PN-ACG-276

Electrostatic Precipitator Improvement Study

Project Number 4390

January 15, 1999

Prepared for
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94304

By:
Grady Nichols Enterprises, Inc
400 Kiowa Street
Montevallo, Alabama 35115

Under:
USAID's Greenhouse Gas Pollution Prevention Project

As a deliverable to:
U S Department of Energy
Federal Energy Technology Center
Pittsburgh, PA 15236

FETC

PN-ACG-276

Electrostatic Precipitator Improvement Study

Greenhouse Gas Pollution Prevention Project

Project Number 4390

January 15, 1999

Prepared by
Grady Nichols Enterprises, Inc
400 Kiowa Street
Montevallo, AL 35115

Project Manager
Dr Grady B Nichols

Authors and Team Members
Grady B Nichols
William W Oberg
G H (Wim) Marchant

Prepared for
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94304

EPRI Project Managers
Drs Ralph F Altman and John Tsou
Energy Conversion Group

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THIS REPORT WAS PREPARED BY THE ORGANIZATION(S) NAMED BELOW AS AN ACCOUNT OF WORK SPONSORED OR COSPONSORED BY THE ELECTRIC POWER RESEARCH INSTITUTE INC (EPRI) NEITHER EPRI ANY MEMBER OF EPRI ANY COSPONSOR THE ORGANIZATION(S) BELOW NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER EXPRESS OR IMPLIED (I) WITH RESPECT TO THE USE OF ANY INFORMATION APPARATUS METHOD PROCESS OR SIMILAR ITEM DISCLOSED IN THIS REPORT INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY OR (III) THAT THIS REPORT IS SUITABLE TO ANY PARTICULAR USER S CIRCUMSTANCE OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS REPORT OR ANY INFORMATION APPARATUS METHOD PROCESS OR SIMILAR ITEM DISCLOSED IN THIS REPORT

ORGANIZATION(S) THAT PREPARED THIS REPORT

Grady Nichols Enterprises Inc

Tennessee Valley Authority

Southern Research Institute

ORDERING INFORMATION

Requests for copies of this report should be directed to the EPRI Distribution Center 207 Coggins Drive P O Box 23205 Pleasant Hill CA 94523 (510) 934-4212 There is no charge for reports requested by EPRI member utilities

Electric Power Research Institute and EPRI are registered service marks of Electric Power Research Institute Inc

Copyright © 1999 Electric Power Research Institute Inc All rights reserved

EXECUTIVE SUMMARY

This report provides the results of a task from the Greenhouse Gas Pollution Project between the U S Agency for International Development and the Center for Power Efficiency and Environmental Protection associated with the National Thermal Power Corporation of India This project was performed jointly by AID, DOE, TVA, Electric Power Research Institute (EPRI) and the Indian Organizations Several electrostatic precipitator experts from the U S represented the sponsoring organizations in this team effort The purpose was to transfer U S developed technology for obtaining the best possible performance from electrostatic precipitator (ESP) systems installed in electric power generating facilities to India The sponsoring organizations provided modern test equipment, technical training, experience with conducting and interpreting data from experiments and establishing appropriate corrective measures for upgrading the performance of ESP systems The same approach to troubleshooting and upgrade studies also apply to the design of particle control equipment for new installations

The program started with a combined Seminar-Workshop to provide the CENPEEP team the background information about the technology of electrostatic precipitators and the use of the U S supplied computer ESP model This model was developed under the sponsorship of the U S EPA and the Electric Power Research Institute of Palo Alto, California

The U S Team members led the Indian members through measurement programs at both the Dadri and Rihand ESP systems The Technology Transfer process continued with the interpretation of the data and the interpretation of the results of the measurement programs Finally, a set of corrective measures to improve the performance of the ESP systems was developed based on the understanding gained through the test program

This report includes sections dedicated to discussions of the appropriate measurement techniques, step by step analysis and interpretation of test data, and

4

evaluation of the results by the use of an ESP computer model This model and knowledge of how to use the model were transferred to the Indian team members Sets of recommendations that apply to the tested stations, other stations in the NTPC system and new power stations are included in the report

There are also recommendations to CENPEEP about the suggested directions for the establishment of a very strong ESP technology capability to serve both the electric utility and the Environmental Protection functions of the Indian Government A recommendation about a demonstration project for their immediate consideration is given as well as a recommendation to establish a Technology Evaluation Facility

It is anticipated that the U S and Indian Team members will continue to work together in future projects One person from CENPEEP visited the U S in 1998 to investigate the particulate control technologies, in use and under development, at a number of utility stations in the U S There have been discussions of potential areas for continued cooperation between the participants

5

CONTENTS

1 INTRODUCTION 1-1

2 PHASE ONE *TEAM FORMATION AND PROGRAM DEVELOPMENT* . . . 2-2

Workshop with CENPEEP 2-2

***3* PHASE TWO *DADRI POWER STATION PROGRAM*. . .. 3-4**

Dadri Power Station Measurement Program 3-4

Training to Familiarize Indian Participants with U S Equipment and Techniques 3-4

Measurements on ESP with Power Plant Operating 3-4

Measurements and Inspection with Power Plant Off Line 3-6

Data Collection 3-8

Mass Loading Measurements 3-8

Particle Size Distribution 3-11

Electrical Power Supply Readings 3-11

Internal Inspections 3-12

Gas Velocity Distribution 3-13

Dadri Data Analysis, Model Studies and Evaluation of ESP Improvement Options 3-15

Computer Model Studies 3-16

Evaluation of Performance Upgrade Options 3-19

Add Anti Sneak Baffles to Ash Hoppers 3-19

Add Temperature Controlled Precharger Sections 3-21

Reduce Ash Resistivity 3-22

***4* PHASE 2 *RIHAND POWER STATION PROGRAM* . . 4-24**

6

Rihand Power Station Measurement Program 4-24
Mass Tests *4-24*
Particle Size Distribution *4-24*
Power Supply Electrical Readings *4-26*
Rihand Data Analysis, Model Studies and ESP Improvement Option Evaluation 4-27
Computer Model Studies *4-27*
Evaluation of Performance Upgrade Options 4-28
Upgrade Power Supply Controls to Intermittent Energization *4-28*
Add Anti-Sneak Baffles in Hoppers *4-29*
Add Temperature Controlled Prechargers Behind First Two Fields *4-30*
Reduce Ash Resistivity *4-31*

5 PHASE 3 *RECOMMENDED PLANT ACTIONS* . . . 5-33
Dadri Power Station 5-34
Optimize the IE or Charge Ratio *5-34*
Install Anti-Sneak Baffles in the ESP Hoppers . *5-35*
Optimize the Rapping Intervals *5-36*
Add Hoppers to Outlet Ducts *5-36*
Measure Gas Velocity Distribution in All Passes *5-37*
Rihand Power Station 5-37
Measure Gas Velocity Distribution and Correct Flow as Needed *5-37*
Upgrade Power Supply Controls and Operational Mode *5-38*
Install Anti-sneak Baffles in Ash Hoppers *5-38*
Optimize Rapping Intervals *5-38*
Conduct Water Fogging and Moisture Conditioning Evaluation *5-38*
General Items Pertinent to All Power Stations 5-39
Emission Tests, Sampling Ports and Opacity Meters *5-39*
Water Fogging and Moisture Conditioning *5-39*
Corona Electrode Failure *5-40*
Ash Handling Systems *5-41*
Dust Dropout in Ductwork *5-41*

1

Investigate Air Infiltration 5-41
Improve Gas Velocity Distribution 5-41
Optimize Rapping System 5-42
Thermal Insulation Integrity 5-42
Upgrade Auxiliary Equipment 5-42
Combustion Process Modification 5-42
New Power Stations to Be Constructed 5-43
Flue Gas Temperature at Control Device Inlet 5-43
Add Cyclonic Collectors and Hoppers 5-44
Sampling Ports 5-44
Technology Evaluation Facility 5-45

6 RECOMMENDED ACTIONS FOR CENPEEP 6-46
Team Formation 6-46
Establish Laboratory Capability 6-47
Resistivity Measurement 6-48
Coal and Fly Ash Chemistry 6-49
Particle Size Distribution 6-49
Sulfur and Nitrogen Oxides 6-49
Construct and Operate Technology Evaluation Facility 6-49
Conduct Demonstration Project for Sodium Conditioning 6-51
Data Base for Coal and Fly Ash 6-51
Future Regulations and Emissions Monitoring 6-51
Coal Washing 6-52

8

1 INTRODUCTION

The purpose for the Electrostatic Precipitator Improvement Study task of the Greenhouse Gas Pollution Prevention Project is to establish, in India, the capability for conducting tests and analyzing the data from ESP systems to develop and execute plans for upgrading, troubleshooting and designing ESP systems The U S Agency for International Development (AID) and the U S Department of Energy (DOE) established a team of U S experts to work with a team in India, provided the equipment necessary to conduct the measurement program, and provided the training to familiarize the Indian Team with the U S equipment and techniques to establish this capability The India team is led by the Center for Power Efficiency & Environmental Protection (CENPEEP) associated with the National Thermal Power Corporation Ltd (NTPC) of India The entire team, consisting of U S and Indian members, has worked together to achieve the goals of this project

This project provided for a technology transfer of information, expertise and equipment developed under the sponsorship of various agencies of the United States Government, primarily the Department of Energy and the Environmental Protection Agency, as well as contributions to that technology by the Electric Power Research Institute in Palo Alto, California for use in India

The various aspects of this interchange included seminars, cooperative test programs to collect data, familiarization with U S developed ESP computer models to be used for analyzing the data, and evaluation of results for the purpose of upgrading, troubleshooting or designing new environmental control equipment Two specific test programs were conducted at the Dadri and Rihand Stations, serving as examples for guiding the CENPEEP-NTPC team through upgrade programs The Dadri test was the first program with the U S team participating more actively than at Rihand This second test was conducted almost exclusively by the Indian team

2 PHASE ONE

TEAM FORMATION AND PROGRAM DEVELOPMENT

Workshop with CENPEEP

The U S team presented a workshop at the Power Management Institute (PMI) auditorium near New Delhi, to provide the technical background for the theory and practice of electrostatic precipitator (ESP) technology, training in the use of the ESP computer model, and an introduction to the test methods required to understand the performance characteristics of ESP systems This workshop was presented to a group of Indian participants during June of 1997 During this three day seminar, lectures, questions, and discussions provided the participants an opportunity to establish common ground to approach this project The U S team provided written material covering their presentations Several of the Indian participants presented information on the design and operation of some ESP systems at their coal burning utility installations

Power Station Visits

The team members visited several NTPC power stations to identify the appropriate plants for inclusion in the measurement program, as well as to discuss the specific ESP systems and operational characteristics with NTPC plant personnel The Dadri and Rihand stations were selected for the follow-on measurement program, which began in September of 1997 During the visit to the Badarpur Station and in discussions that followed, the team members decided to conduct water fogging and humidification tests during the September 1997 test program The plant was provided with two Lechler dual fluid nozzles to be installed in the Badarpur ductwork preceding the ESP This installation was accomplished during the time the testing was being conducted at Dadri The nozzles were installed and inspected by the team members during the September 1997 visit to India The India team members were and still are conducting this task independently The Badarpur Station startup was delayed until after the Dadri test program was completed The initial tests were conducted in December 1997, with a reduction in outlet emissions

10

of about 18%, while injecting water at a rate of 18 liters per minute into half of the ESP on a 90 megawatt power station The tests continued in 1998 with increased injection rates of 25 to 30 liters per minute using both Lechler nozzles The variability of the conditions of the plant make a detailed evaluation of this technology very difficult at Badarpur However, the data indicate a very positive response to water fogging Further tests should be conducted at other NTPC stations as a continuation of this initial experiment Dadri seems to be an acceptable location, but a station with a higher operating temperature, such as Rihand, is more appropriate

3 PHASE TWO *DADRI POWER STATION PROGRAM*

The Dadri and Rihand Stations were selected as the two locations where the Indian team would work together with the U S team to establish their familiarity with the U S supplied test equipment and methods The members of the team from CENPEEP, NTPC and the U S selected the Dadri Station as the initial test location

Dadri Power Station Measurement Program

Training to Familiarize Indian Participants with U S Equipment and Techniques

The phase two portion of the project started with class room training in the use of the new equipment provided for this test program Measurement test equipment was provided to CENPEEP prior to the arrival of the U S team The equipment was described and demonstrated to the Indian team members, after which the test team assembled the equipment and conducted ambient air tests to become familiar with the equipment operation After this formal instruction period, the equipment was packed and moved to the Dadri Power Station for the first actual in-plant test of the performance of an ESP with the new test equipment

Measurements on ESP with Power Plant Operating

The U S team leaders assisted the Indian team in conducting the initial measurements at the Dadri station The first data set collected included all of the information available from the ESP during normal full load operation This information included a determination of the mass loading of fly ash into and out of each ESP pass (A, B, C, & D) of unit three and in the stack, where all four ESP gas streams are combined These tests were successfully conducted and the data recorded The results indicate that ESP passes A, B, & D were working well, while the emissions from pass C were somewhat elevated The cause for this behavior was investigated further during the inspections conducted after plant shutdown

12

In all of the outlet passes, the lower portion of the duct exhibited very high mass loadings, suggesting that the ash in that region was almost "fluidized", rather than behaving as ash suspended in a gas stream The bottom port in each duct was not sampled since this would bias the data by picking up ash from the floor of the duct Adding a hopper in this region to remove this material from the outlet ductwork, and thereby preventing its contribution to the outlet loading may prove to be beneficial It is more likely that reentrainment will occur during ramping load situations after the ash dropout reaches steady state It is important to determine how long it takes for the ash layer in the bottom of the hopper to reach an equilibrium thickness

The particle size distribution of the fly ash entering the ESP was the next parameter determined during the tests The size distribution of the material present in the stack was also measured The mass loading and particle size distribution data provide the information needed to compare the actual performance of each pass of the ESP with that predicted from a computer ESP model The inlet mass loading and particle size data serve as inputs to the model, while the outlet particle information is compared with the data from the model outlet study This comparison and evaluation is discussed in Phase Five of the project report These tests were successfully completed with the data recorded for further analysis The results of these measurements are discussed in the section on data analysis and evaluation that follows later in this report

The Dadri plant personnel collected information about the operational characteristics of the furnace and boiler systems and the electrical readings from the individual transformer-rectifier (TR) sets, at intervals during the test period These data were necessary in order to verify that the power station conditions were stable during the time of testing and the electrical data are required as input data for the model study portion of this project

The U S and Indian team jointly conducted the measurement program described above The members of the Indian team very quickly understood the operation of the new equipment and, because of their previous experience and interest, contributed greatly to the success of this portion of the data gathering The CENPEEP-NTPC team is now capable of independently conducting measurements of mass loading and particle size distribution with the new equipment at other locations within the utility The Technology Transfer effort is complete and was very successful

The U S part of the team submitted a test final report for the mass and particle size distribution measurements at the completion of the test program This test report provided a detailed summary of the results of the tests, including the appropriate data reduction formulae and the test summaries The test results utilized in this report were taken directly from that report Some of those data are summarized in this report

Measurements and Inspection with Power Plant Off Line

The mechanical conditions of the ESP system can best be determined from an internal inspection and from electrical data obtained with the ESP off line The internal inspection is conducted in two phases first with a dust layer remaining on the corona and collecting electrodes and later after the ESP has been cleaned, so that the electrodes themselves can be inspected The plant turned off the rapping system prior to de-energizing the electrical sets, in order to preserve the dust layer on the plates and corona wires The condition of the dust, as it exists on the plates, gives a good indication of the effectiveness of the rappers and whether the fly ash is upsetting the gas velocity distribution by forming mounds in the ductwork or plugging the gas velocity distribution screens The plate and wire spacing uniformity can also be evaluated during the inspection

During normal operation before the shutdown, the "A" pass of the ESP was isolated and the access doors were opened on Sept 23, 1997, to allow inspection of the ash layer on the collecting electrodes under operating conditions Fly ash has a tendency to absorb moisture when exposed to ambient air Therefore, as the plant cools down after shutdown, the physical characteristics of the ash on the plates may change as the ash picks up moisture The addition of moisture causes the ash layer to consolidate and cake This situation was suggested by the appearance of ash on the plates in one of the units in the June 1997 time period This "on line" observation of the ash layer indicated that this Dadri Unit 3 ash is, in fact, very light and flows readily The ash layer on the plates was only 1 to 2 mm thick, indicative of adequate rapping forces

Plant electrical personnel provided the information to define the secondary voltage versus current (V-I) curves for each electrical section in unit 3, after the plant was shut down, with air flowing through the ESP from the natural draft of the chimney Some air flow is important to avoid the buildup of ozone in the ESP chamber that occurs during operation with stagnant air The presence of ozone greater than some threshold level modifies the V- I characteristics of the ESP These data were recorded for both the conditions with dust on the plates and wires and after the ESP

internals were washed These data provide information about the condition of the insulators and about the general mechanical alignment of the various electrical sections in the ESP The plant personnel are experienced in collecting these types of data

After the completion of the dirty condition inspection, the ESP was washed internally After washing, a second internal inspection was made in selected areas deemed to be suspect in the dirty inspection The actual conditions of the plates and wires are much more readily determinable in the clean condition

The internal structure of this particular ESP is not well designed for conducting internal inspections What is customarily a walkway of some 300 to 500 millimeters in width, is a single beam about 100 mm wide Plant personnel provided walkway material and lights for use during the internal inspections

CENPEEP was provided a new thermal anemometer for measuring the gas velocity distribution in ESP's An original goal of this program was to instruct NTPC personnel in the measurement of gas velocity distributions in an ESP However, discussions with the plant personnel at Dadri, confirmed that they are experts at measuring gas velocity distributions in ESP's It was only necessary to introduce them to the new thermal anemometer The Dadri plant personnel conducted detailed measurements of the gas velocity distribution with all fans energized and all four ESP passes open These results were provided to the team members The data indicated an average gas velocity of about 0 7 meter per second, which is well within the measurement range for the new anemometer Maintaining all four ESP passes open assures that the flow pattern will more nearly duplicate that for full load operation when all passes are customarily active

It was recommended that the velocity measurements be made at the outlet of the first field at one meter intervals vertically in every third gas passage to provide an array of measurements at about one meter intervals Also, measurements of flows in the hopper below the plates were requested so that an evaluation of gas sneakage through the hoppers could be made Time available for measurements precluded obtaining the hopper flow data The results of the gas velocity distribution measurements were provided to the team members These data were taken from passes C and D only Time available during the short plant outage precluded making measurements in passes A and B Since A and B are mirror images of passes C and D, pass A was modeled with pass D velocity distribution and pass B used the data from pass C

A new oscilloscope was provided to CENPEEP as part of this project measurement equipment The oscilloscope provides the capability to conduct measurements of the voltage and current waveforms from the ESP power supplies We requested that plant personnel contact BHEL for guidance in obtaining the necessary waveforms as part of the complete data package for this project The secondary voltage metering circuit did not provide a readily available voltage reference source for measuring the secondary voltage waveforms In some power supply controls, the secondary voltage measuring circuit provides access to a voltage proportional to the secondary voltage as well as the time resolved actual waveform These characteristics are available when the operating voltage is derived from a set of voltage dividers connected to the secondary side of the high voltage transformer,

Data Collection

Mass Loading Measurements

The mass loading measurements were performed with what is referred to as U S EPA Method 17 techniques These measurements are made using a filter system inserted into the actual gas stream, with the filter thermally equilibrated with the flue gas before the initiation of sample collection The in stack measurement technique is appropriate for evaluating the performance of an ESP This technique assures that all material measured as particles existed as particles in the gas stream Other out of stack techniques, such as U S EPA Method 5 which are made at temperatures other than the flue gas temperature, may allow for the condensation of some materials such as sulfuric acid, in the flue gas of coal combustion systems (SO_3 condensation is not expected for Indian stations burning low sulfur coals)

The ESP inlet gas stream originates from a single furnace with the gas split into four flows with electrostatic precipitators installed in each flow The inlet and outlet ductworks are rather close coupled with relatively short runs of ductwork both for the inlet and outlet connections to each ESP The two outer ESP passes (A and D) are mirror images with the inner passes (B and C) also mirror images A sketch of the plant layout was provided with the test report

The inlet mass measurements were conducted on passes A, B, and C The inlet mass loading is very high, consistent with the high ash content of the coal used for producing electric energy in India The mass loadings from all measurements yielded a very consistent value for the inlet loadings Detailed inlet measurements to passes A, B, and C were conducted Since small variations in inlet loading do not significantly change the calculated value of the ESP performance efficiency,

the inlet conditions to pass D was estimated from the other measurements, to allow the test team to concentrate on the outlet and stack measurements The outlet data are more critical for the evaluations of the four ESP performances The results of the inlet mass measurements for the precipitator ductwork passes A, B, and C, are summarized in Table 3-1 The actual loading values are used in the model studies, since these are the actual conditions in the ESP

Table 3-1 Summary of Inlet Mass Data for Dadri Station

Location	Inlet A	Inlet B	Inlet C	Average	Eng Units
Gas Temperature ^{o}C	137	147	157	147	297 ^{o}F
Duct Pressure mm Hg	720 9	736 8	720 5	726	726
Gas Velocity m/sec	14 46	13 57	13 63	13 89	45 6 ft/sec
Vol Flow m^3/hr (act)	372663	350085	351500	358083	210771 acfm
Mass Load mg/m^3 (act)	31900	33000	35600	33500	14 22 gr/acf
Mass Load mg/dNm^3	49300	51900	56300	52500	23 06 gr/ft^3
O_2 Concentration %	6 3	5	5	5 4	5 4
CO_2 Concentration %	12 7	14	14	13 5	13 5

The outlet loading measurements were made with the same Method 17 technique used for the inlets Individual measurements were made on each outlet to provide the data necessary to evaluate the specific collection efficiency for each ESP unit The results of these outlet mass measurements together with the resultant calculated collection efficiency for these data are summarized in Table 3-2

Table 3-2 Summary of Outlet Mass Data for Dadri Station

Location	Outlet A	Outlet B	Outlet C	Outlet D	Stack
Gas Temperature °C	130	137	146	138	143
Duct Pressure mm Hg	719 0	716 6	710 5	719 8	721 8
Gas Velocity m/sec	14 61	15 01	15 98	13 97	24 43
Vol Flow m3/hr (act)	376700	387000	412000	360000	1404000
Mass Load mg/m3 (act)	46 535	71 685	381 946	102 474	166 200
Mass Load mg/dNm3	71 9	112 5	538 3	141 5	282 1
O2 Concentration %	6 3	5 0	5 0	5 0	6 7
CO_2 Concentration %	12 7	14	14	14	12 35
Collection Efficiency %	99 86	99 79	98 98	99 73	99 47

Mass loading measurements were also conducted in the stack This was the first time that mass loading measurements had been conducted in the stack in any power station of the National Thermal Power Company (NTPC) The stack is the appropriate location for conducting emission measurements for compliance with emission standards, whereas, the outlet ductwork is the appropriate location for conducting measurements to evaluate the performance of individual ESP systems The results of the mass loading measurements from the stack are also summarized in Table 3-2, above

The gas flow from each ESP combines to form the gas flow in the stack The total gas into each ESP should ideally match that flowing out of the ESP (with minor corrections for changes in gas temperature and pressure) The combined flows from all four passes should then match the measured flow in the stack (again with corrections) There is expected to be some small variation in flow to each pass from day to day, but there should be a reasonable agreement between the individual measurements The sum of the outlet flows from Passes A through D is 1,535,000 m^3 per hour, while the stack measured flow is 1,404,000 m^3 per hour, for an error of about 8% These data show a good agreement for the measurements, since they were conducted over a one week period

Particle Size Distribution

The particle size distributions of the fly ash entering the ESP's and that in the stack were measured using a set of five series ganged cyclones, each with a progressively smaller particle size cut-point The inlet cyclone has a D_{50} of about 5 micrometer and the last one has a D_{50} of about 1 5 micrometer (the cut point varies somewhat with sampling velocity) The measurements of the inlet size distribution provided an estimate for the inlet particle size distribution with a mass median diameter (mmd) of about nine micrometers with a geometric standard deviation of 2 5 Similarly, measurements of the fly ash in the stack indicated and mmd of 2 65, with a standard deviation of 2 1 The computer model projects an outlet particle size distribution with an mmd of about 2 7 with a standard deviation of 2 2 This is considered to be excellent agreement The computer model outlet particle size distribution is significantly influenced by the calculation of material reintroduced into the gas stream by rapping reentrainment, since the mass collection efficiency is very high

Electrical Power Supply Readings

The secondary voltages and currents were recorded at regular intervals during the test program There were some day to day variations, but the readings were relatively consistent during the test program Table 3-3 is a representative set of these data that were used as inputs to the computer model

The power supplies were equipped with reasonably modern controls The secondary voltage and currents were available from a readout screen on the controllers as well as the Intermittent Energization cycle information (Charge Ratio) was set manually The power supplies were not designed so that an easy determination of the secondary voltage as a function of time is available BHEL must assist CENPEEP personnel in establishing the capability for conducting these measurements on their power supplies using the oscilloscope provided to them

Table 3-3 Representative Secondary Power Supply Operating Data

ESP	Pass A		Pass B		Pass C		Pass D	
Field	kV	milliamp	kV	milliamp	kV	milliamp	kV	milliamp
Inlet	31	41	31	41	30	40	34	42
2nd	35	62	30	29	35	40	38	68
3rd	40	35	40	81	32	56	40	82
4th	38	127	40	80	35	31	36	112
5th	33	141	32	120	23	60	36	125
6th	35	153	31	110	29	141	38	86

Internal Inspections

The first portion of the internal inspection was conducted with the unit operating under near full load conditions This inspection was a short duration look at the condition of the ash layer on the collecting electrodes while the ESP was at operating temperature Pass A was temporarily isolated on September 23, 1997 by closing the inlet dampers to the ESP allowing the access doors to be opened for an inspection of the fly ash layer on the plates near these inspection entry doors The results of this inspection was the determination that the ash layer on the collecting electrodes was about two to three millimeters thick and that the ash tended to flow easily The ash layer thickness and characteristics indicate that the rapping system is effectively cleaning the electrodes and the condition of the fly ash is such that it can be removed from the electrodes by normal rapping forces

The actual detailed internal inspection of the individual ESP passes was conducted after the unit was brought off line and cooled sufficiently to allow personnel to enter the ESP casing The inspection started with Pass D in the dirty condition, continuing to Pass C and on through Pass A When the inspection was completed for one pass, that chamber was released to the plant personnel for internal washing All four passes were thoroughly inspected in the dirty condition The results of this internal inspection was that the individual ESP systems were in a very good and well maintained condition The dust layers on the electrodes were on the order of a couple of millimeters thick and the internal alignment was good Some individual areas of concern were pointed out to plant personnel for correction

during the shutdown, but the instances of corrective actions needed were very few In all, the internal condition of all four ESP's was good The small items requiring attention were to be corrected during the maintenance outage

The only significant item noted during the internal inspection of the ESP was the absence of what is termed *anti-sneakage* baffles in the ash hoppers The ash hoppers in the Dadri ESP's are very large, compared with many installations The need for very large hoppers results from the 40 to 50% ash content of the coal It is customary engineering practice to install a piece of sheet steel vertically in the center of each large hopper that is perpendicular to the direction of gas flow These baffles should begin near the top of the hoppers and terminate about 500 mm above the bottom of the hoppers This anti-sneakage baffle forces the dust laden gas stream to remain between the collecting electrodes and to minimize the flow through the hopper region This topic is addressed in the modelling and recommendation sections of this report

The internal inspection continued after the internal regions of the ESP's were washed The internal portions of Passes C and D were inspected Passes C and D, were the portions of the ESP system that were performing with less than expected collecting efficiency Regions of the internal portions of these two passes were noted for a re-inspection after washing to verify their condition In general, the condition of these passes (C and D) were very good except for the need to replace a few insulators These insulators were replaced during the maintenance outage The ESP system at the Dadri Power Station Unit Three is considered to be in excellent mechanical condition The only significant item noted was the absence of anti-sneakage baffles in the hoppers, mentioned above

Gas Velocity Distribution

The plant personnel from the Dadri Power Station provided the data describing the gas velocity distribution measurements conducted in Passes C and D These measurements were conducted during the maintenance shutdown that occurred at the end of the on-line data collection period of this program The measurements were not made in Passes A and B, because of time constraints The results of these measurements of the gas velocity distribution in Passes C and D are given in Tables 3-4 and 3-5 The gas velocity is considered to be evenly balanced between the C and D passes The gas velocity distribution in Pass C results in an average velocity of 0 71 meters per second with a standard deviation of 0 10 This is considered to be a very good and uniform gas velocity distribution The measurements for Pass D show an average gas velocity of 0 69 meters per second

21

with a standard deviation of 0 12 This gas velocity distribution is not so uniform as that in Pass C, but it is quite acceptable The velocity control vanes in inlet screens of Pass D could be reset for a more uniform gas velocity distribution during a future shutdown

The gas velocity distribution measurements were made in the space between the first and second electrical fields This location provides a measure of the gas velocity distribution as it appears to the majority of the ESP The inlet field allows the gas velocity distribution to stabilize and should remain essentially the same throughout the remainder of the ESP Since this is a six field ESP, this measurement location is considered to be ideal

Table 3-4 Gas Velocity Distribution in Pass C (meters/second)

Array	A	B	C	D	E	F	G	H	I	J	K	L
1	0 89	0 72	0 74	0 65	0 69	0 74	0 80	0 71	0 77	0 88	0 95	0 96
2	0 95	0 88	0 82	0 75	0 66	0 62	0 70	0 73	0 86	0 89	0 89	0 89
3	0 81	0 88	0 82	0 85	0 72	0 62	0 67	0 69	0 80	0 77	0 76	0 79
4	0 65	0 67	0 68	0 60	0 51	0 52	0 58	0 60	0 71	0 63	0 54	0 65
5	0 54	0 60	0 64	0 73	0 76	0 72	0 68	0 75	0 70	0 75	0 63	0 69
6	0 66	0 69	0 70	0 81	0 79	0 82	0 72	0 71	0 77	0 72	0 70	0 73
7	0 67	0 74	0 72	0 85	0 77	0 80	0 80	0 76	0 74	0 77	0 78	0 76
8	0 66	0 67	0 60	0 61	0 56	0 66	0 67	0 58	0 52	0 63	0 55	0 71
9	0 73	0 73	0 67	0 73	0 63	0 78	0 79	0 77	0 72	0 56	0 56	0 57
10	0 67	0 58	0 68	0 74	0 66	0 63	0 67	0 64	0 52	0 55	0 65	0 68
11	0 76	0 76	0 78	0 74	0 80	0 75	0 71	0 65	0 61	0 63	0 71	0 74
12	0 74	0 86	0 81	0 73	0 80	0 78	0 70	0 75	0 63	0 60	0 79	0 82
13	0 63	0 49	0 56	0 61	0 62	0 62	0 58	0 61	0 71	0 76	0 75	0 69

Table 3-5 Gas Velocity Distribution in Pass D (meters/second)

Array	A	B	C	D	E	F	G	H	I	J	K	L
1	0 89	0 70	0 67	0 74	0 61	0 53	0 49	0 58	0 76	0 69	0 56	0 62
2	0 90	0 79	0 84	0 75	0 68	0 52	0 52	0 62	0 73	0 77	0 69	0 81
3	0 92	0 91	0 92	0 91	0 76	0 65	0 49	0 61	0 64	0 77	0 77	0 87
4	0 64	0 63	0 64	0 58	0 70	0 70	0 66	0 66	0 70	0 65	0 73	0 78
5	0 58	0 66	0 65	0 55	0 61	0 73	0 75	0 66	0 73	0 72	0 81	0 76
6	0 60	0 58	0 66	0 75	0 86	0 90	0 95	0 88	0 76	0 72	0 66	0 62
7	0 59	0 72	0 74	0 89	0 93	0 96	0 99	0 86	0 82	0 71	0 70	0 74
8	0 44	0 55	0 76	0 60	0 61	0 77	0 74	0 62	0 64	0 52	0 57	0 76
9	0 50	0 58	0 76	0 71	0 66	0 74	0 77	0 63	0 61	0 58	0 68	0 90
10	0 58	0 47	0 55	0 68	0 61	0 71	0 75	0 73	0 60	0 60	0 62	0 75
11	0 59	0 53	0 57	0 67	0 58	0 79	0 73	0 69	0 73	0 60	0 66	0 94
12	0 78	0 67	0 66	0 62	0 54	0 80	0 67	0 62	0 77	0 69	0 68	0 99
13	0 71	0 62	0 60	0 46	0 48	0 49	0 54	0 63	0 51	0 65	0 92	1 02

Dadri Data Analysis, Model Studies and Evaluation of ESP Improvement Options

The data analysis in this report relied heavily on the use of computer models of ESP performance This approach is widely used in ESP studies of this nature The data used as model inputs were provided by the U S test team leader, Mr William Oberg with the assistance of Mr G H Marchant These results provided the information necessary to evaluate possible corrective measures for the Dadri Station

The team members considered a number of potential upgrade options to be evaluated Some of the options were identified in the early stages of the program development while others were added during formal and informal meetings between the team members

Computer Model Studies

The computer model used for this model study is the EPA-SRI model that has been developed over several years This model provides the technical basis for other models that are currently in use, specifically, the EPRI ESPM model and the EPA model, ESPVI 4 0a The original model requires a more detailed understanding of the technology than does later versions, which are considered by some people to be more "user friendly" The original model is used widely in design, upgrading and troubleshooting work

Calibration of Model

The first portion of the task to conduct ESP computer model studies was to calibrate the model to match the measured performance of the existing ESP system Measurements of mass loadings, particle size distribution, electrical readings from the power supplies, and the gas velocity distributions in the ESP's proper, provided the data to define the current performance of the ESP's The model predicted performance that closely matched the measured performance of Passes A and B The model predicted outlet loadings that were considerably less than measured for Passes C and D

The reason for the discrepancy between the actual and predicted performance for Passes C and D, is considered to be related to the heavy dust buildup in the outlet ductwork of these passes and to the defective electrical insulators mentioned above The outlet ductwork from all passes contained some ash deposit on the floor of the duct, this is considered to be normal However, Pass C had a deposit that extended well above the location of the bottom sampling port while Pass D also had a considerable amount In addition, Pass D has regions of higher gas velocity than the other passes A deposit such as this can contribute to the measured outlet ash concentration by providing a region of what can best be described as a fluidized bed of ash in the bottom of the duct Some of this material can be routinely reentrained, but the deposit should reach some quasi-stable thickness after some period of time However, any measurements conducted in this fluidized region will indicate a higher mass loading than is actually present in the overall duct This material may not actually become disbursed into the gas stream and be carried out to the stack, but it will appear in the sampling system if this point is sampled These conditions can increase the measured emissions to be above those actually existing downstream in the ductwork and stack

The computer model used for the evaluation of the ESP system at the Dadri Station is programmed to operate with the English system of units The measurement data were converted to English units before the use of the model The inlet loading of 52 5 grams per dry normal cubic meter of gas converts to 23 06 grains per dry normal cubic foot of gas This loading translates to 14 22 grains per actual cubic foot of gas at ESP conditions of temperature and pressure

Actual gas velocity measurements were not available for Passes A and B There was insufficient time available for the test team to complete measurements in all passes Since Passes A and B are mirror images of Passes D and C, respectively, the gas velocity distributions measured in their respective passes were used in the modelling work

Inlet mass loading measurements were conducted in Passes A, B & C The results were reasonably consistent, with an increase in inlet loading from A to B to C The loading may increase from inlet position or with gas volume flow The inlet to Pass D was estimated from the assumption that mass loading increased with position The inlet loadings selected were 34 05 gm/m^3 (actual) for Pass A, 34 90 gm/m^3 (actual) for Pass B, 36 02 gm/m^3 (actual) for Pass C and 37 19 gm/m^3 (actual) for Pass D Small variations in inlet mass loadings do not make any significant difference to the calculated efficiencies, the team concentrated on measuring the outlet mass loadings For example, if the inlet mass loading averages 50 grams per normal cubic meter and the outlet loading averages 100 milligrams per normal cubic meter, the collection efficiency is 99 80% If the inlet loading increases by 20% to 60 grams per normal cubic meter while the outlet remains constant, the collection efficiency only increases to 99 83% Thus, concentrating on the outlet mass loadings was appropriate The results of the measured performance of each ESP is compared with the model predictions in Table 3-6

The outlet ductwork from all passes combine to form the total stack flow The total volume flow rate in the stack should approximate the sum from the four passes while the mass loading in the stack should be the weighted average from all passes Table 3-7 shows a comparison between the weighted average outlet loadings from Passes A through D with that measured in the stack The agreement between individual duct averages and stack measurements is considered to be excellent

26

Table 3-6 Measured and Model Predicted Performance Compared

		Pass A	Pass B	Pass C	Pass D
Item Reported	**Units**	**Measured Performance**			
Volume Flow Rate (Thou)	m^3/hr (act)	376 8	387 0	412 1	360 1
Mass Loading (actual)	mg/m^3	46 535	71 685	381 946	102 474
Mass Loading	mg/dNm^3	71 9	112 5	538 3	141 5
Volume Flow Rate	acfm	221730	227793	242507	211900
Mass Loading	grains/acf	020	031	167	045
Collection Efficiency	%	99 854	99 785	98 905	99 69
Mass Emissions	kg/hr	18 96	29 85	163 65	36 75
		Model Input and Performance			
Volume Flow Rate	acfm	222000	228000	243000	212000
Gas Sneakage Factor	%	15	15	18	18
Inlet Mass Loading	grains/acf	14 88	15 25	15 74	16 25
Outlet Mass Loading	grains/acf	021	031	066	019
Mass Loading	mg/dNm^3	75 3	115	245	70
Collection Efficiency	%	99 86	99 80	99 58	99 90
Opacity	%	18	26	45	13
Mass Emissions	kg/hr	17 51	27 55	62 35	15 94

Table 3-7 Comparison for Pass, Composite and Stack Measurements

		Pass A	Pass B	Pass C	Pass D	Composite	Stack
Vol Flow	m^3/hr act	376779	387039	412145	360127	1536090	1412493
Pressure	mm Hg	719	717	710	719 7	716 5	723 4
Loading	mg/dNm^3	72	112	601	146	236	239
Emissions	kg/hr	19	30	164	37	249	202
Temp	Degrees C	130	137	148	138	138	142

Passes A and B provided collection efficiencies that resulted in outlet emissions of 72 and 112 mg/dNm^3 as averages for the tests Thus, if the goal is to attain an outlet loading less than 100 mg/dNm^3, it is only necessary to improve Passes C and D to match the performance of A and B on a consistent basis The model calibration was successful and predicts the output for the A and B Passes of the ESPs quite well

Evaluation of Performance Upgrade Options

Add Anti Sneak Baffles to Ash Hoppers

One of the major non-ideal factors that contributes to an ESP not performing as well as it could is the amount of the ash laden flue gas that bypasses the collection zones The regions for bypass are primarily through the ash hopper region and the superstructure that contains the support insulators and the rapping gear Good design practices include mechanisms to force the flue gas to be redirected into the active collection zone to re-mix with the main gas flow This re-mixing is accomplished by installing gas flow baffles in the superstructure between the insulator regions Further, it is common practice to install anti-sneakage baffles in the ash hoppers to augment the effect of the ash hopper leading and trailing edges for gas re-mixing These anti-sneakage baffles are installed in a vertical position in the middle of the ash hopper perpendicular to the gas flow There were no hopper baffles installed in the Dadri ESPs

The ESP computer model includes a factor for the number of times the bypass gas is re-mixed into the main flow stream through the ESP This factor is identified as the number of baffled stages in the ESP The model was exercised for all passes

with the addition of anti-sneakage baffles in each ash hopper (adding six baffled stages for a total of eleven) The model projected a reduction in emissions for all passes as indicated in Table 3-8 If the addition of baffled sections improves the performance approximately as well as the model predicts, baffling all four passes should bring the unit three ESP system emissions down by about 30 per cent

Table 3-8 Estimated Performance Improvement with Anti-sneak Baffles

(All Comparisons Based on Model Predicted Results)

Location	Pass A	Pass B	Pass C	Pass D	Composite
Volume Flow m^3/hr (x 10^3)	376 8	387 0	412 1	360 1	1536
Outlet Loading (mg/dNm^3)	75	115	245	70	126
Loading With Baffles	46 9	79 6	171 9	36 8	85
Per Cent Reduction	37	31	30	47	33
Efficiency As Is Model%	99 86	99 80	99 58	99 88	99 64
Efficiency With Baffles %	99 91	99 86	99 71	99 94	99 84

The model projections for adding baffles to each of the ash hoppers provides an estimate that if the actual ESP system can be brought to the performance estimated by the computer model that the outlet emissions will be about 85 milligrams per dry normal cubic meter of flue gas This is, of course, better performance than actually measured for Passes C and D during the measurement campaign If the actual performance of Passes C and D can be improved to match the performance as measured in Passes A and B, the model projections are expected to reflect the expected performance

If the performance of Passes C and D can not be corrected by gas flow and electrical power supply modifications, we can apply the percentage improvement that the model predicts to the actual measured emissions from C and D to estimate that the outlet emissions will be reduced from 236 mg/dNm^3 to 158 mg/dNm^3, with a composite collection efficiency increased from 99 54% to 99 70%

Add Temperature Controlled Precharger Sections

The distance between each collecting field is great enough that there is space available to add a temperature controlled precharger between the existing collecting fields The recommended precharger is constructed of a "collecting" electrode consisting of a metal pipe with a diameter of approximately 50 millimeters spaced the same as the primary ESP collecting electrodes, with a corona wire electrode with a 3 mm diameter centered between each set of collecting pipes The "collecting" pipe electrodes are cooled by a flow of water of sufficient quantity to maintain the surface temperature of the ash layer deposited on the electrode low enough to reduce the electrical resistivity of the ash to about ten to the power of ten ohm-centimeters Maintaining the ash resistivity to this low value allows the precharger to operate with very good electrical conditions, imparting a much higher level of electrical charge than would be provided by the main collecting electrode system, which is severely limited by the resistivity of the ash The computer model projected a reduction in outlet emissions for each pass of the ESP for the installation of temperature controlled prechargers following the first and second electrical fields is indicated in Table 3-9 The increased collecting efficiency results in a reduction in the emissions to almost one half

Table 3-9 Estimated Improvement from Installing Two Prechargers

Projections Based on Model - Prechargers Installed After Fields 1 and 2

	Pass A	Pass B	Pass C	Pass D	Stack
Volume Flow	376 8	387 0	412 1	360 1	1536
Outlet Loading (mg/dNm^3)	75	115 5	245	70	126
Loading With Prechargers	44 4	58 4	154 2	59 3	80
Per Cent Reduction	41	49	37	15	37
Efficiency As Is %	99 86	99 80	99 58	99 88	99 64
Efficiency With Prechargers %	99 92	99 90	99 74	99 90	99 85

The model predicts that the addition of anti-sneakage baffles provides a greater improvement to those passes with greater percentages of the gas bypassing the collecting zones, while the precharger is predicted to provide better improvement

to the flows with a more uniform gas flow Pass B would be a better candidate for conducting a precharger evaluation experiment while Pass D would be the best candidate for anti-sneakage baffles The cost for adding anti-sneak baffles is expected to be quite low This recommendation is based on computer model studies The actual change in performance should be evaluated by adding the appropriate baffles to a single ESP pass and conducting measurements Opacity meters should also be used in this evaluation

Reduce Ash Resistivity

The primary characteristic of the fly ash in the NTPC power stations that limits the performance of the ESPs is the high electrical resistivity The ash exhibits a resistivity on the order of 10^{12} ohm-centimeter There are a number of approaches that can be used to reduce the ash resistivity Some of these techniques include the addition of water to modify the resistivity either by directly conditioning the ash (water fogging) or by a combination of direct ash conditioning coupled with reducing the flue gas temperature, adding SO_3 (sulfuric acid) to the flue gas at levels of a few parts per million by volume or adding a sodium containing compound such as sodium carbonate into the furnace with the coal to modify the chemical composition of the fly ash Either of these approaches can be used for reducing the ash resistivity and the choice is customarily made on economic considerations

NTPC has direct experience with water fogging at some of their stations The Dadri station operates with a flue gas temperature somewhat less than other stations Water fogging and temperature reduction may be more appropriate for other stations with higher flue gas temperatures The results from the tests continuing at Badarpur will provide additional information for evaluating this option

Sulfuric acid conditioning is a generally accepted method for reducing the resistivity of fly ash Lodge-Cottrell of England (now owned by FLS miljo of Denmark) showed good results from experiments conducted at the Kincardine Station in Scotland in the early 1970's Several manufacturers currently supply equipment for SO_3 injection The results from the experiments conducted in an NTPC plant, by the Wahlco company from California in the U S , provided information useful for evaluating this method The ash chemistry of the Indian coals require that for the SO_3 conditioning to be successful, a rather large amount of the conditioning agent must be used

Tests conducted by Wahlco with SO_3 injection alone, NH_3 injection alone and finally a combination of both, verified the need for very large amounts of chemical injection The data reported orally was that 65 ppm of SO_3 combined with 35 ppm of NH_3 resulted in acceptable performance

Sodium conditioning, by the addition of a sodium containing compound to the coal, prior to combustion, is also an option in many NTPC stations In the absence of an effect from sulfuric acid, the electrical conduction in fly ash is principally from the physical migration of sodium ions through the fly ash The coals burned in the NTPC stations are typically high in ash and low in sulfur Further, the ash chemical composition that to not readily react with any sulfuric acid, either injected or naturally occurring in the boiler system Typically, injection rates are used that will increment the sodium content of the fly ash (reported as sodium oxide) up to about 1 to 1 5% by weight The Indian coals typically have an ash content on the order of 40% If the sodium oxide content is to be incremented by 1%, this requires about 4 kilograms of sodium oxide per metric ton of coal, translating to about 7 kilograms of sodium carbonate per ton of coal This method for reducing the resistivity is appropriate if an economical source for sodium is available In some regions of the world, sodium sulfate is available as a by-product from the pulp and paper industry

The expected improvement in performance that would be expected from reducing the electrical resistivity of the ash in either Pass A or B as predicted by the model projection is for an outlet emission rate between 12 and 20 milligrams per normal cubic meter of gas The opacity associated with this level of emission is between 2 and 3 per cent Sodium injection is considered to be an appropriate means for resistivity modification at many of the NTPC stations

There is one precaution to observe when contemplating the use of a sodium containing compound in a power station furnace system If there is a potential for or if there is a history of slagging/fouling in the furnace, care should be exercised during the experimental phase to assure that the boiler operation is not adversely affected

4 PHASE 2 *RIHAND POWER STATION PROGRAM*

Rihand Power Station Measurement Program

The test program at the Rihand Power Station was similar to that at Dadri but the test personnel were more experienced with the test equipment The test program consisted of both mass loading and particle size distribution measurements Internal inspections and gas velocity distribution measurements were planned for a later date The ESP upgrade options considered for Dadri also apply to Rihand The mass tests from Rihand indicate that the ESP is not in as good condition as those at Dadri The model calibration does not provide as good a match as that for Dadri Since the specific collecting electrode area is smaller for Rihand than Dadri (for the worst case coal condition), the upgrade options were rerun with the Rihand design data used in the model that had been calibrated to Dadri This means that the Rihand ESP must be repaired and brought to a good condition, before the upgrade options will provide the full measure of improvement

Mass Tests

The inlet mass test data are summarized in Table 4-1 while the outlet mass tests are given in Table 4-2

Particle Size Distribution

Three sets of particle size distribution measurements were conducted at the inlet to the ESP passes C & D, and in the stack The inlet size distribution is somewhat finer than that at the Dadri Station with an mmd on the order of 7 microns While the outlet size distribution is quite a bit larger than anticipated at about 6 microns The computer model projects an outlet size distribution with an mmd of about 2 5 microns This difference suggests the strong probability of significant gas sneakage around collecting sections or an unusually large amount of reentrainment of agglomerated particles in the Rihand ESP tested Measurements of gas flow in the ESP proper and in the hoppers are needed

Table 4-1 Summary of Inlet Mass Data for Rihand

	Inlet A	Inlet B	Inlet C	Inlet D
Gas Temperature ^{o} C	145 3	138 7	148 3	144 3
Duct Pressure mmhg	723 3	722 4	740 0	741 0
Actual Gas Velocity m/sec	15 48	14 40	14 47	14 11
Vol Flow Rate m^3/hr	1034234	960739	966908	942969
Mass Loading gm/m^3(act)	17 870	20 205	30 179	14 81
Mass Loading gm/dNm^3	29 58	32 53	50 18	23 97
O_2 Concentration %	7 0	5 8	5 8	7 4
CO_2 Concentration %	11 3	12 7	12 8	110 1
Moisture %	10 1	10 0	10 7	9 1

Table 4-2 Summary of Outlet Mass Data for Rihand

	Outlet A	Outlet B	Outlet C	Outlet D
Gas Temperature ^{o} C	145 1	132 8	143 1	141 4
Duct Pressure mmhg	740	739	740 0	742 0
Actual Gas Velocity m/sec	17 0	16 9	16 4	17 1
Vol Flow Rate m^3/hr	980718	974761	942076	983525
Mass Loading mg/m^3(act)	347 78	318 99	889 49	266 08
Mass Loading mg/dNm^3	571 4	512 6	1461 9	427 4
O_2 Concentration %	7 1	6 4	6 3	7 7
CO_2 Concentration %	11 1	11 9	11 8	10 4
Moisture %	10 1	10 6	10 6	10 5
Collection Efficiency %	98 07	98 42	97 09	98 22

Over all Efficiency Inlet Average Loading to Stack Loading = 97 81%

Power Supply Electrical Readings

The power supply controls were programmed to provide electrical readings at intervals during the test program Power supply readings were utilized as input data for the ESP model program in running the initial simulations Secondary voltages and currents are provided below in Table 4-3

Table 4-3 Secondary Power Supply Operating Point (representative

ESP	Pass A		Pass B		Pass C		Pass D	
Field	kV	ma	kV	ma	kV	ma (est)	kV	ma
Inlet	41 2	238	33 9	98	Off	Off	33 6	165 6
2nd	33 4	275	41 1	98	27 6	19 5	37 8	80 4
3rd	35 2	357	36 3	31	37 5	9 1	45 8	179 5
4th	27 3	398	36 2	38 6	34 5	4 0	34 7	433 6
5th	27 8	412	30 7	87 7	19 7	18 3	33 8	108 2
Outlet	26 4	460	29 6	153 3	32 5	280	32 3	507 8

The electrical readings are suspect for several of the electrical sections Especially, the currents in Pass C are extremely low in comparison with the other portions of the ESP The inlet power supply to Pass C was out of service for most of the test period These factors partially explain the very poor performance for that portion of the ESP

Computer Model Studies

The ESP model calibrated quite well with Passes A, B, & D, but very poor gas velocity distribution and gas sneakage parameters were required in all passes for this calibration The model was calibrated to simulate a single ESP Not having actual gas velocity distribution data, this was selected as the starting point for the model studies

The same set of upgrade options were evaluated for Rihand as was used for Dadri However, before the various options were evaluated, it is stipulated that the first corrective measure that must be completed is to conduct a detailed study of the gas velocity distribution and the internals of the ESP to bring the base line performance in line with that measured for Dadri The first order task is to insure that the gas velocity distribution and gas sneakage characteristics are corrected to expected values The calibrated ESP model was set to have reasonable parameters for these factors before the improvement options were evaluated The values selected for these studies was for gas sneakage and gas velocity distribution factors of 15% for each While these are not excellent values, they are acceptable Table 4-4 following shows the measured and model predicted results for the Rihand Station, while Table 4-5 shows the expected performance after the gas velocity distribution has been corrected to something like that at Dadri

The model was modified to include an improved value of sneakage and reentrainment before evaluating the various improvement options The problem with the inlet power supply control was also assumed to be corrected before the evaluation of the options

Table 4-4 Comparison Between Measured and Model Predicted Performance

35

Item Compared	Pass A, B & D	Pass C	Stack	Model
Volume Flow Rate (m3/hr thou)	979 3	966 9	3729404	
Volume Flow Rate (acfm)	576435	569133	2195168	577000
Mass Loading Inlet(mg/m3 actual)	17626 8	50175 6		17870
Mass Loading Outlet (mg/Dnm^3)	503 8	1491 9	448 4	368 4
Mass Loading Outlet (grains/acf)	136	389	118	102
Collecting Efficiency (%)	98 24	97 09	98 68	98 7
Emissions (kg/hr)	341	838	1010[1]	916[2]
Gas Sneakage (S) & Gas Velocity Standard Deviation (σ_g)			%	25 & 25
Opacity (%)				79

1 Should ideally equal sum of A, B, C & D

2 Total emissions are for four equivalent ESPs added

Evaluation of Performance Upgrade Options

Upgrade Power Supply Controls to Intermittent Energization

The electrical readings supplied for the Rihand Station show that the power supply controls are not operating with Intermittent Energization (Charge Ratio) The improvement in performance with the addition of IE capable controls as indicated by the model study is a reduction in emissions, (after the gas flow and internal corrections are made) are indicated below in Table 4-6 ***The remainder of the upgrade options are evaluated based on the assumption that the power supply controls have been upgraded***

Table 4-5 Model Calibration for Original and Improved Gas Flow Factors

Table 4-5 Model Calibration for Original and Improved Gas Flow Factors

Item Compared	Units	Original Calibration	Improved Gas Flow
Volume Flow Rate	m3/hr thou	980230	980230
Volume Flow Rate	(acfm)	577000	577000
Mass Loading Inlet	mg/m3 actual	17870	17870
Mass Loading Outlet	mg/dNm^3	473 4	174 1
Mass Loading Outlet	grains/acf	126	048
Collecting Efficiency	%	98 38	99 39
Emissions (4 ESPs)	Kilogram/hr	1132	432
Gas Sneakage & σ_g	%	25 & 25	15 & 15
Opacity (%)	%	87	66

Add Anti-Sneak Baffles in Hoppers

The data package submitted indicated that the ash hoppers at Rihand were not equipped with vertical anti-sneakage baffles (as was the case at Dadri) The ash hoppers required at the Indian power stations are extremely large to accommodate the very high ash coals burned Because the hoppers are large, there is a strong tendency for the flue gas to flow through these hoppers, bypassing a significant portion of the collecting zones Table 4-7 shows the improvement in performance predicted by the ESP model for the addition of these baffles in the Rihand ash hoppers The inlet conditions are the same in the remainder of the comparisons and will not be repeated in the remainder of the tables

Table 4-6 Performance Improvement with Upgraded Power Supply Controls

Item Compared	Units	Model Calibrated	Add I E Controls
Volume Flow Rate	m3/hr (thou)	980230	980230
Volume Flow Rate	(acfm)	577000	577000
Mass Loading Inlet	mg/m3 (actual)	17870	17870
Mass Loading Outlet	mg/dNm^3	174 1	68 7
Mass Loading Outlet	grains/acf	048	019
Collecting Efficiency	%	99 39	99 76
Emissions	Kilogram/hr	432	176
Gas Sneakage & σ_g	%	15 & 15	15 & 15
Opacity (%)	%	66	44

Table 4-7 Adding Anti-sneakage Baffles to Ash Hoppers

Item Compared	Units	Calibrated with I E	Add Baffles
Mass Loading Outlet	mg/dNm^3	68 7	53 3
Mass Loading Outlet	grains/acf	019	015
Collecting Efficiency	%	99 76	99 81
Emissions	Kilogram/hr	176	140
Opacity (%)	%	44	40

Add Temperature Controlled Prechargers Behind First Two Fields

The same type of precharger as was described in the Dadri Section can be installed in the Rihand Station since the spacing between the fields is approximately the same The calibrated model was exercised to evaluate the addition of these

prechargers following the first two original electrical fields The prechargers provide a significantly greater level of electrical charge on the particles to enhance collection Table 4-8 shows the level of improvement for this addition

Table 4-8 Add Two Temperature Controlled Prechargers

Item Compared	Units	Calibrated with I E	Added Prechargers
Mass Loading Outlet	mg/dNm^3	68 7	33 4
Mass Loading Outlet	grains/acf	019	009
Collecting Efficiency	%	99 76	99 88
Emissions	Kilogram/hr	176	88
Opacity (%)	%	44	25

Reduce Ash Resistivity

Even though the ash content of the coals burned in the NTPC power stations is very high, the fundamental factor restricting the collecting efficiency of the ESPs is the very high ash resistivity If the ash resistivity can be reduced to a value on the order of 5 x 10^{10} Ω-cm, by any of the means described in the Dadri discussion, the outlet emissions will be greatly reduced Table 4-9 reports the results of the model simulation of the expected performance for the Rihand ESPs with the estimated electrical conditions expected for the reduced resistivity case Table 4-10 provides the estimated secondary voltages and currents used for this model projection

This projection clearly shows the desirability of reducing the ash resistivity in the NTPC power stations The electrical conditions should be realistically achieved if the resistivity can be reduced as indicated

Table 4-9 Reduce Ash Resistivity

Item Compared	Units	Calibrated with I E	Reduce Resistivity
Mass Loading Outlet	mg/dNm^3	68 7	9 3
Mass Loading Outlet	grains/acf	019	0025
Collecting Efficiency	%	99 76	99 97
Emissions	Kilogram/hr	176	23
Opacity (%)	%	44	5

Table 4-10 Electrical Conditions Used to Model Reduced Resistivity Case

Electrical Field	Secondary Voltage (kV)	Secondary Current (ma)
Inlet	45	750
Second	43	900
Third	41	1000
Fourth	39	1250
Fifth	37	1350
Outlet	37	1350

5 PHASE 3

RECOMMENDED PLANT ACTIONS

The recommendations in this report address the two stations Dadri and Rihand specifically These recommendations are based on the results of test programs conducted at both stations There are also recommendation sections that apply generally to other stations and to the design of new power stations The items recommended for Dadri and Rihand may also apply to any station in the NTPC system The need for the application of a particular technology depends on the site specific conditions for that plant The recommendations for new ESPs are somewhat broader than those specific to upgrades, since a new station may not be faced with limitations in options that an existing station my have For example, a station with flue gas temperature entering the ESP at 170° C requires a major modification to reduce the temperature to the 140° C Range This reduction may provide superior performance in the ESP However, a new station can be equipped with the appropriate air preheater to meet those conditions readily

Some of the recommendations can be directly applied to other stations without a study as well as to the design of new stations The inclusion of anti-sneakage baffles in the hoppers and superstructure should be applied universally Similarly, gas flow measurements and model studies with follow up verification of the flow characteristics in the unit, after installation of the new flow control devices, may also apply to all stations Finally, the addition of modern power supply controls is a cost effective approach to improving the performance of ESPs collecting high resistivity fly ash

The recommendations made for the individual stations tested under this program are the result of the analysis of the data sets from those stations The approach to the development of a set of corrective measures generally follows the procedures used in these two test programs The potential solutions or upgrade options to be considered would likely be the same as those evaluated for each of these two stations The CENPEEP-NTPC team is now equipped to conduct such a measurement and analysis program

It is noted that the particular solutions to be applied in each power station will probably be different There is no guarantee that a solution at one station will

universally apply to all stations, ***because each plant may well be limited in performance by a variety of factors*** For example, the Dadri station operates with a flue gas temperature significantly lower than Rihand, Badarpur and other stations Water fogging may be an appropriate technology that applies much more successfully at one of these stations than at Dadri The determination of the "correct" solution will be site specific and must be evaluated at that particular station with its particular fuel(s) and combustion characteristics

Dadri Power Station

The following recommendations were developed from the inspections, analysis of the test data and the results of the computer model study of the Dadri unit three ESP system The recommendations apply specifically to the Unit Three ESP, but should in general apply to the remainder of the Dadri units as well The gas velocity distribution in unit three may differ somewhat from that in the other units, but the data for gas flow can be readily determined The list of recommendations to follow should be applied to the entire Dadri installation for those items deemed to be appropriate

Optimize the IE or Charge Ratio

The electrical resistivity of the fly ash at the Dadri Power Station is considered to be high, even though the flue gas temperature is lower than in some other stations The resistivity is high enough that the collection efficiency is improved by operating the electrical energization systems for the individual fields in the Intermittent Energization (IE) mode (BHEL and Dadri personnel refer to IE as a varied Charge Ratio) There is a reasonable expectation that the collection efficiency for every ESP in operation could be increased somewhat by optimizing the Charge Ration/I E of the individual electrical sections Such an optimization program can best be conducted with an opacity monitor, since the approach to developing an optimized IE and rapping program is largely empirical in nature The Charge Ratio should be optimized before attempting to optimize the rapping interval to be discussed later in this report

The first item to address in this recommended optimization program is to bring all the opacity monitors that are installed in the individual outlet ducts into good operating condition The opacity monitor is a very valuable tool to use in conducting an optimization program on an ESP system The plant personnel

successfully brought one of the units into operational condition to use during the measurement program conducted in September of 1997 This unit was mounted in the stack and provided data for use in the evaluation program The plant personnel did an excellent job of installing and operating this equipment in the stack The other opacity monitors should likewise be brought into operational status, as well When these instruments are operating correctly, instantaneous information is available for interpreting the behavior of the ESP The instrument is almost a necessity for conducting rapper and energization optimization programs

The procedure to follow in the optimization of the Charge Ratio is to begin with the modification of the ratio for the two first fields Begin with a Charge Ratio of 1 on and 8 off Allow this to run for a couple of hours and compare the opacity with the previous value (Of course a steady plant load is required) After the opacity has been optimized, continue to the next two fields and modify them Continue this trial and error approach until the near optimum conditions can be established Start with a Charge Ratio of 1 8 in the inlet and increase in steps to about 1 16 or 20 in the outlet The average current density should be approximately the same in all fields, with the possible exception of the inlet field There may be some space charge current suppression in this field

The factor that governs the formation of back corona in an ESP is the average current density flowing through the dust layer on the collecting electrodes The purpose for conducting an optimization program on each electrical section is to maximize the peak and average secondary voltage on each electrical section, while maintaining the average current density to a value low enough to avoid back corona Since the inlet field would naturally operate at a lower current density for a given secondary voltage than the following fields, the optimum charge ratio will increase as the procedure continues through the ESP The optimum charge ratio should remain relatively constant, with time, for any given station, unless there is a change of fuel or operating conditions that could cause a change in the electrical resistivity of the fly ash

Install Anti-Sneak Baffles in the ESP Hoppers

The internal inspection determined that there are no "anti-sneakage" baffles in the ash hoppers The purpose for these baffles is to prevent the dust laden flue gas from flowing through the very large ash hopper regions, rather than through the collecting region The hoppers in Dadri are very deep in order to provide adequate storage space for the large amount of fly ash collected in each electrical field The computer model was exercised to evaluate the expected improvement in collecting

efficiency by adding a vertical plate in each hopper to cause the flue gas to be driven back into the collecting zone The indication is that the outlet emissions would be reduced by about 30 per cent with the addition of gas flow control baffles in the ash hoppers These anti-sneakage baffles should be added during the next scheduled maintenance outage or at the earliest opportunity It is appropriate to install them in a single ESP (such as Pass A) and test the results before modifying the entire station

Optimize the Rapping Intervals

The rapping interval optimization program will require a longer period of time than the Charge Ratio optimization program The greater amount of time is required because of the very slow rate of ash layer buildup and stabilization on the collection electrodes A rough estimate for the fly ash buildup rate on the inlet field at Dadri is on the order of one half millimeter per hour while that for the outlet field is perhaps 0 003 mm/hr Since there is such a slow build up rate on the outlet collecting electrodes, a long time is required for the influence in the change in the rapping system to be reflected in the dust layer on the outlet collecting electrodes

The inlet and second fields now operate with rapping intervals of five and six minutes, respectively This rapping interval should be retained as this is considered to be a good rapping cycle for them The two middle fields should begin with intervals of fifteen and twenty five minutes respectively The two outlet fields are more critical for rapping emissions The rapping optimization program should begin with the rapping interval on the fifth field to forty five minutes and the outlet to two hours Allow this condition to remain for about four days, then compare the new opacity with the previous value Continue this process of either increasing or decreasing the rapping intervals on the last two fields, until a minimum in opacity is established

Add Hoppers to Outlet Ducts

The outlet ducts from each pass contained a significant ash layer deposit in the bottom of the ductwork This deposit was removed during the maintenance shutdown following the September 1997 test period The plant should be operated normally until the next shutdown that may be required for repairs to boiler tubes or other short term maintenance problems The outlet ductwork should then be

inspected to determine if the ash deposit (equal to that observed in September 97) has again developed If so, an outlet dust hopper and evacuation system should be installed to prevent the development of this deposit if it can be determined that the deposit contributes to the outlet emissions

Measure Gas Velocity Distribution in All Passes

The gas velocity distribution measured in Pass C indicated a very even and uniform gas flow The flow pattern in Pass D was not quite so uniform These data for Passes A and B should be obtained for further analysis The gas volume flow rates for the A and B Passes were about the value that represented the average for the entire ductwork Pass C had a significantly greater flow than Pass D The flow should be balanced between the four passes to maximize the collection efficiency for the entire ESP

Rihand Power Station

The following recommendations apply specifically to the Rihand Power Station based on the results of the analyses of the data provided from the test program and the projections from the use of the ESP model While these recommendations apply specifically to the Rihand Station (as did those for the Dadri Station) they also provide insight into the types of results that might be expected for other stations as well However, it is almost always necessary to conduct a specific study for the other stations, prior to the selection of a course for corrective action

Measure Gas Velocity Distribution and Correct Flow as Needed

The Rihand ESPs collection efficiency is significantly lower than those at Dadri The exercise to calibrate the ESP model to match the existing measured performance required the use of gas flow non-uniformity and sneakage-reentrainment factors much greater than those for Dadri This suggests that the gas flow uniformity and anti-sneakage devices are not as effective as the ones at Dadri

The gas velocity distribution should be measured inside the ESP following the inlet field and just in front of the outlet field If these measurements indicate a gas velocity standard deviation greater than 10 to 12%, flow model studies and corrective measures may be needed to improve the flow characteristics

45

Upgrade Power Supply Controls and Operational Mode

The electrical data supplied for the Rihand station indicated operation without a Charge Ratio These controls should be upgraded at the earliest opportunity to make use of the improved electrical operation available with these new controls The new controls should have the capability to seek and establish an optimum IE ratio independently for each electrical section

Install Anti-sneak Baffles in Ash Hoppers

One of the major factors reducing the collecting efficiency for the ESPs at both Rihand and Dadri is suspected to be ash laden flue gas bypassing the collecting zones by flowing through the hoppers The addition of hopper baffles should be rather inexpensive and have the promise for a significant reduction in mass emissions

Optimize Rapping Intervals

After the gas velocity distribution has been corrected, the power supply controls have been upgraded and the anti sneakage baffles have been added, the rapping operation should be optimized This exercise should follow the procedure described previously in the Dadri discussion It is necessary to have an operating opacity monitor installed in the ESP outlet ductwork to conduct this optimization program

Conduct Water Fogging and Moisture Conditioning Evaluation

The Rihand Station is a good candidate for evaluating water fogging and moisture conditioning technologies The flue gas temperature entering the ESP is sufficiently higher than the temperature at Dadri to make this a more desirable location for evaluating these technologies This recommendation does not mean that the technologies are not appropriate for Dadri, only that Rihand will probably benefit more from the technology The experiment should be conducted with modern spray nozzles that will produce a spray that will readily evaporate before impinging on any surface where an ash deposit might develop The Lechler dual fluid nozzles or perhaps one of the newer single fluid nozzles are the preferred injection equipment The experiments should begin with "water fogging" and then proceed to moisture conditioning where the flue gas temperature can be materially reduced Reductions to the 140° Celsius range are desirable

General Items Pertinent to All Power Stations

There are generic problems common to many power station ESPs that can be addressed by studies like the Dadri and Rihand studies These factors are common to many stations and only need to be recognized The items evaluated for potential performance improvement at Dadri and Rihand are candidate upgrade options for any coal burning power station either currently equipped with or contemplating the addition of an ESP Those items selected were recognized as candidates from the early considerations and from the evaluation of the data collected during the evaluation program Other potential problem areas not discussed for Dadri and Rihand are discussed in the following section

Emission Tests, Sampling Ports and Opacity Meters

Existing ESP and stack installations should be equipped with sampling ports to accommodate mass test equipment and opacity meters Emission tests should be conducted at intervals of time (probably on an annual basis) to assure that the ESP performance is as expected, or when conducting a measurement program for troubleshooting or upgrade studies For the larger installations, sampling ports are needed at the inlet and outlet locations for each ESP as well as sampling ports in the stack for future verification of compliance with emission standards Permanent opacity monitors are desirable, but if fund limitations prevent this, portable units can be used during testing at the sites The test port locations at the Dadri Station can serve as a guide for port locations for any stations not appropriately equipped

Water Fogging and Moisture Conditioning

CENPEEP should continue with the water fogging and moisture conditioning experiments started at Badarpur Even though the combustion stability at Badarpur was less than desirable, the fogging experiments suggested a significant ESP performance improvement These preliminary data suggest that both water fogging and the addition of greater quantities of water (moisture conditioning) have potential for reducing the particle emissions at the Indian power stations CENPEEP should continue the evaluation of these technologies at several NTPC stations

Corona Electrode Failure

Corona electrode failure is more prevalent in the weighted wire designs popular in the U S than in those of European design However, corona electrode failures also occur in the wire-in-frame and wire-in-mast designs Failures typically occur at attachment points, near non-uniformities on the collecting electrode or insulator support point, which lead to electrically induced failures from localized sparking Swinging wire frames or electrodes also contribute to some corona electrode failures When an ESP experiences multiple corona electrode failures, it is important to maintain a log of the failure occurrences and to determine if some localized disturbance is causing the failures or if it is merely the result of the aging of the ESP system An internal inspection is appropriate when there is a history of corona electrode failures in a particular region of the ESP

Electrical erosion was mentioned above as one cause for corona electrode failure Other causes include mechanical failures caused by vibrating wires, localized corrosion from cold air in-leakage, multiple sparkover at points where corona electrodes pass the edge of a grounded plate or structural member (primarily this occurs in weighted wire designs), ash buildup providing a conduction path to ground, shifting of the collecting electrode, thermal excursions that allow structural members to yield or failures caused by manufacturing defects Failures caused by manufacturing or erection defects usually occur shortly after the commissioning of a new installation Whatever the cause for electrode failures, a list of failures and locations is a necessary starting point for the evaluation

One potential solution for corona electrode failures is to install some of the newer rigid electrode systems or a ruggedized mast system When selecting a modified corona electrode design it is important to make sure that the electrical characteristic for the new design is appropriate for the unit One of the current alternatives is a design developed by ELEX (from Switzerland) but currently marketed by Southern Environmental of Pensacola, Florida, (USA) If this design is selected, the length and effective corona wire radius should be appropriate for the high resistivity ashes encountered in India The selection should include higher current electrodes in the two inlet fields and much lower current higher voltage electrodes in the downstream fields The higher current electrodes in the inlet section provides for more charging current in the inlet regions where space charge suppression frequently occurs

Ash Handling Systems

The ash handling system requirements for station burning the very high ash coals used in India require careful attention The inlet hoppers collect very large quantities of ash and frequently require maintenance If the ash handling system is allowed to deteriorate, the ash accumulation in these hoppers may quickly cause an overflow situation that may cause bending of the collecting electrodes and distortion of the corona electrode support system The ash hoppers should be inspected during each outage to assure that the ash disposal system is performing as needed

Dust Dropout in Ductwork

A second problem related to the very high ash content of the Indian coals is the potential for ash buildup in the ductwork and turning vane areas Even though the ash particle size distribution is relatively fine, the high ash loading can lead to significant deposits in the ductwork This problem becomes more acute if the plant is operated with conditions ranging from full load to low load During the low load operating times when tha gas velocity is low, ash will tend to dropout to a greater degree than at full load If the full load period following low load operation does not sweep the ducts and turning vanes free of the buildup, problems may develop Problems anticipated include modifications to the gas flow that may be detrimental to the flow characteristics in the ESP and the potential for a heavy deposit overloading the ductwork support structure

Investigate Air Infiltration

In-leakage of outside air increases the gas volume flow rate through the ESP The integrity of the ductwork and seals is an important part of minimizing the gas volume flow rate through the system Since the ESP efficiency is related inversely to the volume flow rate, it is important to minimize the air in-leakage (all other things remaining the same) Primary sources for air in-leakage includes air preheater seals and gaskets, expansion joints in ductwork, door seals and gaskets, hopper seals, casing weld joints and rapper or insulator penetrations

Improve Gas Velocity Distribution

Gas velocity distribution was discussed in the plant specific recommendations for both Dadri and Rihand The need for maintaining a good gas velocity distribution

in the ESPs is of such importance that the topic is repeated in this general discussion section The test teams of NTPC are very capable of conducting the appropriate measurements to determine the gas flow quality Some assistance may be needed initially to establish the capability to conduct computer or physical model studies for NTPC BHEL may also be able to provide guidance in this technical area The CENPEEP-NTPC test team are the appropriate group to handle this task

Optimize Rapping System

The approach to conducting a rapping program optimizing procedure was described in the plant specific sections In some cases, the rapping system may require upgrading If the rapper optimization program does not provide a sequence that essentially eliminates large rapping opacity spikes, it may be necessary to upgrade the rappers and rapper control system The rapper control system can be readily changed but changes to the rapping gear internal to the ESP is an extensive modification

Thermal Insulation Integrity

The thermal insulation should be checked to assure that the interior surface of the ductwork and ESP proper remain at a temperature above the moisture dew point Both air in-leakage and thermal insulation failure can lead to localized moisture condensation and corrosion if not located and corrected

Upgrade Auxiliary Equipment

The auxiliary systems for heating the hoppers and insulator compartments, vibrators for the ash hoppers, hopper level indicators, thermal expansion provisions and air conditioning/heating system for the equipment areas should be checked at regular intervals to assure proper operation

Combustion Process Modification

The combustion process may also require some modification to obtain the optimum performance from an existing ESP Such items as appropriate excess air, coal mill fineness, distribution between primary, secondary and tertiary air, and air preheater basket modifications are candidates for improving the collecting

characteristics of the fly ash A detailed analytical study is necessary to determine which factors may be appropriate for each installation

New Power Stations to Be Constructed

The same general list of items above pertain to the construction of new power generating facilities However, there is wider range of particulate emission control options available for the new installations First, the consideration for the appropriate pollution control system may include fabric filters as well as ESPs Since there is no experience with the use of fabric filters for Indian Utilities, it will be necessary to conduct studies to evaluate their appropriateness The following section of this report discusses a Technology Evaluation Facility where such new technologies can be studied on a smaller scale than an entire boiler system

Flue Gas Temperature at Control Device Inlet

The characteristics of the coal burned in Indian power stations is such that there is little likelihood of the presence of sulfuric acid in the flue gas The current practise is to design for a flue gas temperature in the 150 to 170°C range for the ESP inlet The selection of this temperature was in the past based on the fear that the actual operating temperature would be below the acid dew point temperature of the flue gas

The actual flue gas contains very little, if any, free sulfuric acid The actual dew point temperature for the flue gas will likely be less than 100° C If this is determined to be accurate, the flue gas temperature into the ESP would more appropriately be in the 120 to 125° C range to allow some safety to avoid corrosion Actual measurements of the sulfuric acid concentration and acid dew point is necessary before building a power station ESP to operate at this temperature

There are three reasons to investigate reducing the design ESP temperature to the 125° C range for new stations First, the thermal efficiency of the power station would be increased by a few percentage points by recovering the thermal energy from the additional 45 to 55° C reduction in the exhaust gas temperature This increase in thermal efficiency reduces the amount of green house gases emitted to the atmosphere because less fossil fuel is required to generate a given amount of electrical energy

The other two reasons are related to the increased collection efficiency of the ESP because of the reduction in temperature The primary influence is the reduction in the electrical resistivity of the fly ash The resistivity of the ash as a function of temperature is an inverted U shape with the peak value occurring between 170 and 225° C If the resistivity is reduced significantly, the collecting efficiency of the ESP likewise increases because of the better electrical conditions allowable in the ESP

A second improvement in performance is brought about by the reduction in volume flow rate of the flue gas in the ESP The reduction in temperature from 170° C to 120° C, reduces the actual volume of flue gas by about 10%, similarly increasing the effective size of the ESP

Add Cyclonic Collectors and Hoppers

The very high ash content in the coals burned in the Indian power stations causes a very heavy inlet loading into the ESPs that places a significant burden on the ash handling system serving the inlet hoppers of the ESP The ESP size required for meeting a given emission standard would not be reduced by adding the collector, but the ash handling requirement for the inlet sections would be reduced

There is also a suggestion that the addition of ash collecting hoppers near the inlet and outlet transition regions may minimize the influence of ash fallout in these regions The ash deposits in the ductwork both in the inlet and outlet regions of the Dadri ESP were several centimeters deep and behaved as a fluidized bed of ash when the sampling program was conducted If this ash could be effectively eliminated, the emissions would likely be reduced

Sampling Ports

It is inevitable that there will be emission standards established for coal burning power generating plants in India Therefore, it is important to design the new stations with sampling ports and access platforms to allow the required measurements to be conducted as needed Therefore, these items should be incorporated in the design of new stations

Similarly, opacity monitors provide very useful data about the day to day performance of the ESP systems Port locations and if practical, dedicated opacity monitors should be incorporated in the initial design

52

Technology Evaluation Facility

The recommendations for new power station air pollution control design is related to another recommendation for CENPEEP in Section Six following It is not clear that the electrostatic precipitator is the only appropriate technology for particle control in Indian power stations Alternate technologies include fabric filtration and perhaps the installation of cyclonic mechanical collectors to precede either ESPs or fabric filters The addition of mechanical collectors will not simplify the job of particle removal in either for ESPs or fabric filters It will, however, reduce the ash loading and ash handling requirements for the inlet sections of an ESP and would likely increase the life of fabrics in a fabric filter installation

These new applications of the above technologies should be verified on a smaller scale than installation in a full scale power station The evaluation must be conducted on "real" flue gas and 'real" fly ash in order to provide an evaluation that might justify a full scale evaluation The recommendation to CENPEEP is to develop a Technology Evaluation Facility at a power station, preferably the Dadri Station, since this is the location of many of the activities for upgrading the power stations in India This is discussed in more detail in the next section

6 RECOMMENDED ACTIONS FOR CENPEEP

CENPEEP is a unique organization that can provide effective assistance to all power stations in the NTPC organization (as well as provide services to others within India) This organization now with excellent measurement instruments and has the expertise to obtain and interpret the data needed to provide guidance to others for improving the performance of electrostatic precipitators They have established a good cooperative relationship with a number of power station personnel while working together on the data gathering portion of the Greenhouse Gas Pollution Prevention project This beginning should provide a good platform for further development of a joint CENPEEP-NTPC team to oversee the performance, evaluation, upgrading and purchase of new air pollution control equipment

Team Formation

A team should be established which includes representatives from each power station and CENPEEP, as a guiding force that evaluates emissions control problems within NTPC A team comprised of such members would combine the knowledge and experience of each plant and assist all plants in better understanding how to improve their pollution control equipment

The importance of having a team that represents all the power stations is that each station can make use of information developed for other stations in each project This opportunity for shared development allows all stations to establish a wide range of expertise and make use of the technology developed in each program

The U S team members strongly recommend that CENPEEP form the core of this technology team The personnel at CENPEEP have the time and mission to maintain the continuity that is necessary for the team to succeed They have hands-on experience with the equipment and are in a position to use this equipment wherever in NTPC (or other Indian utility location) that it is needed

It is further recommended that the Air Pollution Control Team (APCT) establish and maintain a good working relationship with the personnel at each of the power

stations It is important for the APCT to have a good working relationship with the individual departments that will be responsible for actually applying the upgrade technologies that the APCT recommends for each power station

Specifically, the Electrical Maintenance Group from each participating station will have the most up to date information of the electrical conditions in each ESP The APCT will require information about the electrical conditions in each ESP regularly and on a timely basis

Similarly, the Instrument and Controls Group will need to be a part of this program because the integrity of the information provided from each station is dependent on having all the measuring instruments in good operating condition These personnel need to work closely with the electrical group

The Boiler Maintenance Group also needs to be represented in the APCT, as they will be responsible for modifications and perhaps some new construction projects that may result from team studies They can provide useful information for the APCT to consider when developing improvement strategies

The Chemistry Group will also provide critical information about the fuel and fly ash characteristics of each plant They can supply coal and ash samples for the APCT to evaluate as needed This information is useful for conducting an evaluation about changes in performance with individual installations

The APCT plant team members should collect ESP power supply electrical and opacity data from each station on a routine basis and forward those data to CENPEEP If the data can be collected on a computer data logger, five minute intervals and averages are appropriate If the data must be collected by hand, the establishment of a particular time of day with the unit at or near full load is recommended for the data task Furthermore, voltage vs current curves should be obtained for full load conditions about four times per year Air load voltage vs current curves should be obtained for both dirty and clean conditions during each maintenance shutdown

Establish Laboratory Capability

It is important for NTPC to have access to a well equipped analytical and measurement laboratory to provide the information necessary to evaluate the condition and performance of the ESPs on the system CENPEEP provides the framework for the development of such a laboratory It is important for CENPEEP

55

to develop this capability rather than use a commercial laboratory The need for reliable determinations of ash electrical resistivity, ash and coal chemistry, ash particle size distribution, and flue gas concentrations of SO_x and NO_x is very important in order to establish the requirements for either upgrades, troubleshooting or the design for new particle control devices While it is possible to have commercial laboratories conduct these measurements, it is more desirable to have better control over the laboratory measurements than CENPEEP can exercise if an outside laboratory is responsible for these analyses

Resistivity Measurement

Probably the most critical parameter that governs the performance of ESPs in the NTPC power stations is the electrical resistivity of the fly ash The ash resistivity establishes the allowable current density that can be maintained in the unit CENPEEP should establish the capability to measure the resistivity of the ash from each power station on a routine basis and when any significant change is noted in the collection efficiency of an ESP

The electrical resistivity of fly ash can be measured either in situ or in the laboratory For those installations where there is a significant influence on the resistivity from the presence of chemical compounds if the flue gas, (primarily sulfur trioxide), it is important to measure the resistivity in situ However, for those installations where the resistivity is governed by the ash chemistry and the moisture content of the flue gas, laboratory measurements are appropriate The NTPC coals and power stations represent the latter case It is appropriate to measure the ash resistivity for the NTPC stations in the laboratory

It is not necessary for each power station to develop the capability to measure ash resistivity It is more appropriate for CENPEEP to provide this service First, there is the cost saving from having only one set of measurement equipment and second, the data are more useful for all stations if all the ashes in the NTPC system can be compared

The equipment and method for measuring the ash resistivity in the laboratory is described in publications from the ASME and IEEE ASME Power Test Code 28 was the earlier standard for measuring the resistivity in the laboratory In 1984, the Institute of Electrical and Electronic Engineers published a new standard for conducting measurements of resistivity in the laboratory This method is described as P548-1984 The CENPEEP group should review these documents and establish this capability for NTPC (Mr Marchant of SRI can assist)

56

Coal and Fly Ash Chemistry

The coal and ash chemistry is also very important data sets for understanding the performance variations in an installation and for the design of new equipment Many laboratories are capable of conducting these analyses, but the determination of the alkali metals, primarily sodium and potassium requires special care in the measurements A gas chromatograph is a key instrument in the ash analyses Commercial measurements for coal analysis is probably sufficiently accurate, if the laboratory is not initially equipped for this set of measurements

Particle Size Distribution

The ganged cyclones and inertial impactors that operate in situ in the flue gas stream are the best instruments for measuring the ash particle size distribution In some instances, a laboratory measure of size distribution is important A well equipped laboratory will have either a BAHCO or SHIMADZU instrument for laboratory measurements of particle size distributions These instruments should be used in those instances where in situ measures are not available or are too expensive

Sulfur and Nitrogen Oxides

The Cheney-Homalya method for measuring the concentrations of sulfur oxide is the preferred method Since the coals in India are so low in sulfur content, it is not necessary to develop this capability in the beginning If sulfur and nitrogen oxides become important in the future, the U S team members will be glad to assist in the establishment of this capability

Construct and Operate Technology Evaluation Facility

The electrostatic precipitator is the control device currently selected for the collection of fly ash in Indian power stations It is not, however, the only control device that should be considered The very high electrical resistivity of the ash and the high ash contents of the coal, suggest that other technologies should be evaluated The two leading alternative particle control candidates are fabric filters and perhaps adding mechanical collectors to assist the ash handling equipment installed in the inlet fields of the ESPs

It is recommended that new technology be introduced in Indian power stations on a much smaller scale that a full scale power station of several hundred megawatts

capacity The cost of the full scale equipment together with the need to continue to generate electricity at the maximum possible rate, suggest that it is more appropriate to conduct an evaluation of alternative technologies on a much smaller scale such as pilot and demonstration model sizes

It is critical that the new technology be demonstrated under realistic power plant conditions In order for a power station manager to be convinced of the advisability of installing new technology, there needs to be some assurance that the technology will perform as needed The proper conditions for such a determination is in a Technology Evaluation Facility

The facility should be installed in an existing power station where actual flue gas and fly ash provides the realistic evaluation environment Any one of several stations could be likely candidate sites, but Dadri is considered the showcase station for the Greenhouse Gas Pollution Prevention Project, so this station is recommended as the preferred location It is in close proximity to CENPEEP headquarters and the Dadri personnel are very familiar with the test equipment and procedures required for conducting technology equipment evaluations

The evaluation facility should be built near the existing ductwork that carries the flue gas to the electrostatic precipitator The flue gas stream should be extracted from two points, one before the air preheater and one before the ESP This combination of gas extraction points allows the independent control of flue gas temperature, providing the flexibility to evaluate fly ash and flue gas conditions in all of the NTPC stations

The power station should be capable of burning coal from a variety of mines In many instances, one of several coals can be burned for the test facility However, in some instances, it will be important to burn the specific coal that is planned for a new facility While the substitution of a new coal is important, it should not be required for most of the technology evaluation programs

The U S team members have much experience with the construction, operation, and data interpretation from such facilities The team members are prepared to assist in the design, development, operation and training of the CENPEEP-NTPC team, if such a program is desirable and this recommendation is implemented by the Indian team members

Conduct Demonstration Project for Sodium Conditioning

The chemical composition of the fly ash from Indian coals is such that the addition of a sodium containing compound to the coal prior to combustion could probably provide a significant improvement in the collecting efficiency of ESPs There are, of course, uncertainties in the application of this technology to the NTPC stations Therefore, it is important to conduct a well controlled demonstration project before operating a sodium conditioning facility routinely in the stations A carefully controlled demonstration project is the preferred method for evaluating this technology Such a program requires an evaluation of about six months duration where a test crew monitors the plant behavior on a regular basis A matrix of tests with varying parameters, is needed to determine the amount of conditioning required and identify any detrimental contributions to plant operation that may result from the sodium chemical addition to the coal Again The U S team members have the necessary background and experience to assist the Indian team in designing and conducting such a demonstration project A successful application of the sodium conditioning technology has the potential for reducing the particle emissions from all of the Indian power stations by a significant factor

Data Base for Coal and Fly Ash

CENPEEP should develop a data base for ash and coal characteristics from all of the current and potential fuels for use in NTPC stations They need to establish the capability to conduct the tests necessary to characterize the critical parameters related to the formation and collection of ashes from these coals The coal analyses can be conducted either in their own laboratories on in a commercial establishment (see previous discussion about laboratories) Fly ash chemistry determination and the measurement of fly ash resistivity should be conducted in CENPEEP laboratories, if at all possible The determination of the iron, lithium, sodium, free and bound sulfates and other alkali metals is critical to understanding the expected performance implications of the ash chemistry and should be conducted by those directly affected

Future Regulations and Emissions Monitoring

The establishment of emissions regulations and monitoring methods are currently in their infancy in India For example, the first stack emissions test in India was conducted in the test program for the Dadri Station when the Indian and U S teams jointly conducted the program CENPEEP should be the organization that provides the guidance to the Indian Government, when they work to establish

pollution emission limitations and test procedures This group now has the expertise and background to assist the Government in establishing requirements

Particulate matter now is the most critical item considered in establishing emissions standards for the Indian Electric Utility Industry Sulfur oxide emissions are not yet thought to be significant, because of the use of low sulfur coals in power production Oxides of nitrogen will likely become a consideration as the combustion temperatures are increased to improve the thermal efficiency of the stations CENPEEP can provide assistance to other team members that may work to establish standards

Coal Washing

The high ash of Indian coals used for generating electric power in India are prime candidates for coal washing First, if the washing facility is located at the mine or shipping site, the amount of material being shipped can be reduced This advantage alone could justify coal cleaning The reduction of ash decreases the requirements on the ash handling and disposal systems and may in some instances improve the collectibility of the ash There is also the potential for providing some opportunity for chemical conditioning of the coal in the wash plant, with careful design of the suspension medium

Even though the ash content of these coals is around 50%, the amount of ash removable by lower energy washing is only on the order of 20% The ash is distributed inside the actual coal particles as well as between them The ash between the particles is the portion that is readily removable by low energy washing CENPEEP is the appropriate organization to conduct the tests, interpret the data and evaluate the performance of the washing facilities and to distribute the data to the potential users The critical items for evaluation include changes in the boiler operation as well as changes in the ESP performance