

APPLICATION OF MODERN ESP MODELS TO LOW SULPHUR, HIGH-ASH POWER STATION CONDITIONS

ALISTAIR HENDERSON* AND JIPING ZHOU#

***Baltec Australia, Brisbane, Australia**

#Stanwell Corporation, Rockhampton, Australia

alistair@baltecau.com

ABSTRACT

Modern electro-hydrodynamic models of electrostatic precipitator behaviour are now publicly available and have been widely used in the U.S.A., Europe and the NIS. The best known of the new models is ESPVI, developed by the US EPA, which simulates the precipitator on an element basis to give an extensive amount of operating information. The performance of this model with Southern Hemisphere coal ashes has not previously been reported, but is of interest throughout the world due to the large quantity of traded steaming coal from this region.

A complete electrical, mechanical and performance study of a precipitator collecting ash from a utility burning Central Queensland coal was used to test the ability of the ESPVI model to predict actual operating conditions. The study was undertaken before and after a major overhaul, enabling both new and deteriorated conditions to be modeled.

Further studies of other regional precipitators were undertaken to compare the results amongst installations with widely varying ash content and elemental analysis. The results of these studies are presented to allow users to apply the models to their own installations for performance prediction when considering remedial or upgrade work.

INTRODUCTION

An electrostatic precipitator (ESP) is a complex device involving physical, electrical, fluid and chemical processes. This complexity has meant that rigorous analytical solutions for characterization and performance have not been readily available to users in the field. Research workers and manufacturers have created databases of installations to derive empirical relationships of performance to many factors, but this is often not helpful to a user with a single installation in a remote location. Such a user needs to know if his plant is performing as well as it could, and the result of changes to either the plant or the process conditions. This paper describes the use of some modelling techniques to attempt to answer these questions for precipitators collecting flyash from coal used in Australia and India.

Recently reported computer models of ESP operation have fallen into two groups. The first group includes those which concentrate on the dynamic gas and particle flow in the ESP, such as Schmitz and Gibson (2004), to optimize the internal flow in accordance with a particular theory such as skewed or linear flow. These models are normally based on a commercial Computational Fluid Dynamics (CFD) package, and are highly effective at predicting the flows without requiring the traditional measurement by personnel inside the precipitator.

The second group are those models based on theories of particle charging and transport under the influence of an electric field, usually with additional complications such as back corona, sneakage, rapping, and turbulence applied to the model to simulate real conditions in practical industrial precipitators. These models include the European ORCHIDEE, described by Arrondel (2004), based on the theoretical work reported by Gallimberti (2004), which has a rigorous self-consistent basis but uses some assumed and empirical parameters to reduce computing times to acceptable levels. From the work of Lawless (1996) in the USA two models have developed, the EPRI product ESPM and the EPA publicly-available ESP-VI. These models use a bipolar particle charging algorithm to solve Poisson's equations to relate the electrical fields and space charges, from which currents and voltages at any point in the ESP are derived. As with the other models, some empirical parameters are still required to accurately model any real application.

PROCESS CONDITIONS

Coal Specifications

The coals used at the two stations were both relatively low in sulphur, but otherwise quite different, as shown in the brief specifications below in Tables 1.

Table 1: Abridged Coal Specifications

	Bowen Basin, Australia	Singrauli Basin, India
Ash (%)	16.7	39.8
Moisture (%)	10.6	16
Total Sulphur (%)	0.48	0.32
Specific Energy (Gj/kg)	26.23	12.72

The resulting inlet conditions to the precipitators are shown below in Table 2, with both the measured conditions and those derived from the combustion model included where appropriate.

Table 2: ESP Inlet Conditions

	Central Qld Power Station		Northern India Power Station	
	Measured	Modelled	Measured	Modelled
Gas Flow Rate (Am³/S)	270.8	273	70	70
Temperature (° C)	144	150	148	150
Dust Burden (g/Nm³)	12.3	10.3	76	68.4
Dust Resistivity (ohm-cm) @ 150° C	2.31 x 10 ¹²	1.2. x 10 ¹²	4.87 x10 ¹²	3.18 x 10 ¹²
Mass Median Dia (µ m.)	13	-	22.4	-

The two plants modelled were both in good mechanical condition following overhauls when the test measurements were made. The comparative sizes are shown below in Table 3.

Table 3: ESP Dimensions

	Central Qld	Northern India
Total Plate Area (m²)	31,108	14,580
S.C.A. (m²/m³/S)	113.9	206
Electrode Spacing (mm)	400	400
Aspect Ratio	1.84	1.80
Total Treatment Time (sec)	22.8	41

ESP MODEL

The model chosen for these investigations was the publicly-available ESP-VI 4.0W, primarily because of its wide availability outside of the U.S.A. and its ability to run on a typical personal computer now found in most industrial organisations. This model required factors such as resistivity to be entered as part of the input data, and so a complementary model for predicting resistivity using the Bickelhaupt technique was developed using the standard Excel spreadsheet tool. A combustion model was also developed in Excel to provide mass balances for consistency checking and flue gas composition data for resistivity prediction.

Modelling Approach

The purpose of the investigations was to use the modelling tools for predicting future performance of the respective precipitators under a variety of possible scenarios. To gain confidence in these predictions, as many site measurements as could be made were undertaken before, during and after a significant overhaul shutdown. These measurements included VI curves for all fields of the precipitator, isokinetic measurements at both the inlet and outlet of the ESPs, coal sampling during test measurements, and complete ash analysis for size and chemical composition.

Modelling Technology

The ESP-VI program generated a predicted set of electrical conditions, displayed as a VI curve, for a given inlet condition data set. The two principal sets used were a clean air load condition, obtained immediately after the overhaul, and a running set obtained during a series of isokinetic measurements.

The program generated its electrical conditions based on a user-supplied physical description of the ESP mechanical arrangement. The discharge electrodes used were those commonly available in both Australia and India, a spiral wire electrode as used by several manufacturers and a tape and spike electrode with variable spacing as used quite popularly with wide spaced electrodes. The program allowed modelling only round electrodes with variable corona sites if required, but permitted an unlimited number of electrodes with any spacing and misalignment. Thus a complex electrode could be modelled by describing three or more individual elements in close proximity, each with a different diameter, corona site spacing, and distance from the centre line.

In practice, we found the easiest way to generate the required discharge electrode model was to fit the generated VI curve to that obtained from a clean air load test, using a relatively simple single element model. By including the electrode support frames, reasonable fits to the measured VI curves were obtained. An example of a generated air-load VI curve is shown in Figure 1.

MODEL RESULTS

Process Models

The standard Bickelhaupt coefficients did not produce good agreement with measured resistivities, and better results were obtained with the correction factor developed by Juniper (2000), particularly for the Indian coal with its very high ash content. Figure 2 shows the curves of the measured and modelled resistivities against temperature, with agreement within the accepted measurement accuracy of +/- 50%. With the correction applied, this modelling technique appears to hold well even for the high ash coals measured, and further tests against a range of coals would refine the correction factor.

The combustion model was fairly simplistic, assuming complete combustion of the elements available from an ultimate coal analysis, and required trimming of its assumptions on excess air, bottom ash and leakage to generate results within even 5% of the measured gas flows to the precipitator. It did not produce a self-consistent mass balance result without requiring more data than was readily available, and the gas composition results did not reconcile well with the test measurements. It is useful as a guide, but would need to be calibrated against a full isokinetic test in order to reliably predict the flows, composition and dust burden.

Precipitator Model

The ESP-VI4W model was disappointing to use, with inconsistent results and no clear reason for them. The model allowed most important parameters to be either calculated from input conditions or directly over-ridden, which allowed flexibility but also caused problems. The most important of these were electrical energisation conditions, which could be entered from site measurements or internally calculated by modelling VI curves for each field. The internal model used the onset of back corona or sparking to set the electrical operating point, and this produced a consistent, but excessive, value for the precipitator emission. Any site data entered produced results which were both inconsistent and vastly different from the actual situation. A sample output is shown in Figure 1 and some comparative results are in Table 4.

The problem appeared to be the model's treatment of back corona conditions and intermittent energisation. Intermittent energisation is widely used to control back corona in both Australia and

India, and it is quite normal to have Charge Ratios (or Degrees of Intermittence) significantly larger than 25 to 1. The model did not allow a ratio greater than 12 to 1, as would be normal in the U.S.A., where very high resistivity ash is not often encountered. It proved extremely sensitive to the ratio of peak to average voltage, and would not produce accurate results with peak to average ratios even close to those actually used.

Table 4: Comparative Results

	Central Qld Power Station		Northern India Power Station	
	Measured	Modelled	Measured	Modelled
ESP Efficiency (%) Model Voltages	99.67	99.77	99.46	99.59
Penetration (%)		0.23	0.54	0.41
Operating Outlet Burden (mg/Nm³) – Model Voltages	46	21.3	420	328
Operating Outlet Burden (mg/Nm³) – Site Voltages	46	137	420	7,800

The model includes empirical parameters for steady-state and rapping re-entrainment, sneakage, turbulent mixing and back corona loss. Although it appears from Table 4 that a small correction to these parameters should have brought the model to reasonable agreement with the measured values, in practice it was not possible to get consistent agreement with them. As would be expected from real practice, the results were sensitive to particle size, gas composition, temperature and electrical conditions, but we did not expect the number of run-time errors encountered in the calculation modules from minor changes to values.

CONCLUSIONS

The ESPVI-4.0W model is potentially a very useful tool for users in any industry to analyse their plant performance and to track or predict the effects of changes to the process or plant. The usability features such as the ability to reverse model a set of emitting electrodes by fitting the curves of simple arrays mean that a new model of a plant can be developed both quickly and easily. The data required is normally available or readily estimated, so that the model can be applied to most precipitators, and very easily to a combustion plant, where the gas characteristics can also be modelled from fuel data.

The problems encountered with the model related primarily to its inflexibility with intermittent energisation to control back corona as is common in this region, and its poor error handling routines. Further work on these aspects would provide a tool with very wide application.

REFERENCES

- Arrondel V., Salvio J., Gallimberti I. and Bacchiega G. (2004). *ORCHIDEE Efficiency optimization of coal ash in electrostatic precipitation*, Proc ICESP IX South Africa, May 2004.
- Bickelhaupt R. E. (1979). *A Technique for Predicting Ash Resistivity*. U.S. EPA Report No. EPA-600/7-79-204, August 1979.
- Bickelhaupt R. E. (1986). *A Study to improve a technique for predicting flyash resistivity with emphasis on the effect of SO₃*, U.S. EPA Report No. 600/7-86-010, August 1986.

Chandra A., Kumar S. and Kumar S. (2004). *Investigation on Fly Ash Resistivity of Varieties of Coals used in Indian Power Stations*, Proc ICESP IX South Africa, May 2004.

Gallimberti I. (2004). *Detailed mass balance in Electrostatic Precipitators under industrial operating conditions*. Masuda Lecture, Proc ICESP IX South Africa, May 2004.

Juniper L. (2000). *Thermal Coal Technology*. Dept of Mines and Energy, Brisbane 2000.

Lawless P. A. (1996). *ESPVI 4.0 Electrostatic Precipitator V-I Performance Model – User’s Manual*, Center for Aerosol Technology, Research Triangle Institute, Durham, NC, USA

Parker K. and Plaks N. (2004). *Electrostatic Precipitator (ESP) Training Manual*, U.S. EPA Report No. EPA-600/R-04-072, July 2004.

Schmitz W. and Gibson D. (2004). *The Effect of Non-Uniform Dust Distribution on ESP Performance*, Proc ICESP IX South Africa, May 2004.

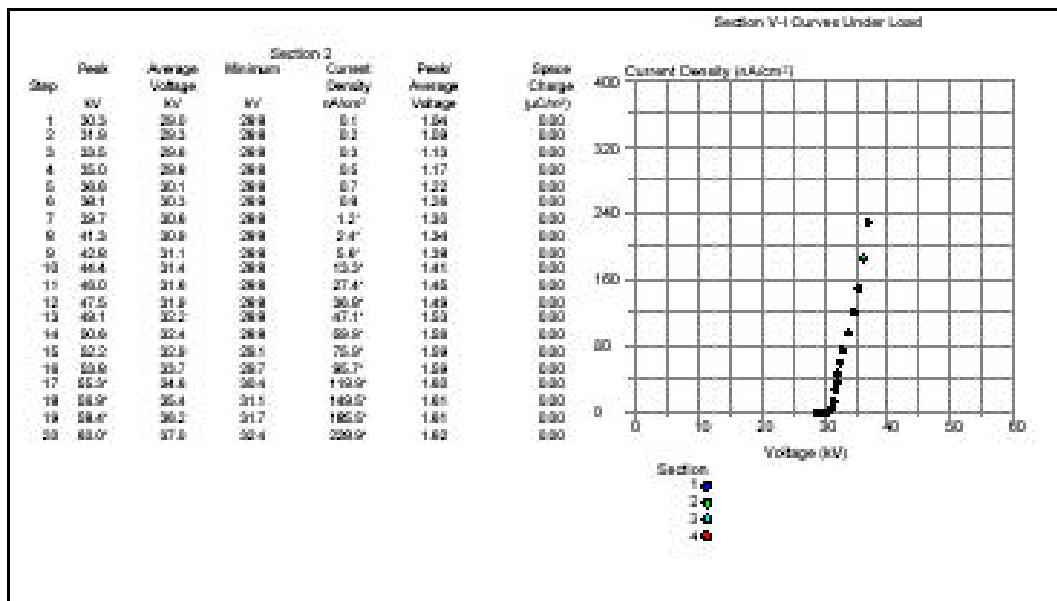


Figure 1: Modeled VI Curve

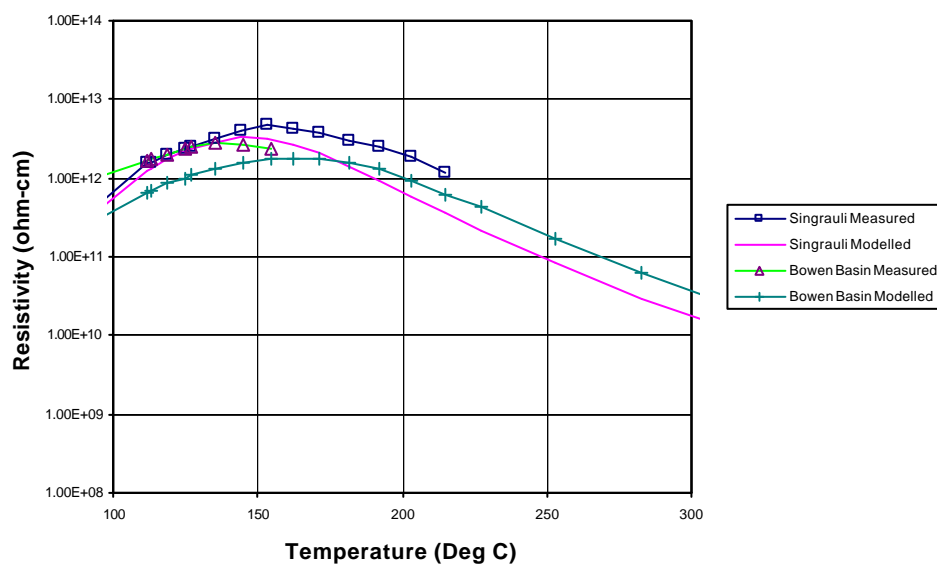


Figure 2: Measured and Modelled Resistivities

----- ESPVI 4.0 Windows Model -----

Overall results for BOWEN_BASIN_COAL

Efficiency	=	99.77 %	
Penetration	=	0.23 %	
Emissions	=	13.79 mg/m ³	(0.0060 gr/acf)
	=	21.34 mg/nm ³	(0.0093 gr/dscf)
	=	7.74 ng/J	(0.0180 lb/MBTU)
PM10	=	9.96 mg/m ³	(0.0043 gr/acf)
PM2.5	=	5.26 mg/m ³	(0.0023 gr/acf)
Opacity	=	5.2 % @ 3.1 m ²	

RAPPERS OFF

Efficiency	=	99.87 %	
Penetration	=	0.13 %	
Emissions	=	7.58 mg/m ³	(0.0033 gr/acf)
	=	11.74 mg/m ³	(0.0051 gr/dscf)
	=	4.25 ng/J	(0.0099 lb/MBTU)
PM10	=	6.44 mg/m ³	(0.0028 gr/acf)
PM2.5	=	5.21 mg/m ³	(0.0023 gr/acf)
Opacity	=	4.6 % @ 3.1 m ²	
Rapping Contribution	=	45.0 % of total emissions	

Modelled using October 2005 properties of Unit 3 where possible

Figure 3: Sample ESP-VI 4.0w Output for Central Qld Station