australian bituminous coal, the mode of energisation applied to the precipitator has a considerable effect on the precipitator performance. Assuming a required outlet dust loading of 100 mgm^{-3} it was found that with continuous energisation a precipitator with a specific collecting area (SCA) of 80 m^2/kgs^{-1} would be required. However with intermittent energisation utilising an on/off ratio of 1:10 this required SCA was reduced to 44 m^2/kgs^{-1}, and with pulsed voltage with a pulse rate of greater than 50 pulses per second the SCA was further reduced to 33 m^2/kgs^{-1}.

2. With intermittent energisation the on/off ratio has a marked effect on the precipitator performance. At a constant mean operating voltage as this ratio is increased from 1:10 to 1:50 the precipitator slip increases by a factor of three and doubles again as the ratio increases to 1:100. At a ratio of 1:400 the slip is increased to fifteen times that at a ratio of 1:10, but is still lower than when the precipitator is not energised.

3. Intermittent Energisation does not appear to fully charge the particles until the voltage is high. A mean voltage of about 41 kV was required before the particles appeared to be adequately charged and being collected properly.

4. With pulsed energisation the particles appear to be fully charged at pulse rates greater than 50 pulses per second, but at only 10 pulses per second the particles were not fully charged.

6. References

1. Paulson, E.C. Potter and R. Kahane, "New Ideas on Precipitation Technology from the CSIRO Combustion Rig," presented at the Institute of Fuel (Australian Membership) Symposium on the Changing Technology of Electrostatic Precipitation, Adelaide, Australia (November 1974).

2. Paulson and E.C. Potter, "Reduction of Particulate Emissions to Air by Improved Assessment of Electrostatic Precipitators," presented at the 2nd National Chemical Engineering Conference, Surfers Paradise, Australia (July 1974).

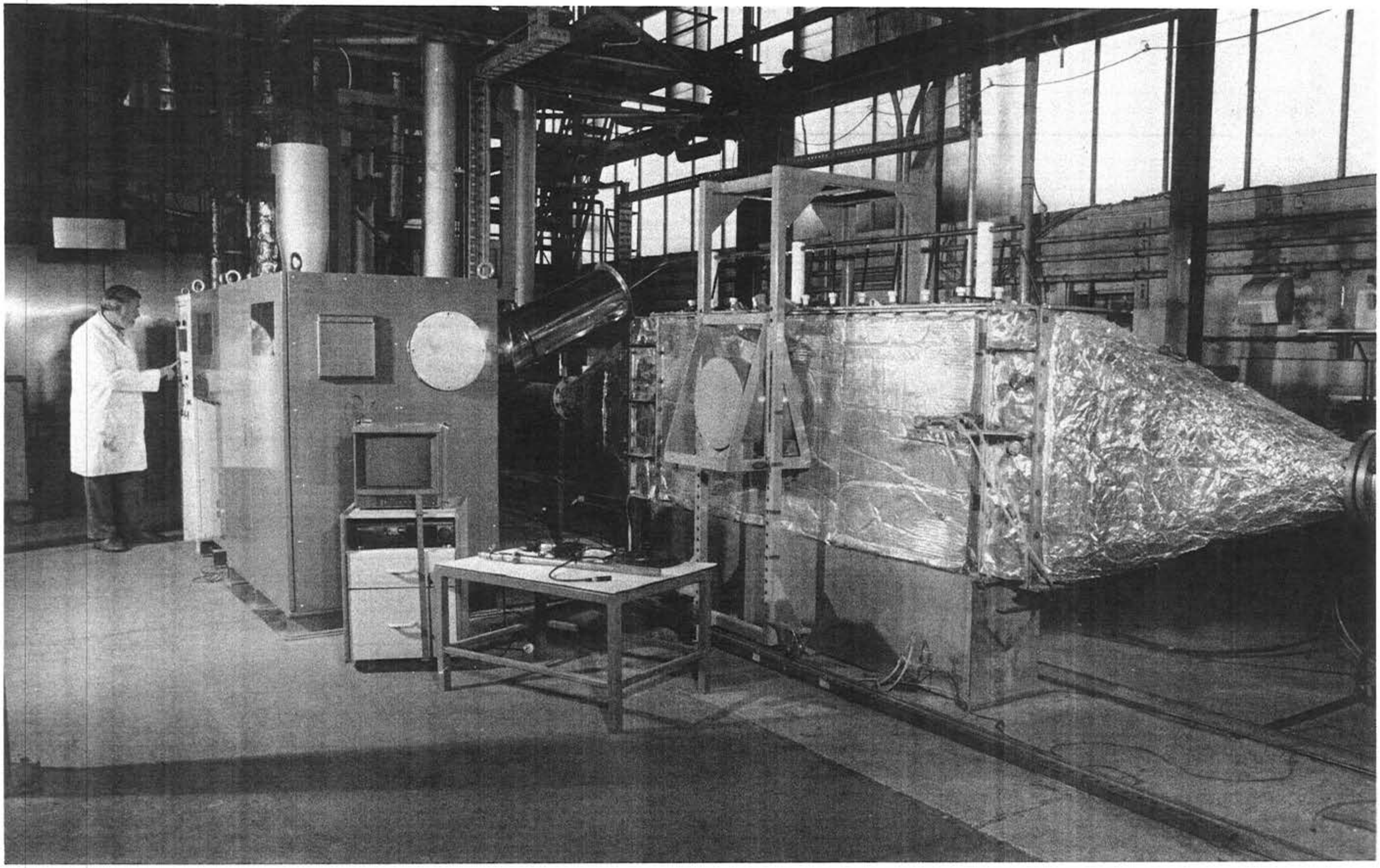

FIGURE 1. PILOT-SCALE ELECTROSTATIC PRECIPITATOR

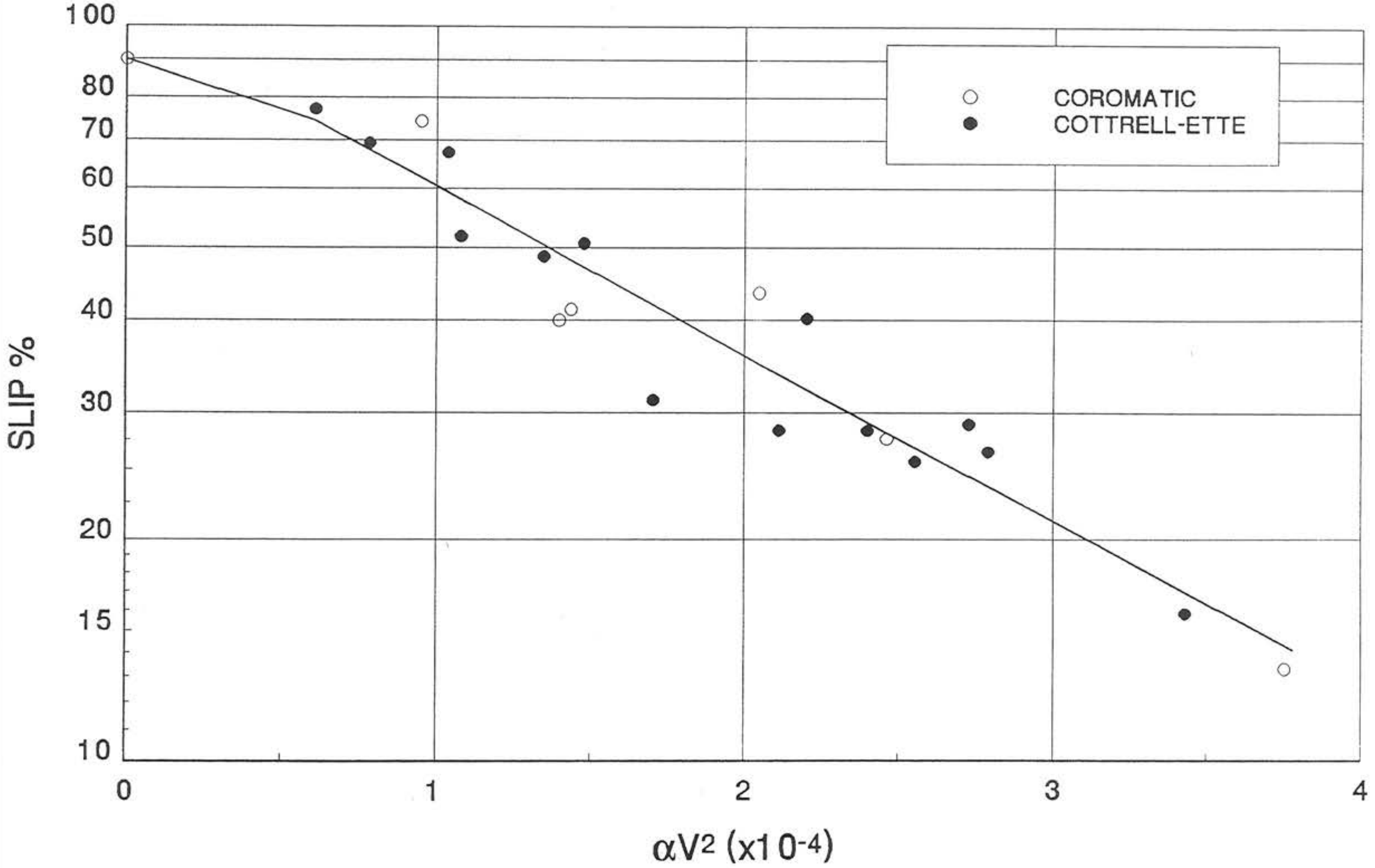

FIGURE 2. PRECIPITATOR PERFORMANCE WITH CONTINUOUS ENERGISATION

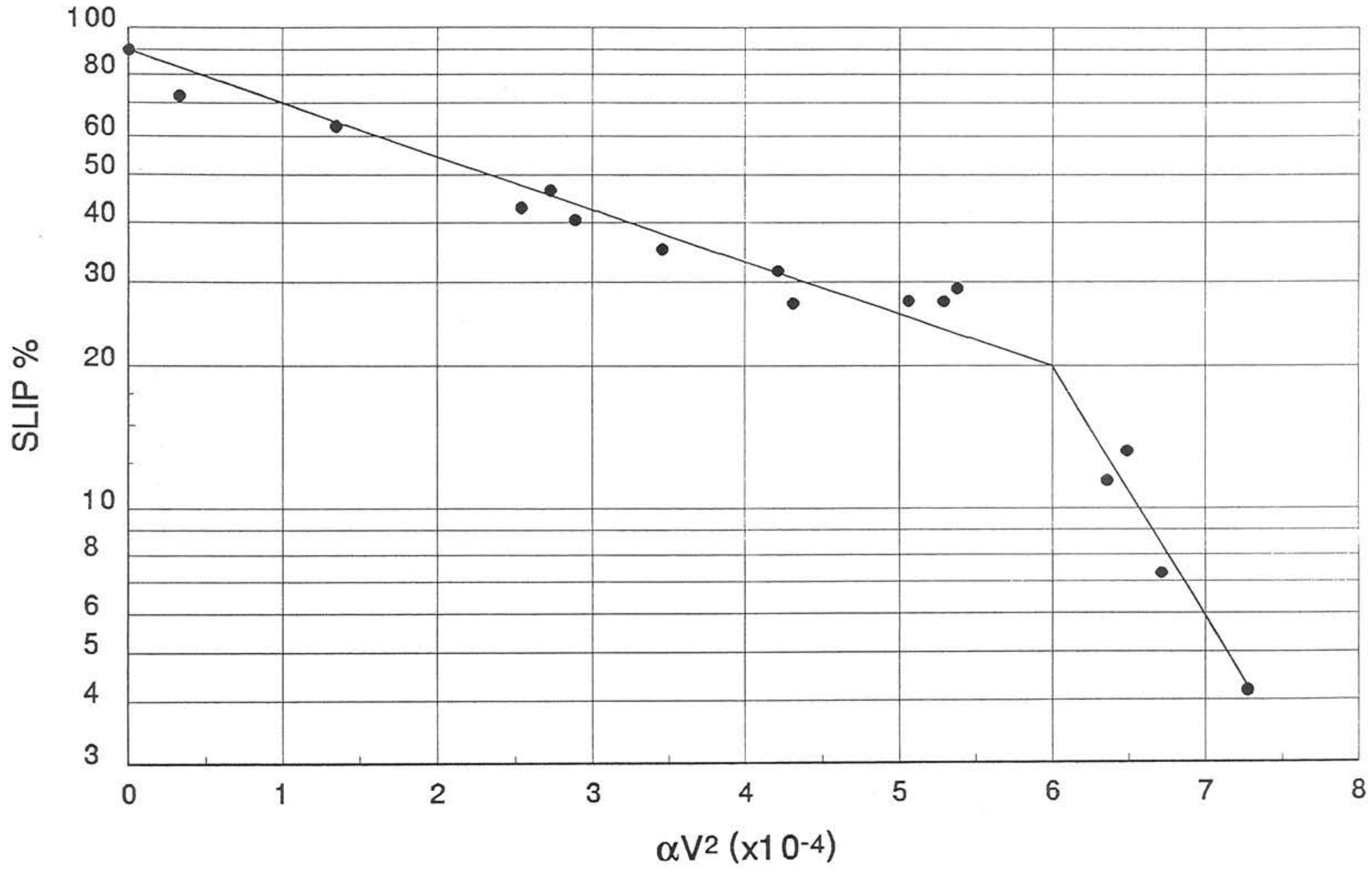

FIGURE 3. PRECIPITATOR PERFORMANCE WITH INTERMITTENT ENERGISATION

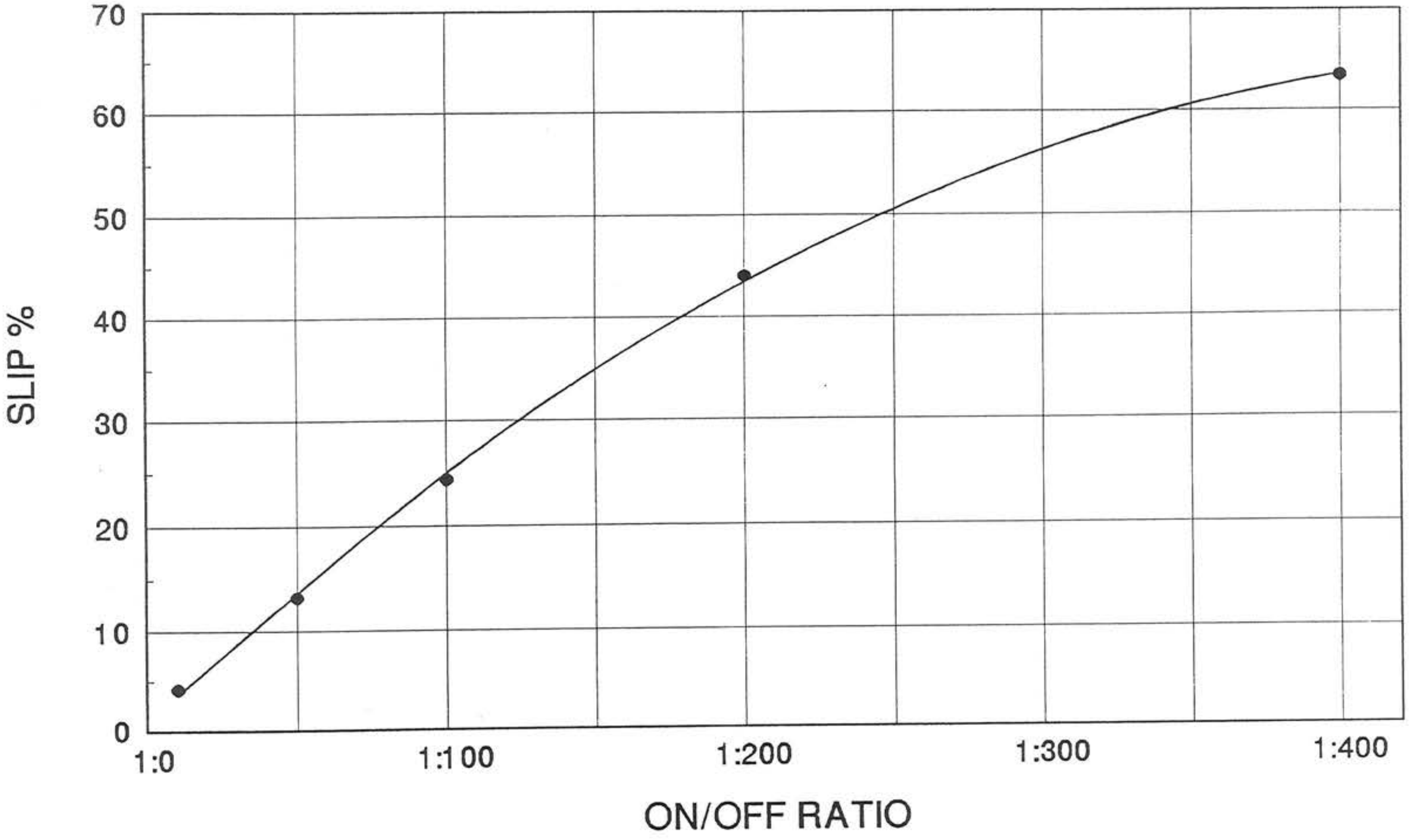

FIGURE 4. THE EFFECT OF ON/OFF RATIO ON PRECIPITATOR PERFORMANCE

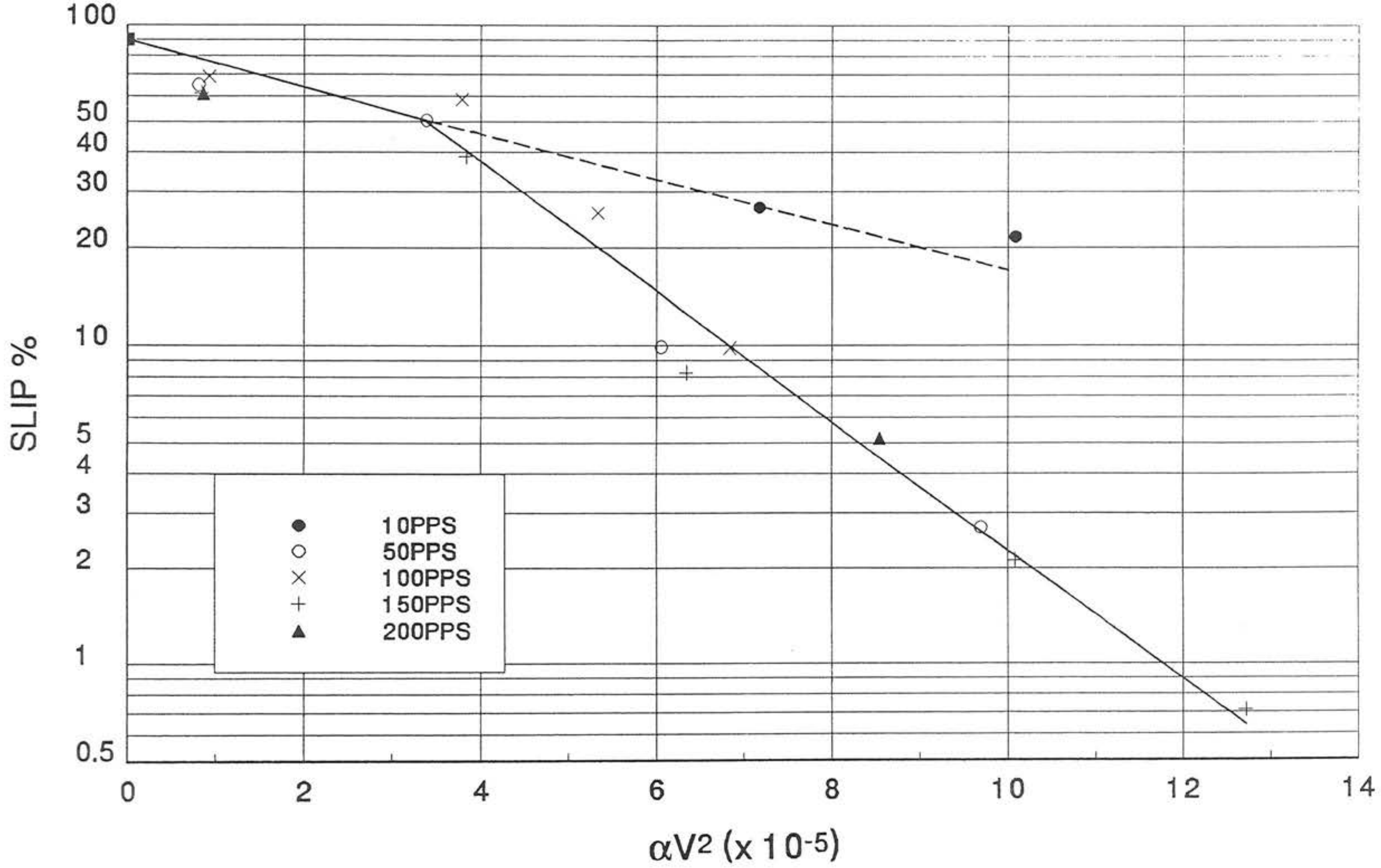

FIGURE 5. PRECIPITATOR PERFORMANCE WITH PULSED ENERGISATION