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Assessment of Requirement of Bag filter vis a vis Electrostatic Precipitator in Thermal Power Plants

CENTRAL POLLUTION CONTROL BOARD
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FOREWORD

The Central Pollution Control Board has published several documents under Programme Objective Series (PROBES), envisaging the environmental issues and preventive measures. The present study on “Assessment of requirement of Bag filter vis a vis Electrostatic Precipitator in Thermal Power Plants ” is in continuation of the series on PROBES. The study was taken by the Central Pollution Control Board through Environment Engineers Consortium, Kolkata in which an assessment of requirement Bag filter vis a vis Electrostatic Precipitator in coal fired thermal power plants in Indian conditions was conducted.

This report provides detailed information on the fundamentals of coal-fired boilers and accessories like fuel system, mills, firing system, burners and flue gas system, technical design and basic operating parameters of electrostatic precipitators (ESP), technical parameters of bag filter installed at Unit VI Koradi TPS, performance monitoring of selected ESP and bag filter. The detailed technical information along with reasons for under-performance of ESP is also provided. The cost benefit analysis of two technologies, ESP and bag filter for three different scenarios was also taken up

I would like to express my sincere appreciation for the work done by M/s EEC, Kolkata in association with M/s EMTRC, Delhi.I also appreciate the efforts made by my colleagues Dr. S.K. Paliwal, Scientist B and Er. J.S. Kamyotra, Additional Director for coordinating and finalizing the study under guidance of Dr. B. Sengupta, Member secretary, CPCB.

We in CPCB hope the study will be useful to the electricity generators, regulatory agencies, research organisations and to all concerned in pollution control.

21st March, 2007

(J.M. Mauskar)

CONTENTS

CHAPTER – 1

INTRODUCTION

Power development is the key to the economic development. The power Sector has been receiving adequate priority ever since the process of planned development began in 1950. The Power Sector has been getting 18-20% of the total Public Sector outlay in initial plan periods. Remarkable growth and progress have led to extensive use of electricity in all the sectors of economy in the successive five years plans. Over the years (since 1950) the installed capacity of Power Plants (Utilities) has increased to 128000 MW (31.10.2006) from meager 1713 MW in 1950.

A range of pollutants are generated from coal-fired and coal co-fired power generating plants and some are more specific to a particular technology. However, attention has focused mainly on controlling emissions of Particulates. Numerous systems have been developed and applied for control of Particulates. Some control specifically one type of pollutant; whereas others may integrate several control systems, thus allowing for the control of two or more pollutants (e.g. combinations of SO_2, NO_X and particulates). When the addition of emissions control systems to a plant is being contemplated, a number of issues require consideration in order to determine the most appropriate variant(s), and many will reflect the configuration and age of the particular plant. Where, for instance, an ageing PF-fired power plant is involved, there are several possible options that may be pursued. Such options can be effective for significantly increasing a plant's efficiency, as well as reducing its environmental impact. Where a newer, more efficient power plant is involved, it may be more appropriate to upgrade or add to the existing emissions control systems, or to replace them with more effective variants. Again, the replacement of the existing combustion plant may also be in order. In most cases, the selection of appropriate emissions control systems will require consideration on a case-by-case basis.

High particulate matter (in the form of fly ash) emission from coal fired thermal power plants (TPP) has been a matter of concern since the beginning. Electrostatic Precipitator (ESP) is presently used to limit the particulate matter emission from this industry to the emission standard of 150 mg/Nm^3. The continuous deterioration of coal quality with increase in ash content has seriously affected the efficiency of ESP. As a result, the compliance of emission standard is far from satisfactory. The power plants are explaining that poor quality of coal and high resistivities of fly ash are mainly responsible for poor performance of the ESP.

Unit VI of Koradi Thermal Power Station of Maharastra State Electricity Board has retrofitted bag filter in their existing ESP and improved the emission compliance status. The main objective of this project is to assess the feasibility of installing bag filter or retrofitting bag filter in the existing ESP in Indian TPP. ESPs are supplied as a part of boiler packages and as such specific separate cost of ESP is not available. The available O&M cost for ESP are far from reliable. Therefore, the cost benefit analysis has been also carried out based on whatever information available.

CHAPTER - 2

FUNDAMENTALS OF BOILER AND ASSCESORIES

2.1 Coal Fired Power Station

This chapter provides the basic understanding of generating steam from coal in a thermal power station. The illustration given in figure 2.1 shows general arrangement of a boiler burning pulverised coal. The coal is carried from coal store on a conveyor belt (1) and discharged by means of a coal tipper (2) into the bunker (3). It then falls through a weigher (4) into the coal pulverising mill (5), where it is ground to a powder as fine as flour. The mill usually consists of a round metal table on which large steel rollers or balls are positioned. The table revolves, forcing the coal under the rollers or balls, which crush it.

Air is drawn from the top of the boiler house (6) by the forced draught fan (7) and passed through the air preheaters. (8), to the hot air duct (9). From here some of the air passes directly to the burners (10) and balance is taken through the primary air fan (11) to the pulverising mill where it is mixed with the pulverised coal, blowing it along pipes to the burners (10) of the furnace (12). Here it mixes with the rest of the air and burns with great heat.

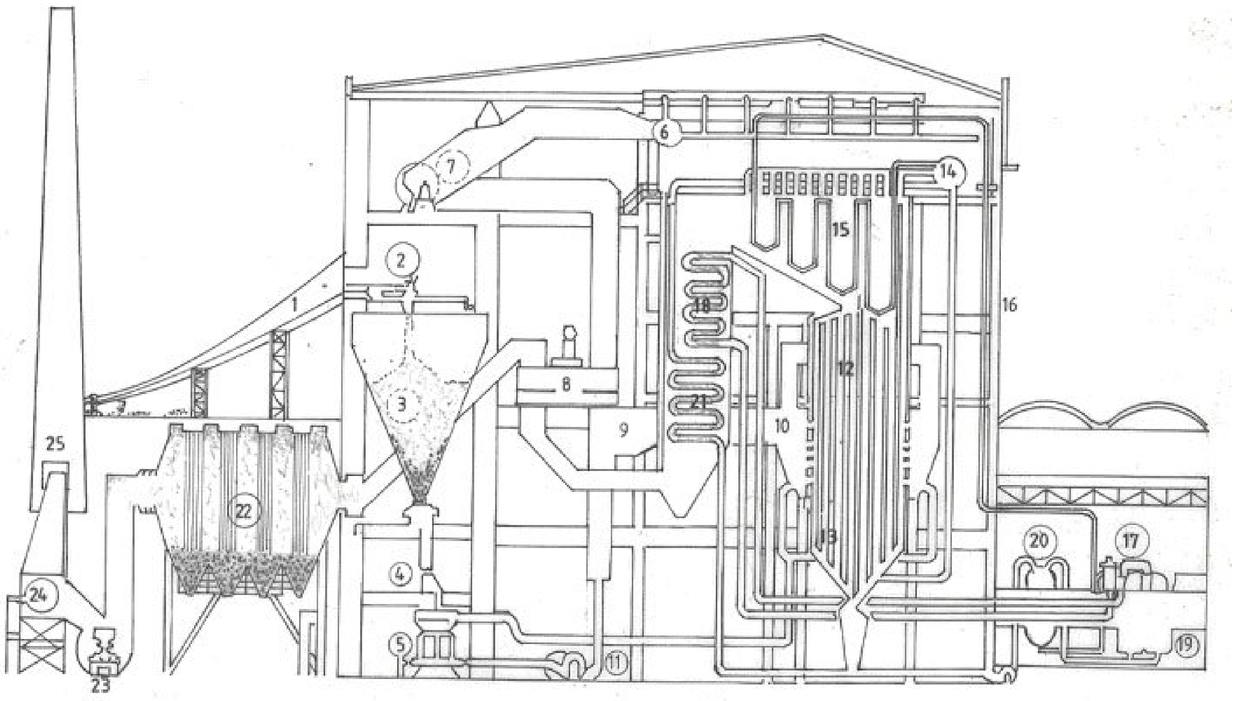
The boilers consists of a large number of tubes (13) extending the full height of the structure and the heat produced raises the temperature of the water circulating in the pipes to create steam which passes to the steam drum (14) at very high pressure. The steam is then heated further in the superheater (15) and fed through the outlet valve (16) to the high pressure cylinder of the steam turbine (17).

When the steam has been through the first cylinder (high pressure) to the turbine, it is returned to the reheater of the boiler (18) and reheated before being passed through the other cylinders (intermediate and low pressure) of the turbine.

From the turbine the steam passes into a condenser (19) to be turned back into water called condensate. This is pumped through feed heater (20) to the economiser (21) where the temperature is raised sufficiently for the condensate to be returned to the lower half of the steam drum (14) of the boiler.

The flue gases leaving the boiler are used to reheat the condensate in the economiser (21) and then passed through the air preheaters (8) to the electrostatic precipitator (22). Finally the gases are drawn by the induced draught fan (23) into the main flue (24) and to the stack (25).

The electrostatic precipitator consists of metal plates, which are electrically charged. Dust (fly ash) in the flue gases is attracted on to these plates, so that they do not pass up the stack to pollute the atmosphere. Regular mechanical hammer blows cause the accumulation of dust to fall to the bottom of the precipitator, where they collect in a hopper for disposal. Additional accumulations of ash (bottom ash) also collects in the hopper beneath the furnace.



2.1 PULVERISED COAL BOILER

2.2 Coal Fired Boiler

The primary objective of the coal burning systems in the process of steam generation is to provide controlled efficient conversion of the chemical energy of the coal into heat energy, which is then transformed to the heat absorbing surfaces of the steam generator. The combustion elements of coal consist of carbon and hydrogen. When combustion is properly completed the exhaust gases will contain carbon dioxide and water vapour. The traces of sulphur present in coal get converted to sulphur dioxide. When carbon burns incompletely it forms carbon monoxide. Nitrogen of air and coal get converted to oxides of nitrogen.

Coal must be ignited before it can burn. Combustion is brought about by raising the temperature of the coal to its ignition temperature in the presence of atmospheric air. The amount of air required to burn coal is theoretically calculated but in practice this quantity is not sufficient to ensure complete combustion and excess air has to be supplied. The loss of combustibles and unburned gas loss reduces as excess air is added, reaches a maximum and any further addition of excess air beyond this stage will increase boiler loss.

The combustion efficiency depends upon the correct quantity of air together with good mixing of coal and air to obtain maximum heat release. Maximum combustion efficiency depends on design of the boiler, fuel used, skill in obtaining combustion with the minimum amount of excess air. Thermal efficiency of a boiler is measured by the amount of heat transferred to the water in the boiler by each kg of coal used and is expressed as percentage of the total heat energy in one kg of coal. The thermal efficiency is dependent on the factors governing efficient combustion.

2.3 Classification and Types of Boiler

Boilers are designed to transmit heat from an external source contained within the boiler itself. The heat generating unit includes a furnace in which the fuel is burned. With the advent of water-cooled furnace walls, superheaters, air heaters and economisers, the term steam-generator got evolved as a better description of boiler. Boilers can be classified on the basis following characteristics like use, pressure, material of construction, size, tube content, tube shape and position, firing mode, heat source, fuel type, fluid, circulation, furnace position, furnace type, general shape and trade name.

Boilers are generally categorised as follows:

1. Steel boilers
    a) Fire tube type
    b) Water tube type
        i) Horizontal straight tube
        ii) Bent tube
            - Natural circulation
            - Positive circulation
    c) Shell type

2. Cast iron boilers

3. Special design boilers

4. Nuclear reactors

2.3.1 Fuel System

Two primary aspects of preparation and firing of coal are described. The coal preparation equipment like feeders and mills, firing systems and the firing equipment like the burners and their arrangement are described.

Feeders – Feeders are used to transport coal from bunker to the coal mills. The type of feeders include:

- ➢ Chain feeders : This comprises of continuous chain moving round the sprockets. On the chain MS plates are connected at different intervals which are called scrappers. This is also called scrapper feeders.
- ➢ Belt feeders – This comprise of continuous belt carrying the coal. The coal feed can be controlled by the speed of the conveyor belt.
- ➢ Table type rotary feeders – This are just paddle feeders or blade feeders which load on to conveyor and the conveyor discharge the fuel into the pulverisers.
- ➢ Gravimetric type of feeders – This is used for feeding the coal from the bunker to pulveriser as per requirement.

2.3.2 Mills

Pulveriser or milling plant is used to crush the coal to fineness such that 70% to 80% passes through 200-mesh sieve and carried forward by air through pipes directly to burners or via storage bins from where it is passed to burners. When discharged into combustion chamber, the mixture of air and coal ignites and burns in suspension. Milling plant is of three types; low speed mill, medium speed mill and high speed mill. The low speed mill is also called tube ball mill and operates at 17 to 20 rpm. The medium speed mill is of vertical spindle design and operates at 30 to 100 rpm. The high speed mill is directly coupled to the motor thus eliminating speed reduction gears and operates at 500 to 1000 rpm.

Bowl mill is one of the most advanced designs of coal pulveriser and important design features of bowl mill are high temperature air flow, easy replacement of parts and have external lubrication system. Tramp iron sprouts provided in the mill base remove the undesirable foreign material from coal.

2.3.3 Firing systems

The firing systems can be broadly classified into direct firing system and indirect firing or intermediate bunker system. In direct firing system coal is fed to the mill at controlled quantity. Hot air whose temperature can be controlled with the help of cold air is permitted to flow through the mill. The fine coal is carried by the air through the coal burner to the combustion chamber. In indirect firing system the mills are operated independent of boiler loading and pulverised coal is stored in the intermediate bunker. From the bunker it is taken to the combustion chamber with the help of primary air fan.

Methods of firing : The following methods are used to fire coal in the furnace.

- Vertical firing
- Horizontal (front) firing
- Impact firing
- Tangential (coner) firing

In vertical firing, a number of rectangular fans shaped nozzles are set across the width of the furnace in an arch immediately under the boiler setting. The pulverised coal mixture ignites under the arch and is directed vertically downwards to the bottom of the furnace where the gases are made to turn upwards to pass through the combustion chamber. This gives a long path to the flame and is particularly suitable for coal with low volatile content.

In horizontal firing, the burners are usually set up in the front or rear walls of the furnace. The burners consist of an inner cone for primary air and coal which is given a rotary motion as it passes through the burner. This mixes with a stream of rotating secondary air before burning.

In impact firing, the ash is kept in a molten state on the furnace floor and tapped off as and when necessary.

In tangential firing the burners are set at each corner of the furnace and are directed to strike the outside of an imaginary circle in the centre of the furnace. Because the streams of coal strike each other, extremely good mixing is obtained.

2.3.4 Burners

Oil burner – Oil burner must completely atomise the oil without drooling, fouling or clogging and the jet must be so shaped that it will completely mix with air necessary for combustion. Oil burners are classified according to the method used for atomisation, as follows:

Air atomised burners : uses compressed air of low pressure for atomisation

Steam atomised burners : uses auxiliary steam for atomisation

Mechanically atomised burners : uses mechanical pressure for atomisation

Coal burner – Coal burner mainly comprise of coal nozzle, steel nozzle tip, seal plate and tilting link mechanism. These are housed in coal compartment in all sides of furnace and connected with coal pipes. The one end of the nozzle is rectangular (outlet) and another end is cylindrical. The rectangular end those forms the nozzle is connected with nozzle tip by pivot pin. The tip can be tilted on this pivot. The nozzle tip is divided into several sectors to form separate coal and air passages. To seal the coal and air passages, seal plates are provided.

Burner arrangement – In a typical 210/200 MW boiler, 24 pulverised coal burners are arranged at a height of 18 to 25 m and 12 oil burners are arranged in between two pulverised fuel burners.

2.3.5 Flue Gas System

This section provides information about the importance and usage aspects of two major equipment located in the flue gas path, air preheaters and flue gas cleaning equipment.

Air heaters – Air heater is a heat transfer surface in which air temperature is raised by transferring heat from flue gas. For every 20°C drop in flue gas exit temperature, the boiler efficiency increases by about 1%. Air heaters can be classified into recuperative type and regenerative type based on their operating principle.

In recuperative type the heating medium is on one side and air is on the other side of the tube or plate and heat transfer is by conduction through the material, which separates the media. In regenerative type the heating medium flows through a clearly packed matrix to raise its temperature and then air is passed through the matrix to pick-up the heat.

Flue gas cleaning equipment: In flue gas cleaning equipment, properties of coal like amount of ash, sulphur, potassium and sodium content and type of firing influences the size of dust particles, loading rate and type of control equipment. The most popular flue gas cleaning equipment applied in coal fired boilers is electrostatic precipitators (ESP). Of late, bag filter technology is emerging as an alternate technology to ESP. The historical and technology details of bag filter are described in subsequent chapters.

CHAPTER - 3

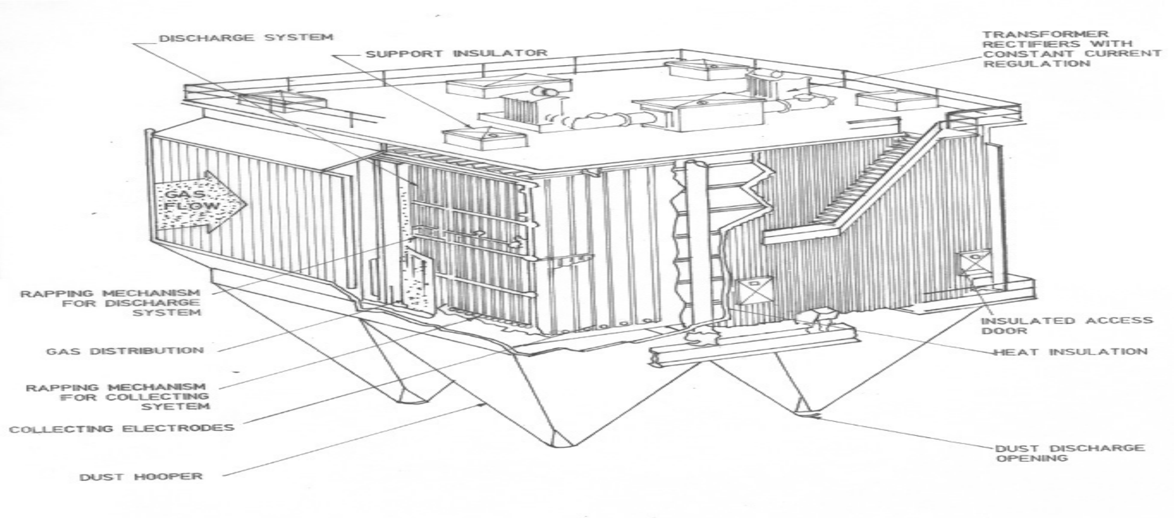
DESIGN AND OPERATING PARAMETERS OF ELECTRO STATIC PRECIPITATOR (ESP)

3.1 Background Information

When coal is burned in the boiler, ash is liberated and carried along with the flue gas. To arrest the ash particles, ESP is used. The additional advantage of ESP is that the wear of the ID fan blades is reduced due to precipitation of dust. The ESP is efficient in precipitation of particles from sub-micron range to large sizes. The ESP consists of a large chamber in which collecting and discharge electrodes are suspended. The collecting electrodes are made up of steel plates with a special profile and discharge electrodes are made of thin wire wound to a helical form. The discharge electrodes are kept in between collecting electrodes and the electrodes are arranged alternatively. A typical cross sectional arrangement of ESP is shown in Figure 3.1.

At the inlet of the chamber, gas distributor screens are provided which consist of perforated steel plate. The screens help in uniform gas distribution across the section of the chamber. The collecting plates at its power portion contain shock bars over which rapping hammers hits periodically, to dislodge the dust from it. Rapping is provided for discharge of emitting electrode to dislodge ash from the wire.

ESP consists of several auxiliary components like access doors, dampers (guillotine or louver type for adjusting the gas quantity), safety grounding devices and gas distribution systems. There is a weatherproof gas-tight enclosure over the ESP that houses the high voltage insulators, transformers and rectifiers.



3.1 ELECTROSTATIC PRECIPITATOR

3.2 Design Parameters

In ESP the flue gas stream is passed between two electrodes, across which a high potential difference is maintained. Out of the two electrodes, one is the discharging electrode and the other a collecting electrode. Because of high potential difference and the discharge system, a powerful ionising system is formed. Gas ionisation is the dissociation of gas molecules into free ions and potentials as high as 40 to 60 KV are used. Consequently, ionisation creates an active glow zone (blue electric discharge) called the corona or corona glow.

As the particulate in the carrier gas pass through this field, they get charged and migrate to the oppositely charged collecting electrode. The particles, once deposited on the collecting electrode, lose their charge and are removed mechanically by rapping or vibration to a hopper placed below.

The four steps in ESP process are as follows:

- Place charge on the particle to be collected
- Migrate the particle to the collector
- Neutralise the charge at the collector
- Remove the collected particle.

The function of ESP depends upon the properties of gas and fly ash particles, which are governed by the characteristics of coal burned, the boiler design and operation practices. The composition, temperature and pressure of the flue gas govern the basic corona characteristics of the ESP. The size, concentration and electrical resistivity of the fly ash particles affect both the corona and collecting aspects.

3.2.1 Gas flow quantity

The quantity of combustion gas produced in the boiler depends on the composition and amount of coal burned, the excess air used for combustion and air in-leakage. The volume flow rate through the ESP is also a function of temperature and pressure.

3.2.2 Coal quality

The performance of ESP is dependent on the properties of coal burned in the furnace. Upon burning, coal release ash and other residues of combustion like inert oxides and silicates.

3.2.3 Flue gas quality

The sulphur trioxide produced in the combustion process is important in ESP because of its effect in reducing the resistivity of fly ash. Dew point of the flue gas is substantially elevated by the presence of SO_3 and it affects the ESP performance.

3.2.4 Fly ash characteristics

The chemical composition of fly ash, particle size and resistivity are the three main components that are critical for ESP performance. The resistivity of fly ash is dependent upon the composition and size of fly ash as well as temperature, water vapour and SO_3 content of the flue gas. Although most of the sulphur in coal is converted to SO_2 after burning, about 1% of the total sulphur is converted to SO_3. Therefore the amount of SO_3 produced increases with the content of sulphur in coal and the relationship is variable. Fly ash from low sulphur coal has high resistivity and is difficult to precipitate. Fly ash from high sulphur coal has low resistivity and is relatively easy to precipitate.

3.2.5 Particle resistivity

Particle resistivity is a measure of the resistance of the dust particle to the passage of current. For practical operation the resistivity should be 10^7 and 10^{11} ohm^{-}cm. At higher resistivities, fly ash particles is too difficult to charge and lead to decrease in efficiency. At times, particles with higher resistivity may be conditioned with moisture to bring them to the desired range. If the resistivity is too low, particles accept a charge easily but dissipate it so quickly that the particles are not collected at the electrode and are re-entrained in the gas stream. Particle resistivity depends upon the composition and continuity of dust, gas temperature and voltage gradient that exists across the dust layer.

3.3 Design Criteria

The basic design criteria for ESP is the determination of the principal parameters for precipitator sizing, electrode arrangement and the electrical energisation needed to provide specified levels of performance.

3.3.1 Specific collection area (SCA)

The collection surface of an ESP required for a given gas flow and efficiency is usually computed from the modified Deutsch-Andersion Equation. The practical values of SCA usually range between 140 and 250 $m^2/m^3/s$, the higher values for higher collection efficiency.

3.3.2 Gas velocity

The importance of gas velocity is in relation to rapping and re-entrainment losses of fly ash from the collecting electrode. Above some critical velocity, these losses tend to increase rapidly. The critical velocity depends upon the composition, temperature and pressure of gas flow, plate configuration, ESP size. The gas velocity is calculated from the gas flow and cross section of ESP. The maximum gas velocity is 1.1 m/s and the optimum limit is 0.8 m/s for high efficiency ESP.

3.3.3 Aspect ratio

The importance of aspect ratio is due to its effect on rapping loss. Aspect ratio is defined as the ratio of the total active length of the fields to the height of the field. Collected fly ash is released upon rapping and is carried along the gas flow path. If the total field length is too short compared to height, some of the carried particles will not reach the hopper and goes out. The minimum aspect ratio should be between 1.8 to 2.4, the highest figure for highest efficiency.

3.3.4 High tension sectionalisation

The optimum number of high tension section per 1000 m^3/m of gas flow rate is between 0.73 to 0.78, the lower value is for higher ESP performance. The performance of ESP improves with degree of high tension sectionalisation due to the following reasons:

- Small sections have less electrode area for sparks to occur.
- Electrode alignment and spacing are more accurate for smaller sections.
- Smaller rectifiers are needed that are more stable under sparking conditions
- Outages of one or two sections have a lesser effect on ESP performance.

3.3.5 Migration velocity

The ESP manufacturers based on individual experience determine migration velocity. The important variables that are used to determine migration velocity of fly ash are its resistivity, size distribution, gas velocity distribution, re-entrainment and rapping.

3.3.6 Series field

Good design practices calls for at least 5 or 6 separately energised series of high tension sections in an ESP. The number of fields in series needed for ESP depends mainly on the efficiency required and on the redundancy necessary to ensure performance with section outages.

CHAPTER - 4

INTRODUCTION TO BAG FILTER TECHNOLOGY

4.1 Background information

Filtration, using cloth filter as media is one of the most reliable, efficient and economic methods by which particulate matter can be removed from gaseous streams. The theory of removal of particulate matter by a bag filter is not thoroughly known. It is postulated that the initial deposition of particles takes place through interception and impingement of the particles on the filter bags because of combined activity due to diffusion, electrostatic attraction and gravity settling.

A bag filter consists of numerous vertical bags of 120 to 400 mm diameter and 2 to 10 m long. They are suspended with open ends attached to a manifold. The hopper at the bottom serves as a collector for the dust. The gas entering through the inlet duct strikes a baffle plate, which causes the larger particles to fall due to gravity. The carrier gas then flows to the tubes and then outward through the fabric leaving the particulate matter as a cake on the bag surface.

Efficiency during pre-coat formation is low but increases as the pre-coat (cake) is formed. Once formed, the pre-coat forms part of the filtering medium that helps in further removal of the particulate matter. The accumulation of dust increases the air resistance of the filter media and therefore filter bags have to be periodically cleaned. They are cleaned by rapping, shaking or vibration or by pulse jet or reverse jet air flow, causing the filter cake to be loosened and to fall in the hopper. The normal velocity at which the gas is passed through the bags is 0.4 to 1 m^3/minute.

The efficiency of bag filters are affected by the following four main factors:

1. Filter ratios – Filter ratio is defined as the ratio of carrier gas volume to gross filter area, per minute flow of gas.
2. Filter media – It is important to have filter media that are temperature resistant, resistant to chemical attack and abrasion resistant.
3. Temperature – Fabric filters do not perform properly if the gas temperature exceeds the upper withstand limit of the fabric material. Generally the upper temperature limit for bag filters is about 290^{o}C. Another temperature related problem occurs when the stream contains a reactive gas like SO_2 and SO_3 that can form acid if the temperature in the bag filter falls below the dew point.
4. Bleeding – Bleeding is penetration of the fabric by the fine particles and can occur when the weave is too open or if the filter ratio is too high.

4.2 Filter Cleaning

Following are the common methods of filter cleaning in a bag filter:

- Rapping
- Shaking
- Reverse air flow (back wash)
- Pulse jet

The latest technology of cleaning is high pressure cleaning with pulse jets. In a pulse jet bag filter, periodically a jet of high pressure air is blasted down the inside of the bag which is supported internally by a wire frame. During the cleaning operation, the bag is collapsed on the frame because of the pressure of the gas being cleaned on the outside. When the bag is inflated, the dust cake is loosened and falls into the hopper below. The two important advantages of the method are, there are no moving parts and continuous cleaning is possible. It is not necessary to isolate an entire row or a compartment from service.

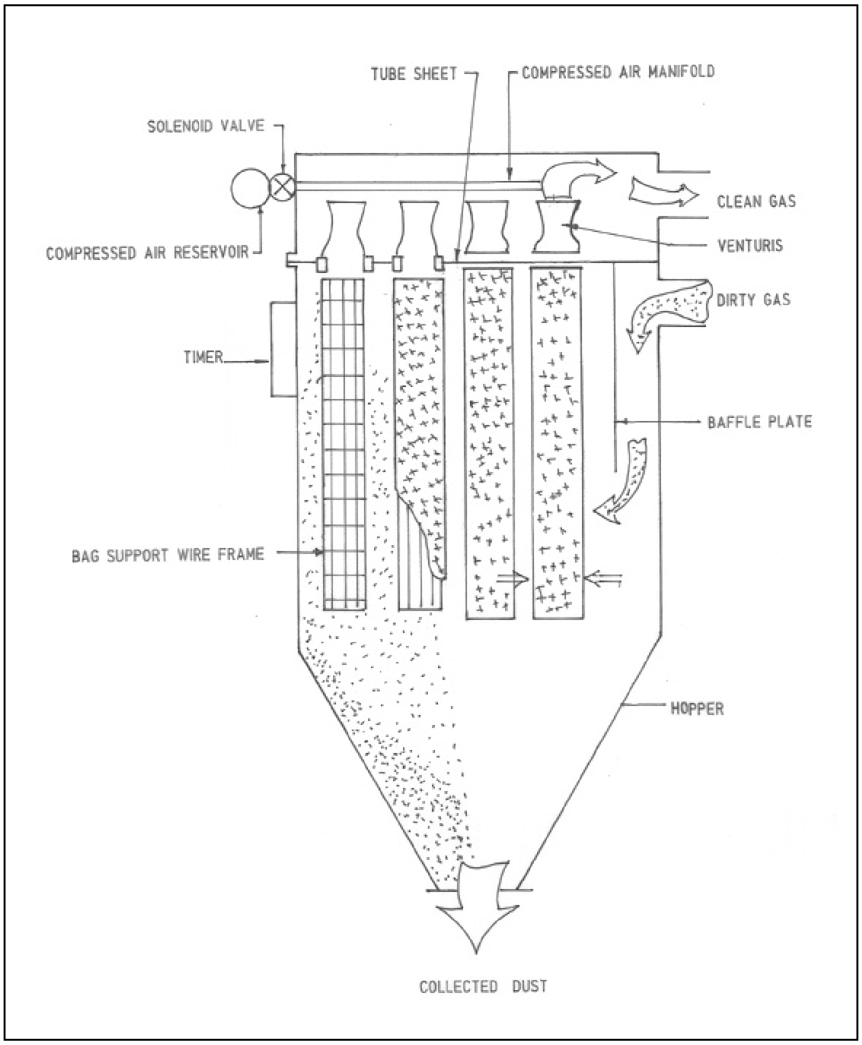
In improved pulse jets, the only nozzle for passing compressed air above the bag is replaced by a venturi on the top of the bag so that all the air pressure is used to create a pressure wave down the inside of the bag. With this mechanism, even hygroscopic particles are removed but the disadvantage is due to high mechanical stress that can rupture the bags.

Pulse jet bag filters were designed to operate at higher air to cloth ratio than other cleaning styles while handling the same volume of airflow in a small physical shape. Generally requiring less housing, the pulse jet filters relies on filter bags that hang vertically and are firmly held in place by clamps, snapbands or holddowns.

When dust laden gas enters the system and comes in contact with the filters, the dust is collected on the outside surface. To clean the filters, a blast of compressed air is directed into the top opening of the filter. The air is supplied through a blowpipe which feed into venturies (to increase the velocity) located above each filter. The air blast creates a shockwave that causes the fabric to flex down the length of the filter. As the filter flexes, the dust cake fractures and dust falls into the hopper below.

The cleaning frequency and cycle for the pulse jet system is critical for maximum efficiency and is set by an adjustable timer to ensure proper cleaning. Pulse jet cleaning requires no moving parts, cleans on demand.

General arrangement of a typical bag filter is shown in figure 4.1



4.1 FILTER CLEANING USING PULSE JET

A comparison between low ratio bag filters and high ratio bag filters has been drawn and shown below.

Low ratio bag filters	High ratio bag filters
1. Woven fabrics	Felted fabrics
2. Inside collection	Outside collection
3. Off-line cleaning	On/Off-line cleaning
4. Shaker or Reverse air cleaning	Pulse jet cleaning
5. 1.5 - 3.0 FPM filter speed	3.0 - 6.0 FPM filter speed
6. Panel & Modular design	Panel & Modular design

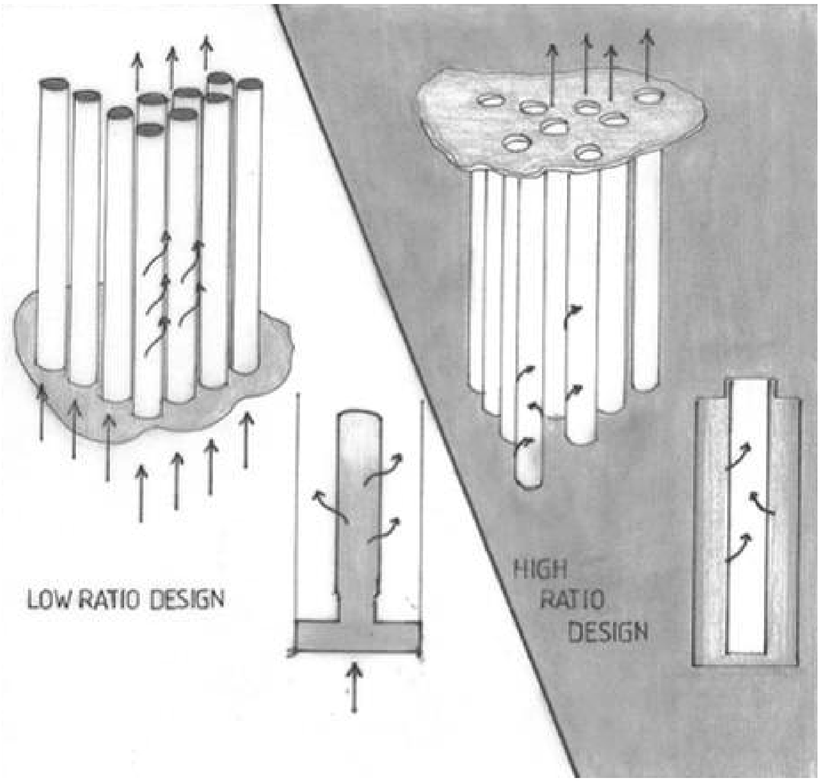
The advantages & disadvantages of high ratio bag filter are as follows:

1. More compact design due to higher filter velocities
2. On-line cleaning of bags, compartment isolation not needed
3. Bags and cage replacement from the clean air side of the unit.
4. Operating temperature limited by synthetic filter media
5. Bag cage required for every bag
6. Limited bag length (upto 8 m)
7. Bag life less than reverse gas type low ratio filter.

The advantages & disadvantages of low ratio bag filter are as follows:

1. Use of woven fiber glass media up to 450^{o} F
2. Bag length up to 36 feet
3. Increased bag life compared to high ratio
4. Larger ground space required
5. Off-line cleaning necessary
6. Increased capital cost

The general arrangement of bag filter based on low ratio design and high ratio design is shown in figure 4.2



4.2 WORKING OF BAG FILTER

4.3 Filter Media

While selecting the filter media for bag filters, the following characteristics of the carrier gas needs to be considered.

- Carrier gas temperature
- Carrier gas composition
- Carrier gas flow rate
- Size, shape and concentration of dust particles in the carrier gas.

As for the fabric concerned, its abrasion resistance, chemical resistance, tensile strength and permeability needs to be considered. The physical properties of some common fabrics are shown below.

Fabric	**Operating Temperature**	**Acid resistance**	**Alkali resistance**	**Abrasion resistance**	**Tensile strength**
Cotton	82	Poor	Good	Good	4920
Wool	93	Good	Poor	Good	1755
Nylon	93	Fair	Excellent	Excellent	5625
Dacron	135	Good	Excellent	Excellent	5625
Polypropylene	130	Excellent	Excellent	Excellent	7730
Fibre glass	290	Excellent	Excellent	Good	14060

Operating temperature ^{0}C is maximum continuous, tensile strength in kg/cm^2

The summary of various filter media that are applied in bag filter is given below.

Fibre	**PP**	**PES**	**PAC**	**PPS**	**APA**	**PI**	**PTFE**	**GLS**
Polymer Trade name	Polypropylene	Polyester	Dralon T	Ryton	Nomex	P84	Teflon	Fibre glass
Temp. limit ^{o}C	90	135	125	180	200	240	230	240
Price related to PES	1	1	1.6	5	5	6	15	2-3
Resistance Properties								
Acid	5	4	4	4	2	4	5	4
Alkali	5	2	3	4	4	2	5	3
Hydrolysis	5	1	4	5	2	2	5	5
Oxidation	3	5	3	1	3	-	5	5
Abrasion	5	5	4	3	5	4	3	1
1-Bad, 2-Mediocre, 3-Generally good, 4-Good, 5-Excellent								

4.4 Bag Filter Technology – World Experience

The variation in ESP performance with coal and ash characteristics when burning low sulphur coal has been experienced by many power utilities. Since Bag filters operate mainly on mechanical forces for collection, they are largely insensitive to coal and ash characteristics. As a result, trials were started in the earlier seventies in both USA and Australia, with the first full scale plant installed in Tallawarra Power station of Australia in 1975.

The plants installed in USA and Australia were of low ratio type. The plant installed in Australia was a shaker cleaner type fitted with acrylic bags. The plant installed in USA was a reverse flow cleaned type fitted with fibreglass bags. The reasons attributed for selection of technology was attributed to plant back end temperature. In USA, coal was purchased from different sources leading to wide variation in coal characteristics. Because of this, the boiler back-end temperatures were normally in the range of 160^{o}C and greater in order to avoid dew point and consequent corrosion. At that time the only material that can be thought of was fibreglass and the draw back of fibreglass is it is not a robust material sufficient to withstand the flexing and forces involved with shaking. In Australia, coal was purchased from same source with low sulphur content and as a result the boiler back-end temperatures were normally in the range of 120^{o}C to 135^{o}C that could be handled by acrylic filters. Higher temperatures above 135^{o}C leads to shrinkage of acrylic bags but acrylic material can withstand the rigors of shaking. The acrylic bags were protected from high temperature above 130 o C by the use of attemperating air.

In the mid-seventies trials was also being carried out by Alstom (then Flakt) in Europe with high ratio bag filters of pulse jet type for utility boilers. The first full scale installation was commissioned on a 60 MW boiler at Kyndby Power station in 1978.

Bag filters are considered as an alternative technology to ESP for control of particulate matter from pulverised coal fired boilers. Similar gas velocity as applied to ESP, can also be applied to bag filters regardless of the source of coal. With the development of new filtration media, it has become possible to operate bag filters at much higher temperatures on a sustained basis. A considerable number of pulverised coal fired boilers in the Australia, US and other countries are using bag filters; both pulse jet type and reverse air type bag filters.

The high ratio bag filter installed in one 30 MW boiler unit of Enstede Power station in 1978, fitted with 736 acrylic bags 7.2 m long has worked successfully. High ratio filters were also installed at one unit of 150 MW boiler of Milner Power station in Grand Cache, Canada in 1979. The Milner station used washery tailings containing 50% ash for power generation. During the initial period, the boiler was operated at low load with lower back-end temperatures and therefore, the bag filter was fitted with 5184 acrylic bags 6 m long. Thereafter the boiler was upgraded to full capacity with high back-end temperature and the acrylic bags were replaced with both PPS and Nomex filter bags (on different occasions). The bag filter has separate compartments and the bags in each compartment were fitted in removable cassettes. This feature allowed the cassette to be removed complete with old bags and cages and replaced with new cassette. The old cassette is taken to the bag changing facility to be rebagged.

A bag filter was retrofitted at one unit of 66 MW boiler at Wabamun Power Station in Canada with 3456 Nomex filter bags 6 m long. The 300 MW boiler unit at Fynsverket Power station is fitted with 7560 Ryton filter bags 7 m long. The 150 MW boiler unit at Vasteras is fitted with5824 acrylic filter bags 7 m long.

Each of the three 600 MW boiler units at Duvha Power Station (ESKOM) in South Africa is fitted with 26896 acrylic bags 8 m long. The bag filter is divided into four compartments that can be isolated. The main problem occurred in the bag filters is due to acid attack. The fly ash in Duvha Power Station did not neutralise the acidic gases formed through the dew point. Even the bags were coated with lime at the initial start up but acid attack continued. Trials have been carried out with PPS filter bags , the use of which allows the operation at higher temperatures. The bag life was found to be lower than expected.

4.5 Bag Filter Technology - Australian Experience

High ratio bag filters are now the preferred method of controlling particulate emission from PF fired boilers in NSW and Queensland in Australia. In Victoria the ESP continue to be used because lignite as fuel produces relatively low resistivity ash.

The installation at Tallawarra power station proved very successful and subsequently all boiler units at the station were converted from either mechanical collectors or ESPs to bag filters. By 1978 the Electricity Commission of NSW (now Pacific Power) installed bag filters in their four 660 MW boiler units at Eraring Power station. Each boiler unit was fitted with 50,000 filter bags. These units initially experienced major problems with differntial pressure (DP) and bag life, but these were subsequently overcome. Subsequently the company installed identical shaker type bag filter in their six 660 MW boiler units at Bayswater and Mt. Piper Power stations, with a total of 500,000 bags. All these units are operating satisfactorily, with acceptable differential pressure and bag life of 48,000 service hours.

In addition to above plants, high ratio bag filters (high pressure pulse jet) were retrofitted in NSW at Wangi Power Station on 3 units of 60 MW boilers in 1976-1976. Shaker filters were retrofitted in the same power station on 3 units of 50 MW boilers in 1976.

4.5.1 Tallawara Power Station

The first medium pressure pulse jet type bag filter was installed on one unit of 30 MW boiler at Tallawarra Power station in 1982 (by ABB Alstom and named Optipulse filter). The bag filter contained 648 acrylic bags. The pulse jet bag filter uses a medium pressure (200-500 kPa) pulsing system to clean the bags. This optipulse system feature large, fast opeing pulse valves and an air distribution system to the bags of much larger diameter than those normally used on conventional high pressure pulse systems. This is done in order to minimise pressure losses. No venturi is used at the top of the bag so that in combination with the air distribution system, the pulse energy generated by the fast acting valve is not dissipated, allowing effective pulsing of long filter bags. The optipulse features a unique gas distribution system. In earlier pulse jet filters, dust laden gas enters the bag filter via the hopper and risen upwards to the bags. In doing so, the dust cleaned off the bags during the on-line pulsing had to overcome the upward gas flow in order to settle in the hoppers for removal. This upward flow limited the length of bags which could be cleaned. In the optipulse system, gas enters the bag sideways across the bags, so that the gas flow is across and down, actually assisting removed dust to fall to the hopper.

4.5.2 Tennyson, Bulimb, Callide A

In Queensland, the Queensland Electricity Commission (QEC) placed order for installing bag filters in twenty eight boiler units at Tennyson, Bulimba and Callide Power stations, which were commissioned in 1983. At the time of placement of order, this was the largest air pollution control contract ever let in Australia. All bag filters were fitted with PTFE filter bags, some of which are still in operation today. The PTFE filter bags can sustain operation for 5 years but the cost was around US 130$ each in 1982.

The boilers at Tennyson and Bulimba were of the stroker type, while the boilers at Callide fired pulverised coal. The bag filters on each 32 MW boiler unit at tennyson were fitted with 1080 filter bags 6 m long. The bag filters on each 16 MW boiler units at Bulimba were fitted with 714 filter bags 6 m long. The bag filters at Tennyson and Bulimba performed satisfactorily.

The bag filters at four units of 30 MW boiler units at Callide power station did not perform well and the PTFE filter bags were unable to filter the fine ash particles generated from the power station. The resultant differential pressure was high and the fine ash particles migrated through the filter media. Following investigations, the problem was overcome by extending another 33% filter area to the existing one. Each of the 30 MW boiler unit at callide power station was extended to contain 1440 filter bags 6 m long. The bag filters operated satisfactorily.

4.5.3 Munmorah Power Station, Unit 4

In 1986, the ECNSW placed order for optipulse filter for the 350 MW pulverised coal fired unit 4 at Munmorah power station. The fabric filter was to be installed within the existing 4 gas path, 3 field ESP. the workscope included the supply of new goods and personnel elevator, ID fans, motors and silencers. He bag filter consist of eight separate compartments, each containing 1140 acrylic filter bags 7.2 m long, giving a total of 9120 bags and a filter velocity of 0.02 m/s. The emission level was 50 mg/Nm3 and the DP across the filter bags was 1.65 kPa. Each of the eight compartments can be isolated for servicing. The eight compartments were formed by adding a division wall along the centreline of each of the four ESP gas flows and modifying the inlet ducting system to allow the installation of additional inlet dampers. The entire outlet ducting system was replaced to accommodate new outlet dampers, silencers and ID fans.

The plant was commissioned in 1988 and performed satisfactorily. The initial set of bags was replaced after 33,000 service hours, due to gradually rising DP limiting unit load. Less than 100 bags were found to be defective and replaced during the total service hours. There is no bag filter bypass and there was no noticeable effect from boiler start-up or shut-down. Boiler start-up and flame stabilisation at low load is done using light fuel oil having 1% minimum sulphur content. The boiler problems occurred during the life of bags includes number of incidents of tube leaks and a serious incident of flame out during start-up when 1000 litres of oil reached the bags. At this stage a white plume was visible at the stack top and oil could be seen running down the inside of the bag filter case. The bag filter experienced very high DP and the boiler was shut down. The plant was restarted with oil firing to heat the fabric filter and evaporate the oil, after which the unit was brought back to normal operation. Within three days there was no noticeable effect from the incident.

4.5.4 Liddel Power station Units 1 to 4

In 1989 ABB Alstom received an order from ECNSW to retrofit optipulse bag filters within the existing ESP on the four units of 500 MW boilers at Liddell power station. The existing ESP contained 5 gas paths each of 3 fields. The gas flows from primary to secondary air heaters were kept separate in order to avoid high resistivity part of the resistivity Vs temperature curve. The secondary gas stream was running at about 110°C and the primary gas stream at about 170°C. The scope for the project included the following parameters:

- Mixing the primary and secondary gas streams before the gas reached the bag filter Upgrading the ID fans by adding new impellers and motors
- Supply of a compressed air system
- Supply of goods and personnel elevator
- Supply of all control systems and instrumentation necessary for the operation of the plant
- Modifying the ash removal system.

The bag filter for each boiler unit contained 14664 filter bags 8 m long. The bag filter contains five gas flows. The bag filter was installed during a 10 week outage. The bag filter operated satisfactorily and bags were replaced after 23,000 service hours. The bag replacement was necessitated by a gradual rise in DP and bag shrinkage. The shrinkage causes the bags to become tight on cages and reduces the effectiveness of the cleaning system.

Shrinkage of acrylic filter bags in high ratio filters has become a major concern in recent years. Initially the filter material was fabricated using Dralon T fibre manufactured by Bayer-Germany. Now Bayer has stopped the manufacture of Dralon T. Therefore, alternative homopolymer acrylic materials are used.

4.6 Bag Filter Technology - Indian Experience

Ash content in Indian coal is high and the typical concentration of particulate matter at the inlet of air pollution control equipment is 30 to 80 g/Nm^3 compared to 15 to 30 g/Nm^3 in Australia. Resistivity of fly ash generated from Indian coals is high and is comparable to fly ash generated from Australian coal. Because of the high ash and resistivity, the ESP needs to be far larger than would be required in Australia or USA. The Indian ESPs are very expensive because of the larger collection area. The ESPs of old power stations in India perform far below the design specifications.

Given this scenario and the increase in use of bag filters in Australia, there has been an increase in interest in bag filter technology in Indian Power stations. The first major installation of a bag filter on a utility pulverised coal fired boiler in India was at Maharastra State Electricity Board’s (MSEB) Koradi Power Station, Unit 6 (Near Nagpur).

4.6.1 Koradi Unit 6

Koradi Power Station, Unit 6 is a pulverised coal fired boiler. The unit was originally fitted with four gas path, six field series ESP. The ESP was performing poorly and the emission levels was of the order of 800 mg/Nm^3. MSEB therefore, investigated the feasibility of retrofitting a bag filter within the existing ESP casings. ABB Alstom showed that sufficient number of bags can be fitted within two of the existing ESP casings. MSEB subsequently issued specification for bag filter retrofit in the two ESP path / casings and convert them into bag filter. The other two ESP path has been retained as operational ESP. In the specifications, the back end temperature was provided as 160^{o}C and based on Australian experience, the costly PPS bags would have been offered without any additional gas cooling system. However, due to financial constrains, MSEB preferred the cheaper acrylic bags with additional water spray cooling system to cool the flue gases to a temperature suitable for acrylic bags.

The bag filter was initially supplied by a joint venture between ABB Alstom Australia and ABB Alstom India. ABB Alstom Australia provided the conceptual and process design of the bag filter compartments and procurement of bags. ABB Alstom India carried out detailed design of the bag filter, other than the filter compartments, including the ID fans and control systems and carried out the erection of the plant. Included in the contract was the supply of all controls and instrumentation, the supply of air compressors for bag cleaning and for the water spray system, and an emergency water spray system to protect the bags in the event of an air heater stoppage or fire.

The two outside path of ESP has been converted to bag filters. Each gas path contains 4124 acrylic bags 7.2 m long, giving a total of 8248 bags with a filter area of 23754 m2. The entire filter, including the internal gas distribution ducts and clean gas plenum, is fitted within the confines of the existing ESP casings.

The two outside gas inlet ducts have been replaced with larger ducts to cope with the doubling of flow involved in the conversion. A stand-by attemperating air system with multiple dampers and injection points was installed under each air heater. An independently controlled spray water cooling system has been installed in each bag filter inlet duct. The sprays are compressed air atomised, using special type of nozzles to achieve fine atomisation suitable for complete droplet evaporation in a 6 m distance in the horizontal inlet duct. There are 6 horizontal lances, each with seven spray nozzles. The supply of air and water to the lances is controlled in two zones, namely the bottom two lances and the top four lances. A thermocouple grid is located downstream of the lances, and the grid is used to control both the water spray and attemperating air systems.

The outer ducting from the filter to the stack has been modified to accommodate the extra flow through the fabric filter passes and to allow the installation of new ID fans. New ID fans and motors have been installed to provide the additional pressure needed to overcome the pressure loss across the bag filter. Implosion dampers are provided to limit the pressure that occurs below the bag plate level in the filters, in the unlikely event that the air heaters block or the bag filter dampers close accidentally before the outlet dampers are closed.

4.6.2 Design concerns at Koradi Unit 6

Several concerns arose during the design and manufacture period that centred around the water spray cooling system and the use of heavy fuel oil.

- Primary concerns with the bag filter are the reliability of the spray water cooling system, bag shrinkage and load limitations caused by a combination of bag shrinkage and high boiler gas flow.

- The main concern was regarding the ability to inject cooling water in the horizontal duct section as well as full evaporation of water prior to the gas reaching the bags so that dust does not build up on the floor and walls of the duct.

- Common practice in Australian power plants was for light fuel oil (0.5% average sulphur content), to be used for light up of boiler and flame stabilisation. In USA where heavy fuel oil is used, the bag filter was bypassed at start-up, in much the same way as ESP is not energised at start-up until stable coal firing is achieved. At MSEB-Koradi, heavy fuel oil was used and that too very frequently during monsoon. While it was considered likely that the high inlet concentration of fly ash will protect the bags from acid attack under most circumstances, it was decided use light furl oil with maximum 1% sulphur content and switch to ESP operation whenever boiler load dropped below 120 MW, thereby avoiding start up and periods of heavy oil firing. The decision was made taking into account concerns over bag failures which had occurred at Duvha power station and in some other plants of Europe where heavy fuel oil was being burned.

4.6.3 Commissioning of BF at Koradi Unit 6

The installation was done as per schedule and there were major problems encountered with the sealing of the pulse valves in the pulse tanks with major leakage making it impossible to pressurize the tanks. The tanks were repaired in-situ and the problems were solved. After commissioning major problem occurred with the spray water system and bag failures. The problem with spray water system included problems with control system, water flow control valves, blockages in the spray lances, wear in the spray nozzle tips and with the gas flow pattern in the spray location. The gas flow leaving the boiler being different from that specified for design and the air heater outlet temperature was varying wildly were identified as the main reasons for these problems. The combined effect of these problems was that both the attemperating air and the water spray system had to be operated to control the temperature to satisfactory levels.

Some of the technical problems with the spray system have been overcome. The control system now works satisfactorily and maintenance procedures have been established to check for and clear blockages in the spray lines. The gas distribution at the spray station was remodeled resulting in better gas mixing between the air heater outlet and the water sprays and even gas temperature distribution after the water sprays. These improvements have allowed the bag filter to operate with very little addition of attemperating air most of the time, thereby reducing the load on the bags. Water valve operation and nozzle blockages continue to be of concern and the higher gas flow needs to be regulated for bringing it under control/.

4.6.4 Bag Damage and Replacement at Koradi Unit 6

The initial bag failures were found to be related to four main factors:

1. Damaged by water reaching the bags during the commissioning of water spray system leading to cementing of ash on the surface of bags. Some bags near the inlet of the bag filter may have got damaged due to high gas temperature. These problems have not re-occurred after the modifications to the water spray system.
2. Bags at the inlet and along the internal gas distribution ducts showed erosion damage from impact of high velocity gas and ash particles. These problems have also been eliminated after modifications following the re-modeling of the inlet ducting in relation to the water sprays.
3. Bags got damaged due to poor quality of nag cages. New cages have been used to replace the defective cages as bags fail and are being replaced.
4. Bag shrinkage on account of high temperature leading to reduced cleaning and high differential pressure. This in turn has reduced the boiler load. Many bags have been replaced due to severe shrinkage.

During the 17000 service hours period, about 30% of the originally installed bags have been replaced and the achievable emission limit is below 150 mg/Nm^3.

In order to overcome the initial bag failures and temperature control problems, revisions to the inlet ducting were done after a series of site measurements and flow modeling. The effectiveness of the water spray system improved and the problems stopped. A set of recommendations was made to enable the water spray cooling system to function well with minimum maintenance and downtime. Despite concerns over acid dew point operation and the effects of oil firing, the bags have retained their mechanical strength and there are no signs of acid attack.

Primary concerns with the bag filter are the reliability of the spray water cooling system, bag shrinkage and load limitations caused by a combination of bag shrinkage and high boiler gas flow. The bag filter in such terms is undersized. And therefore very little can be done to take care of the high gas flow. The undersizing can result in reduction of bag life due to high filtering velocities and more frequent cleaning and loss of generating capacity due to outage of spray water system. It is likely that long service life can be achieved using PPS bags that may provide a cost-benefit to the use of these bags even taking into account the cost difference in the initial purchase price. This is particularly so when the energy consumption of the atomising air compressors for the water spray system is taken into account. The use of high temperature filter bags would completely eliminate the need for a complex temperature control system.

Alternatively it is further proposed to improve the spray water cooling system by making the following modifications:

- Modify the spray lances and lance support system and online replacement
- Have adequate spare spray lances so that the defective lances can be repaired without the need of boiler shut down.
- Replace difficult to maintain overseas water control valves with locally supplied valves.
- Add filters in the water supply line to improve water quality and reduce lance blockages and wear of nozzle tips.

Finally the following situation existed in Koradi Unit 6

- All the 8248 polyacrylamide bags were replaced with Ryton bags (PPS) in April 2001. The Ryton bags can withstand temperature as high as 180^{o}C and less water spraying is required. The evaporative water system can now be dispensed with and air attemperation system can suffice the purpose of flue gas conditioning.
- The service life of Ryton bags is 20,000 hours compared to 2400 hours for polyacrylamide bags. The cost of one Ryton bag is 140US$ compared to 50US$ for polyacrylamide bags.

CHAPTER - 5

TECHNOLOGICAL DETAILS OF BAG FILTER AT KORADI UNIT 6

5.1 Justification for Bag Filter Retrofit

Koradi power station is located close to Nagpur city just outside the municipal limits. The power station has two 210 MW units, one 200 MW unit and four 115 MW units, totaling to 1080 MW generation capacity. The existing ESP of 210 MW Unit 6 boiler was designed with the following properties:

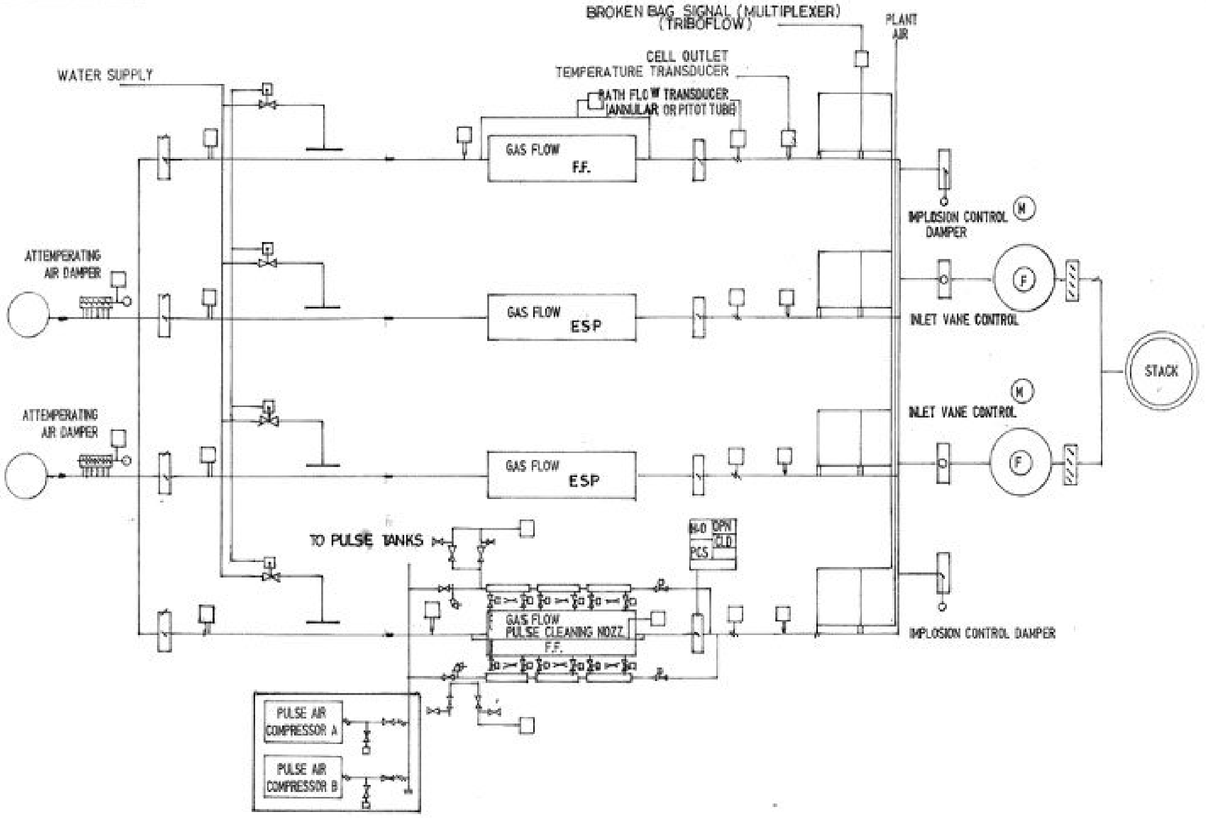
- Type – 2 FAA-(36)-5X36-9590-2
- No. of gas path –4
- No. of fields in each path –5
- Gas flow – 371 m^3/s
- Specific Collection Area - 132.74 $m^2/m^3/s$
- Gas temperature – 143°C
- Inlet dust concentration – 24.8 g/m^3
- Outlet dust concentration – 800 mg/m^3
- Guaranteed efficiency – 99%
- Pressure drop – 15 mm WC
- Velocity of gas at electrode zone – 1.085 m/s
- Treatment time – 16.59 seconds

Since the ash content in coal has increased over the past several years, the ESP was inadequate to meet the emission standards. The augmentation of ESP was necessary to bring down the particulate matter emission from 800 mg/Nm^3 to 150 mg/Nm^3. The following requirement was suggested to upgrade the existing ESP.

- Increase the SCA by 75%
- Space constraints
- High resistivity fly ash
- Flue gas temperature at air heater inlet was 145 to 155°C. The fly ash resistivity is maximum at this temperature.
- Sulphur content of the coal is less
- 90% of ash particles are less than 10 micron size.

Considering all the limitations it was found that ESP augmentation will not be feasible and to try alternate technology for achieving the emission standards. Bag filter technology was considered because it requires less space and the efficiency does not drop with changes in quantity and properties of ash. The choice was therefore limited to install bag filters by replacing the ESP or to retrofit the bag filters in the ESP. Detailed calculations revealed that with use of pulse jet type high ratio filters, the required cloth area can be accommodated in 50% of the existing ESP. Hence it was decided to retrofit the bag filters in path A and D of the ESP. Remaining B and C path of the ESP will be kept as such and used during heavy oil firing and when the load is below 120 MW.

A simplified P&I diagram showing the four ESP gas paths with two paths converted to bag filter are shown in figure 5.1.



5.1 BAG FILTER – MSEB KORADI

5.2 Guaranteed Performance Parameters of Bag Filter

ABB India Ltd. was awarded contract for retrofitting of Bag Filter with following guaranteed parameters

1	Maximum dust emission at MCR condition	80 mg/Nm^3
2	Maximum pressure drop across the bag filter at the MCR condition	150 mm WC
3	Maximum auxiliary power consumption at the equipment shafts at MCR condition for ID fans, Compressors and Other auxiliaries	2318 KW
4	Total boiler outage period	20 weeks (140 days)
5	Total number of boiler outages	1 (one)
6	Fabric bag life	2400 hours

5.3 Construction Problems Faced at Koradi Unit 6

Problems faced during pre-commissioning

In order to accommodate the auxiliaries and ducting with new layout of fabric filters, it was necessary to relocate and divert the existing facilities as mentioned below:

1. Diversion of bottom ash slurry lines and fly ash slurry lines of adjacent unit No5.
2. Clear water pipeline of Unit –6 and 7.
3. HT cables leading to CHP and Unit –5
4. Lube oil station and IGV control unit of ID fan – 6A
5. Shifting of ESP control room air conditioner blower and diversion of seal water pipeline.
6. Diversion of underground water fire fighting line and drainage line.

Problems faced during erection

1. As only one crane was available (80 tons capacity), work was held up for 10 days due to crane failure.
2. Preshut down work was not completed
3. Drawing approval of compressor and ID fan received late.
4. There is no approach space left, except unit-6 RHS and LHS approach road.

5. LHS ESP outlet duct was fauling with live cable leading to Unit-7 and ESP Unit-6 control room air conditioning blower chilled water pipeline.
6. Fan lower casing was fauling with fan foundation casting. After modification in lower casing by fan manufacturer, fan erection continued and delayed by 20 days.
7. Due to vast differences in duct outlet (old duct – 2.5 m and new duct – 5.15 m) and requires joining in a short lane, erection of ESP inlet duct got delayed.
8. Delay in PLC erection and thereby delay in link connection.

Problems faced during commissioning

1. Compressor – Loading, unloading and solenoid coil problem.
2. ID fan IGV – IGV link detaching, Brg. Housing bolt loosening and ring shifting from its position.
3. ID fan IGV control – As old power cylinder were used for IGV control, linkage were modified accordingly. IGV were not operating as per draft.
4. Implosion damper setting – Implosion damper was operating due to false command.
5. Seal air fan commissioning – four Nos. of seal air fan motor damaged during commissioning.
6. Pulse tank problem due to poor workmanship – Pulse tank valves were heavily passing due to improper matching of pulse tank valve seat.
7. PLC problem – Sudden opening of ID fan IGV, damper false indication of 'ID fan Brg. Motor Wdg. Temperature high'.
8. Evaporative cooling system – Atomization was not proper and heavy ash accumulation at ESP inlet duct.

Replacement of Bags :

- All the 8248 polyacrylamide bags were replaced with Ryton bags in April 2001. The Ryton bags can withstand temperature as high as 180^{o}C and less water spraying is required.

- The evaporative water system can now be dispensed with and air attemperation system can suffice the purpose of flue gas conditioning.

- The service life of Ryton bags is 20,000 hours compared to 2400 hours for polyacrylamide bags.

- The cost of one Ryton bag is 140US$ compared to 50US$ for polyacrylamide bags.

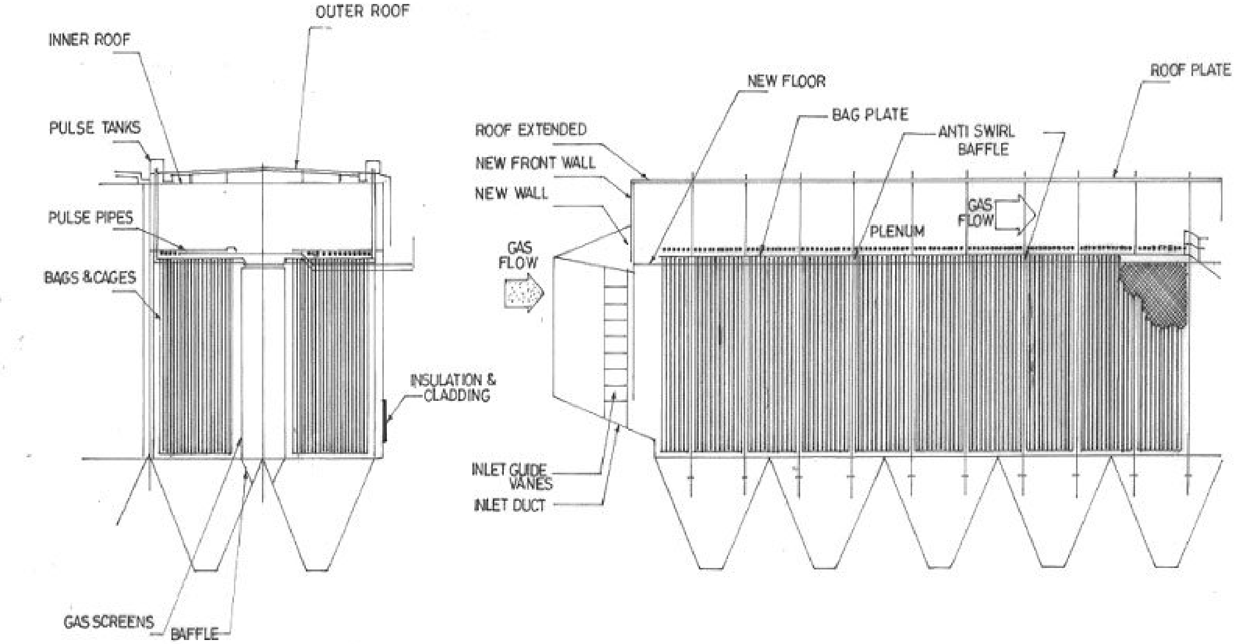
5.4 Technical Parameters of Bag Filter

The cross section of one compartment of the retrofit bag filter is shown in figure 5.2. The technical parameters of the bag filter are given below.

S. No.	Description	Details
1	Manufacturer	ABB
2	No. of Bag Filters	Two, one in each pass A and D
3	Type of bag filter	Pulse Jet
4	Details of bag filter and bags	
	Total number of bags in each pass	4124
	Dimensions of bag filter compartment	
	Height (m)	7.35
	Length (m)	25.85
	Width (m)	9.70
5	Dimensions of clean air compartment	
	Height (m)	2.74
	Length (m)	25.85
	Width (m)	9.70
6	Bag filter nominal height (m)	7.2
	Bag filter nominal dia (m)	0.129
	Filter area per bag filter (m^2)	12033.5
	Material of bag fabric	Homopolymer of polyacrylonitrile
	Weight of bag material (g/m^2)	600
	Bag stitching details	Acrylic stitch with PTFE thread
	Dia of wire of bag cages (mm)	4
	Dia of support ring (mm)	126 (OD star shaped)
	No. of pieces & No. of wires per bag cage	3 & 8
	Joining material of bag cage	MS
	Size of bottom cage cap	120 mm diameter

S. No.	Description	Details
7	Gas flow at the inlet of bag filter at MCR condition (m^3/s) Design condition (m^3/s)	 187 per pass 233.75 per pass
8	Flue gas temperature entering bag filter (^oC) Flue gas temperature to be maintained in the bag filter casing Short duration temperature excursion	120 (after evaporative cooling) 120 (maximum) 130 (max. 15 minutes per bag)
9	Inlet dust concentration (g/Nm^3)	78
10	Outlet dust concentration (mg/Nm^3)	80
11	Collection of ash in each hopper (TPH)	33.4 (evenly distributed in all the hoppers except last row of hoppers on the outlet side)
12	Estimated pressure drop in flue ducts laid between APH outlet and Bag Filter inlet at MCR conditions (total in Pa)	171
13	Estimated pressure drop across bag filter at MCR condition (Total Pa)	1350
14	Pressure drop in flue ducts laid between bag filter outlet and ID inlet at MCR condition (Pa total)	90
15	Total pressure drop in bag filter system at MCR condition, between APH outlet and inlet to chimney (Pa)	1735
16	Velocity of flue gas in the bag filter inlet duct at MCR conditions (m/s)	12.5 (average)
17	Filtration velocity of flue gas through bag filter at MCR condition (m/s)	0.0157
18	Velocity of flue gas in the bag filter outlet duct at MCR condition (m/s)	16.5 (average)
19	Method of gas distribution system each pass Uniform at bag filter inlet Within the bag filter	 By baffle plates By screens

S. No.	Description	Details
20	Gas distribution material	MS
	Thickness of distribution screen/ baffle	3 mm
21	No. of inspection doors provided in the casing of each pass	2
	Size of door	153 m height x 0.63 m width
22	Pulse cleaning air system	Solenoid operated plunger valve
	Make	ABB
	Size	80 Nb
	Material of construction	Die cast Al alloy
	No. of valve	428 (214 per casing)
	Air quantity per valve per opening (Nm^3)	0.00047
	Compressor	6
	Operating pressure of pulse air (kg/cm^2)	3.8
23	Maximum pressure fluctuation in the furnace draft due to bag filter cleaning process (mm WC)	10 (as only few bags (1% of total bags) are cleaned at any instant of time, there is little effect on furnace draft pressure)
24	Gas cooling system	
	Fabric withstand temperature (^oC)	125 (continuous)
	Method of gas cooling	Evaporative cooling on continuous basis. Air attemperation during emergency
	Water flow required to achieve inlet flue gas temperature for continuous evaporative cooling (kg/cm^2)	5.9 (total for two phases)
	Maximum allowable temperature of flue gas at bag filter inlet (^oC)	120 (continuous)
25	Control of cleaning air system	
	Frequency of cleaning for complete cycle (mins)	15 minutes average
	Method of frequency control	DP and overriding timer
26	Implosion damper (Type and Make)	Puppet (make ABB)



5.2 RETROFIT BAG FILTER – CROSS SECTION EVALUATOR

CHAPTER - 6

PERFORMANCE MONITORING OF SELECTED ESP

The performance monitoring of selected electrostatic precipitators were carried out in consultation with CPCB. Additional study has been undertaken at one unit (Unit V - 60 MW unit at Indraprastha Power Station, DVB, Delhi), where major modifications have been made in the ESP to improve the efficiency. The performance monitoring has also been conducted at Unit VI of Koradi Thermal Power Station (MSEB), where bag filter has been retrofitted within the existing ESP shell. The name of the selected units where performance evaluations were carried out is given below.

1. 67.5 MW unit at Rajghat Power Station, DVB, Delhi
2. 210 MW unit at Badarpur Power Station, NTPC, Delhi
3. 250 MW unit at Budge Budge Power Station, CESC, Calcutta
4. 500 MW unit at Chandrapur Super Thermal Power Station, MSEB, Chandrapur
5. Unit V- 60 MW at Indraprastha Power Station, DVB, Delhi
6. Unit VI – 210 MW at Koradi Power Station, MSEB, Koradi

6.1 Performance Study No. 1 - Rajghat Power Station, Delhi Vidyut Board, Delhi

The technical details of the ESP attached to boiler units of Rajghat Power Station and the fundamental problems faced in the ESP are given below.

Capacity	Stack	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit I – 67.5 MW	One stack of 160 m height	Yes	64	150	99.77%	High resistivity fly ash
Unit –II 67.5 MW		Yes	64	150	99.77 %	High resistivity fly ash
Total – 135 MW		Remarks – Though fly ash resistivity is cited as a fundamental problem, no resistivity figures are available				

ESP Design (Unit I & II)

1. Electrode arrangement – Spiral emitting electrode and plate collecting electrode
2. Electric power supply – Multipulse energisation
3. Number of series field – Two paths, 5 series
4. Specific collection area – 206.4 $m^2/m^3/s$
5. Gas velocity inside ESP– 0.56 m/s
6. Plate configuration – 31 rows, 9 plates in each row
7. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 31 seconds
8. High tension sections (per $1000m^3$ of gas flow rate) – Not known
9. Migration velocity of particles (designed)- Not known
10. Resistivity of Particles- Not known
11. Collecting electrode spacing (mm)- 300 mm
12. Electrode Rapping - Mechanical hammer rappers
13. Corona electrode rapping mechanism- Available
14. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP– Deflector divertor plates, primary and secondary screens at inlet

Most probable reasons stated for under performance of ESP

Fundamental problems	**Mechanical problems**	**Operational problems**
➢ High resistivity particles ➢ Re-entrainment of collected particles ➢ Poor gas flow ➢ Gas velocity too high	➢ Poor electrode alignment ➢ Vibrating or swinging corona wires ➢ Distorted collecting plates ➢ Excessive dust deposits on collecting electrodes and corona electrodes ➢ Air leakage into hoppers, shells or gas ducts ➢ Formation of dust mountain in ESP inlet and outlet ducts	➢ Full or overflow hoppers ➢ Shorted corona sections ➢ ESP overloaded by excessive gas flow ➢ Process upsets (poor combustion, steam leaks, etc.) ➢ Rectifier sets or controls poorly adjusted ➢ Poor adjustment of rapper intensity / frequency.

Performance Monitoring Results

Date of Monitoring – 1-8-2002
Unit – II
Load – 50 MW (74% of rated capacity)
Boiler – Pulverised coal fired
ESP Voltage – 21 to 41 KV in 10 fields

Monitoring location – ESP inlet duct
Stack gas temperature – 483 K
Stack gas velocity – 16.7 m/s
SPM at ESP inlet –35 g/Nm^3

Monitoring location – ESP inlet duct
Stack gas temperature – 463 K
Stack gas velocity – 15.2 m/s
SPM at ESP outlet – 125 mg/Nm^3

Water vapour in flue gas – 5.2%
CO_2 concentration in flue gas – 13.6 %
O_2 concentration in flue gas – 4.3 %

ESP efficiency – 99.6%

Coal characteristics

Total moisture	Ash	Volatile matter	Fixed carbon	Sulphur	GCV Kcal/kg
7%	40%	22.5%	31.5%	0.4%	3894

Fly ash characteristics

Unburnt carbon	Silica	Iron oxide	Aluminum oxide	Sodium	Sulphate	Calcium oxide	Potassium oxide
4%	66%	16.4%	4.7%	0.4%	0.02%	1.1%	0.4%

Capital cost of ESP – Not available
O&M Cost of ESP - Not available

Particle Size Distribution Studies

Particles less than 10 micrometers (mean particle diameter) - 40%
Particles greater than 10 micrometers (mean particle diameter) - 60%

6.2 Performance Study No. 2 - Indraprastha Power Station, Delhi Vidyut Board, Delhi

The technical details of the ESP attached to boiler units of Indraprastha Power Station and the fundamental problems faced in the ESP are given below.

Capacity	Stack	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit II to IV – 62.5 MW	Two stacks of 60 m Height	Yes	66	150	99.81%	High resistivity fly ash
Unit –V 60 MW		Yes	70	150	99.9 %	High resistivity fly ash
Total – 247.5 MW		Remarks – Though fly ash resistivity is cited as a fundamental problem, it has not been measured any time				

ESP Design (Unit II to IV)

1. Electrode arrangement – Strip emitting electrode and plate collecting electrode. Plates are provided with hooks at the top for suspension and held at the bottom by shock bars. The strips are fixed at both ends.
2. Electric power supply – Semipulse energisation
3. Number of series field – Two paths, 5 series
4. Specific collection area – 132.32 m^2/m^3/s
5. Gas velocity inside ESP – 0.81 m/s
6. Plate configuration – Not known
7. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 19.85 seconds
8. High tension sections (per 1000m^3 of gas flow rate) – Not known
9. Migration velocity of particles (designed)- Not known
10. Resistivity of Particles- Not known
11. Collecting electrode spacing (mm)- 300 mm
12. Electrode Rapping - Mechanical hammer rappers
13. Corona electrode rapping mechanism- Available
14. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Perforated gas distribution screen are provided at inlet of ESP.

ESP Design (Unit V)

1. Electrode arrangement – Strip emitting electrode and plate collecting electrode. Plates are provided with hooks at the top for suspension and held at the bottom by shock bars. The strips are fixed at both ends.
2. Electric power supply – Semipulse energisation
3. Number of series field – Two paths, 5 series field + Two additional parallel paths, 3 series field provided and commissioned during 1999. The modofication work was stabilised in March 2001.
4. Specific collection area – 132.32 + 58.57 = 190.89 $m^2/m^3/s$
5. Gas velocity inside ESP– 0.98 m/s
6. Plate configuration – 31 rows, 9 plates in each row
7. Aspect ratio (ratio of total length of the fields to the height of the fields) – 1.1
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 19.85 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – Not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- Not known
12. Collecting electrode spacing (mm)- 400 mm
13. Electrode Rapping - Mechanical hammer rappers
14. Corona electrode rapping mechanism- Available
15. Perforated gas distribution screens provided at both inlet and outlet of ESP.

Most probable reasons stated for under performance of ESP

Fundamental problems	**Mechanical problems**	**Operational problems**
➢ High resistivity particles ➢ Gas velocity too high for unit No.V	➢ Distorted collecting plates ➢ Air leakage into hoppers, shells or gas ducts	➢ Full or overflow hoppers ➢ Shorted corona sections ➢ ESP overloaded by excessive gas flow ➢ Process upsets (poor combustion, steam leaks, etc.)

Performance Monitoring Results

Date of Monitoring – 1-8-2002
Unit – V
Load – 26 MW (43% of rated capacity)
Boiler – Pulverised coal fired
ESP Voltage – 17 to 41 KV in 16 fields

Monitoring location – ESP inlet duct
Stack gas temperature – 456 K
Stack gas velocity – 14.5 m/s
SPM at ESP inlet – 17.4g/Nm^3

Monitoring location – ESP outlet duct
Stack gas temperature – 451 K
Stack gas velocity – 13.6 m/s
SPM at ESP outlet – 89 mg/Nm^3
Water vapour – 5%
CO_2 concentration in flue gas – 12.4 %
O_2 concentration in flue gas – 6.2 %

ESP efficiency – 99.5%

Particle Size Distribution Studies

Particles less than 10 micrometers (mean particle diameter) - 38%
Particles greater than 10 micrometers (mean particle diameter) - 62%

6.3 Performance Study No.3 - Badarpur Power Station, Delhi (NTPC)

The technical details of the ESP attached to boiler units of Badarpur Power Station and the fundamental problems faced in the ESP are given below.

Capacity	Stack	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit I to III – 95 MW	Two stacks of 150 m Height	Yes	38.2	150	99.6%	High resistivity fly ash
Unit IV to V 210 MW		Yes	31.8	150	99.5 %	High resistivity fly ash
Total – 705 MW		Remarks – Though fly ash resistivity is cited as a fundamental problem, it has not been measured any time				

ESP Design (Unit I, II & III)

1. Electrode arrangement – 51 rows, 6plates per row, 306 plates for two paths
2. Electric power supply – Semipulse energisation
3. Number of series field – Two paths, 4 series
4. Specific collection area – 151.87 $m^2/m^3/s$
5. Gas velocity inside ESP – 0.8 m/s
6. Plate configuration – 13.5 m height, 750 mm length
7. Aspect ratio (ratio of total length of the fields to the height of the fields) – 1.33
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 28.8 seconds
9. High tension sections (per $1000m^3$ of gas flow rate) – Not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- 7.04×10^9 Ohm-cm
12. Collecting electrode spacing (mm)- 300 mm
13. Electrode Rapping - Mechanical hammer rappers
14. Corona electrode rapping mechanism- Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP –Gas distribution screens are provided at inlet of ESP.

ESP Design (Unit IV)

1. Electrode arrangement – 39 rows, 9 plates per row.
2. Electric power supply – Semipulse energisation
3. Number of series field – Four paths, 5 series field
4. Specific collection area – 132.88 $m^2/m^3/s$
5. Gas velocity inside ESP– 1.08 m/s
6. Plate configuration – 9 m height, 400 m length
7. Aspect ratio (ratio of total length of the fields to the height of the fields) – Not known
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 16.62 seconds
9. High tension sections (per $1000m^3$ of gas flow rate) – Not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- Not known
12. Collecting electrode spacing (mm)- 250 mm
13. Electrode Rapping - Mechanical hammer rappers
14. Corona electrode rapping mechanism- Available
15. Gas distribution screens provided at both inlet and outlet of ESP.

ESP Design (Unit V)

1. Electrode arrangement – 38 rows, 8 plates per row.
2. Electric power supply – Multipulse energisation
3. Number of series field – Four paths, 5 series field
4. Specific collection area – 115 $m^2/m^3/s$
5. Gas velocity inside ESP– 0.93 m/s
6. Plate configuration – 9 m height, 400 m length
7. Aspect ratio (ratio of total length of the fields to the height of the fields) – 1.77
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 17.24 seconds
9. High tension sections (per $1000m^3$ of gas flow rate) – Not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- Not known
12. Collecting electrode spacing (mm)- 300 mm
13. Electrode Rapping - Mechanical hammer rappers
14. Corona electrode rapping mechanism- Available
15. Gas distribution screens provided at both inlet and outlet of ESP.

Most probable reasons stated for under performance of ESP

Fundamental problems	**Mechanical problems**	**Operational problems**
➢ High resistivity particles	➢ None	➢ ESP overloaded by excessive gas flow

Performance Monitoring Results

Date of Monitoring – 27-3-2001
Unit – V
Load – 205 MW
Boiler –Pulverised coal fired
ESP Voltage – 38 to 50 KV in 20 fields; all fields working

Monitoring Location – ESP inlet duct
Stack gas temperature – 423 K
Stack gas velocity – 19.1 m/s
SPM at ESP inlet – 28.9 g/Nm^3

Water vapour – 6%
CO_2 concentration in flue gas – 16.0 %
O_2 concentration in flue gas – 2.8 %

ESP efficiency – 99.5%

Coal characteristics

Total moisture	Ash	Volatile matter	Fixed carbon	Sulphur	GCV Kcal/kg
7.8%	39.5%	17.4%	35.3%	0.2 to 0.6%	3890

Fly ash characteristics

Unburnt carbon	Silica	Iron oxide	Aluminum oxide	Sodium Oxide	Sulphur trioxide	Calcium oxide	Potassium oxide
--	62%	8.9%	25.5%	0.58%	0.13%	2.0%	2.32%

Costing Figures

Capital cost of ESP – Rs. 20 Crores for 210 MW
O&M cost – Rs.0.1 Crores per annum for each units

Particle Size Distribution Studies

Particles less than 10 micrometers (mean particle diameter) - 35%
Particles greater than 10 micrometers (mean particle diameter) - 65%

6.4 Performance Study No.4 - Budge Budge Power Station, CESC, Calcutta

The technical details of the ESP attached to boiler units of Budge Budge Power Station and the fundamental problems faced in the ESP are given below.

Capacity	Stack	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit I – 250 MW	One stack of 275 m height	Yes	72.8	100	99.86%	No problem
Unit –II 250 MW		Yes	72.8	100	99.86 %	No problem
Total – 500 MW						

ESP Design (Unit I & II)

1. Electrode arrangement – Hanging from top via pin insulators; divided into three segments. ESP size is 13.95 m x 4.8 m.
2. Electric power supply – Multipulse energisation
3. Number of series field – Two paths, 7 series
4. Gas velocity inside ESP – 2.86 m/s
5. Plate configuration – Parallel to gas path, 10 plates
6. Aspect ratio (ratio of total length of the fields to the height of the fields) – 2.9
7. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 12 seconds
8. High tension sections (per 1000m^3 of gas flow rate) – Not known
9. Migration velocity of particles (designed)- Not known
10. Resistivity of Particles- 10^9 to 10^{10} ohm-cm
11. Collecting electrode spacing (mm)- 300 mm
12. Electrode Rapping - Mechanical hammer rappers
13. Corona electrode rapping mechanism- Available
14. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Plates with honey comb opening.

Performance Monitoring Results

Date of Monitoring – 12-4-2001
Unit – I
Load – 200 MW (80% of rated capacity)
Boiler – Pulverised coal fired
Coal feed rate – 127 tph
ESP Voltage – 24 to 40 KV in 14 fields; 4 fields not working

Monitoring Location – ESP duct
Stack gas temperature – 419 K
Stack gas velocity – 22 m/s
SPM at ESP outlet – 290 mg/Nm^3

Water vapour – 5%
CO_2 concentration in flue gas – 13.2 %
O_2 concentration in flue gas – 0.2 %

ESP efficiency – Not obtained because the inlet concentration could not be monitored due to lack of facilities.

Coal characteristics

Total moisture	Ash	Volatile matter	Fixed carbon	Sulphur	GCV Kcal/kg
6.1%	42.5%	18.1%	33.3%	0.45%	3952

Fly ash characteristics

Unburnt carbon	Silica	Iron oxide	Aluminum oxide	Sodium	Sulphate	Calcium oxide	Potassium oxide
4.6%	54%	4.2%	30%	0.33%	0.08%	3.1%	0.7%

Capital Cost of ESP – Not available
O&M cost – Rs.30 Lakhs per annum per ESP

6.5 Performance Study No.5 - Chandrapur Super Therma Power Station, MSEB - Chandrapur

The technical details of the ESP attached to boiler units of Chandrapur Power Station and the fundamental problems faced in the ESP are given below.

Capacity	Stack Height	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit I & II 210 MW	2 stacks of 90 m	Yes	50.5	740	98.5%	High resistivity fly ash particles.
Unit III & IV 210 MW	2 stacks of 150 m	Yes	39.33	350	99.24	No major problems in ESP for Unit V to VII except that they are overloaded by excessive gas flow
Unit V & VI 500 MW	2 stacks of 200 m	Yes	74.51	100	99.87	
Unit VII 500 MW	One stack of 275 m	Yes	62.0	70	99.88	
Total – 2340 MW	7 stacks					

ESP Design (Unit I & II)

1. Electrode arrangement – spriral hook of 2.7 mm dia
2. Electric power supply – Multipulse energisation
3. Number of series field – Two paths, 3 series
4. Specific collection area – 141.53 $m^2/m^3/s$
5. Gas velocity inside ESP– Not available
6. Plate configuration – 7.5 m height, 0.495 m length
7. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- Not known
8. High tension sections (per 1000m^3 of gas flow rate) – Not known
9. Migration velocity of particles (designed)- Not known
10. Resistivity of Particles- 8.7 x 10^9 ohm-cm
11. Collecting electrode spacing (mm)- 300 mm
12. Electrode Rapping - Mechanical hammer rappers
13. Corona electrode rapping mechanism- Available
14. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Perforated plates in three rows

ESP Design (Unit III & IV)

1. Electrode arrangement – spiral hook of 2.7 mm dia
2. Electric power supply – Multipulse energisation
3. Number of series field – Four paths, 5 series
4. Specific collection area – 142.22 $m^2/m^3/s$
5. Gas velocity inside ESP– 0.75 m/s
6. Plate configuration – 9 m height, 0.4 m length
7. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 21.33 seconds
8. High tension sections (per 1000m^3 of gas flow rate) – Not known
9. Migration velocity of particles (designed)- 0.2 m/s
10. Resistivity of Particles- 9.6 x 10^9 ohm-cm
11. Collecting electrode spacing (mm)- 150 mm
12. Electrode Rapping - Mechanical hammer rappers
13. Corona electrode rapping mechanism- Available
14. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – 1st and 2nd screen of gas distribution plate of 80 mm hole at inlet of ESP.

ESP Design (Unit V & VI)

1. Electrode arrangement – spiral hook of 2.7 mm dia
2. Electric power supply – Multipulse energisation
3. Number of series field – Four paths, 6 series
4. Specific collection area – 167.96 $m^2/m^3/s$
5. Gas velocity inside ESP– 0.9 m/s
6. Plate configuration – 12.5 m height, 0.75 m length
7. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 25.2 seconds
8. High tension sections (per $1000m^3$ of gas flow rate) – Not known
9. Migration velocity of particles (designed)- Not known
10. Resistivity of Particles- 9.5×10^9 ohm-cm
11. Collecting electrode spacing (mm)- 150 mm
12. Electrode Rapping - Mechanical hammer rappers
13. Corona electrode rapping mechanism- Available
14. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Inlet perforated plate 2 sets, Thin sheets formed to U shape.

ESP Design (Unit VII)

1. Electrode arrangement – spiral hook of 2.7 mm dia
2. Electric power supply – Multipulse energisation
3. Number of series field – Four paths, 8 series
4. Specific collection area – 226 $m^2/m^3/s$
5. Gas velocity inside ESP– 1.0 m/s
6. Plate configuration – 15 m height, 0.75 m length
7. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 21.33 seconds
8. High tension sections (per $1000m^3$ of gas flow rate) – Not known
9. Migration velocity of particles (designed)- 0.20 1m/s at 740 m^3/second
10. Resistivity of Particles- 2.9×10^{10} ohm-cm
11. Collecting electrode spacing (mm)- 300 mm
12. Electrode Rapping – Tumbling hammer
13. Corona electrode rapping mechanism- Available
14. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – By distribution screen, two at inlet and one at outlet.

Fundamental problems	**Mechanical problems**	**Operational problems**
➢ High resistivity particles ➢ Insufficient number of corona sections in Units I to IV. ➢ Undersize ESP in Units I to IV.	➢ Vibrating or swinging corona wires in Units I to IV. ➢ Distorted collecting plates in Units I to IV. ➢ Air leakage into hoppers, shells or gas ducts in Units I to VI.	➢ Shorted corona sections in Units I and II. ➢ ESP overloaded by excessive gas flow in Units V to VII

Performance Monitoring Results

Date of Monitoring – 17-5-2001
Unit – VII
Load – 385 MW (77% of rated capacity)
Boiler – Pulverised coal fired
ESP Voltage – 15.6 to 39.8 KV in 32 fields; 2 fields not working

Monitoring Location - ESP inlet duct
Stack gas temperature – 424 K
Stack gas velocity – 11.6 m/s
SPM at inlet – 42.6 g/Nm^3

Monitoring Location - Stack (at 90 m level of the 275 m tall stack)
Stack gas temperature – 414 K
Stack gas velocity – 7.0 m/s
SPM at outlet – 65 mg/Nm^3

Water vapour – 9%
CO_2 concentration in flue gas – 16.4 %
O_2 concentration in flue gas – 6.2 %

ESP efficiency – 99.8 %

Coal characteristics

Total moisture	Ash	Volatile matter	Fixed carbon	Sulphur	GCV Kcal/kg
14.5%	39.4%	20.1%	25.96%	0.5%	3298

Fly ash characteristics

Unburnt carbon	Silica	Iron oxide	Aluminum oxide	Sodium oxide	Sulphur trioxide	Calcium oxide	Potassium oxide
7.2%	55.3%	4.7%	28.82%	0.52%	1.2%	1.8%	0.77%

Capital cost of ESP – Not available
O&M Cost of ESP - Not available

Particle Size Distribution Studies

Particles less than 10 micrometers (mean particle diameter) - 35%
Particles greater than 10 micrometers (mean particle diameter) - 65%

6.6 Performance Study No. 6 - Koradi Therma Power Station, MSEB - Koradi

The technical details of the ESP attached to boiler units of Koradi Power Station and the fundamental problems faced in the ESP are given below.

Capacity	Stack Height	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit I to IV 115 MW	2 stacks of 75 m	Yes	55	800	99%	High resistivity fly ash particles.
Unit V 200 MW	1 stack of 90 m	Yes	55	800	99%	No major problems in ESP except that they are overloaded by excessive gas flow
Unit VI & VII 210 MW	2 stacks of 90 m	Yes	55	800	99%	
Total – 1080 MW	5 stacks					

ESP Design (Unit V)

1. Electrode arrangement – not known
2. Electric power supply – Multipulse energisation
3. Number of series field – Two paths, 5 series
4. Specific collection area – 132.74 $m^2/m^3/s$
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 1.085 m/s
6. Plate configuration – Not known
7. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 11.33 seconds
8. High tension sections (per $1000m^3$ of gas flow rate) – Not known
9. Migration velocity of particles (designed)- Not known
10. Resistivity of Particles- Not known
11. Collecting electrode spacing (mm)- 250 mm
12. Electrode Rapping - Mechanical hammer rappers
13. Corona electrode rapping mechanism- Available
14. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Perforated plates at inlet of ESP

ESP Design (Unit VII)

1. Electrode arrangement – emitting electrodes of spiral hooks of 2.5 mm dia. 1368 spirals are present in each path. (27360 spirals in unit VII, total length of spirals is 6820 m)
2. Electric power supply – Multipulse energisation
3. Number of series field – Four paths, 5 series
4. Specific collection area – 132.74 $m^2/m^3/s$
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 1.085 m/s
6. Plate configuration – 39 rows of plates per path, 9 plates in each row. (7020 plates in Unit VII; plates are 9 m height and 400 mm length). Plate – wire/spiral spacing is 125 mm.
7. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 16.59 seconds
8. High tension sections (per $1000m^3$ of gas flow rate) – Not known
9. Migration velocity of particles (designed)- Not known
10. Resistivity of Particles- Not known
11. Collecting electrode spacing (mm)- 150 mm
12. Electrode Rapping - Mechanical hammer rappers
13. Corona electrode rapping mechanism- Available
14. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Perforated plates, 2 sets located at the inlet of ESP.

Most probable reasons stated for under performance of ESP

Fundamental problems	Mechanical problems	Operational problems
➢ High resistivity particles ➢ Poor gas flow ➢ Gas velocity too high ➢ Undersize ESP	➢ Poor electrode alignment ➢ Distorted collecting plates sometimes encountered ➢ Air leakage into hoppers, shells or gas ducts	➢ Full or overflow hoppers sometimes encountered ➢ ESP overloaded by excessive gas flow ➢ ESP overloaded by excessive dust concentration

Performance Monitoring Results

The Unit No. VI has been retrofitted with bag filters and the description of the bag filter has been provided in earlier chapter. The performance of bag filter has been monitored and the results are provided below.

Date of Monitoring – 16-5-2001
Unit – VI
Load – 187 MW (89% of rated capacity)
Boiler – Pulverised coal fired

Monitoring location – Bag filter inlet duct
Stack gas temperature – 426 K
Stack gas velocity – 19.6 m/s
SPM at Bag Filter inlet – 77.8 g/Nm^3

Monitoring location – Bag filter outlet duct
Stack gas temperature – 420 K
Stack gas velocity – 16.5 m/s
SPM at Bag Filter outlet – 46 mg/Nm^3

Water vapour – 5%
CO_2 concentration in flue gas – 9.16 %
O_2 concentration in flue gas – 10.3 %
SPM at Bag Filter outlet (CO_2 corrected to 12%) – 60 mg/Nm^3

Bag Filter efficiency – 99.9%

Coal characteristics

Total moisture	Ash	Volatile matter	Fixed carbon	Sulphur	GCV Kcal/kg
14.2%	34.2%	23.2%	27.6%	0.8%	3844

Fly ash characteristics

Unburnt carbon	Silica	Iron oxide	Aluminum oxide	Sodium oxide	Sulphur trioxide	Calcium oxide	Potassium oxide
5%	63.6%	4.7%	25.1%	1.08%	0.23%	1.7%	0.92%

Capital cost of ESP – Not available
O&M Cost of ESP - Not available
Costing Figures – Bag filter cost described in Chapter 5. O&M cost not available

Particle Size Distribution Studies

Particles less than 10 micrometers (mean particle diameter) - 34%
Particles greater than 10 micrometers (mean particle diameter) - 66%

6.7 Conclusion

The main parameters for the six ESPs monitored for performance tests are summarised below.

Parameters	Chandrapur Unit VII	Budge Budge Unit I	Badarpur Unit V	Indraprastha Unit V	Rajghat Unit II
Capacity, MW	500	250	210	60	67.5
Load, MW (during monitoring)	385	200	205	26	50
ESP field total	32	14	20	16	10
ESP field working	30	10	20	16	10
Coal consumption TPH (during monitoring)	292	127	148	20	32.8
Inlet conc mg/Nm^3	42600	--	28900	17400	35000
Outlet conc. mg/Nm^3	65	290	142	89	125
Efficiency %	99.8	--	99.5	99.5	99.6
Particle size, < 10μ	35%	--	35%	38%	40%
SCA m^2/m^3/s	226	--	115	132.32 + 58.57 = **190.89**	206.4
Gas velocity m/s	1.0	2.86	0.93	0.98	0.56
Treatment time, s	21.3	12.0	17.2	19.9	31

1. The particulate emission level of power plant at Chandrapur-Unit VII 500 MW, Badarpur-Unit V 210 MW, Indraprastha-Unit V 60 MW and Rajghat-Unit II 67.5 MW was below the MINAS limit of 150 mg/Nm^3. Unit VII at Chandrapur plant was meeting particulate emission of 75 mg/Nm^3. Budge Budge Unit I 250 MW was not meeting the emission standard probably because of non-functional 4 fields of the ESP during the monitoring period.

2. Indraprastha power station Unit V had 8 fields ESP of BHEL make and has serially added by retrofitting 8 more fields of ABB. The retrofitting cost was Rs.3.5 Crores (1994 price). The additional 8 fields were commissioned in 1999 and got stabilized in March 2001. The particulate emission levels monitored after stabilization was 89 mg/Nm^3, with ESP efficiency of 99.5% (load 26 MW, that is 43% of rated boiler capacity). Indraprastha TPP being an old plant, the load never exceeds 40 MW. The aspect ratio of the ESP, the gas velocity and the treatment time after retrofitting is satisfactory. The experience gained at Indraprastha Unit V can be emulated for all ESP renovation and modernisation cases.

3. The performance of Rajghat power station Unit II is satisfactory and the ESP is achieving the emission limit of 150 mg/Nm^3. The SCA of the ESP is good (206), gas velocity is optimum (0.56) and treatment time is sufficient (31 seconds).

4. The performance of Budge Budge Unit I was found to be poor and the particulate emission level exceeded the design limit of 100 mg/Nm^3 by over 2.5 times. This is probably because the ESP is oversized, gas velocity is too high at 2.86 m/s, aspect ratio is abnormal at 2.9 and the treatment time is very less at 12 seconds. The emission level is likely to improve when all 14 fields will be in service but the ESP design parameters needs to be re-investigated.

5. The performance of Badarpur Unit V is satisfactory mainly due to efficient O&M of the entire power plant. The SCA of the ESP is poor (115) but the performance is probably compensated by optimum gas velocity (0.93), fair aspect ratio (1.8).

6. The performance of Chandrapur Unit VII is excellent and it is a newly constructed ESP meeting all the modern concepts of ESP design for achieving particulate emission limit of 75 mg/Nm^3. The SCA is high (226), gas velocity (1.0) and treatment time (21.3) is most optimum. This ESP can be emulated by all new power plants.

7. It is observed that the number of high tension sections in the ESP and fly ash resistivity values were not available in any of the six power plants monitored for performance study. The Budge Budge plant could not provide the most elementary SCA value of its ESP. Badarpur and

Indraprastha plant provided the aspect ratio value of 1.8 and 1.1 respectively, other four plants did not have the value of aspect ratio. This indirectly shows the status of manpower expertise involved in O&M of the ESPs in Indian TPP and the extent of their job knowledge.

8. The performance of bag filter retrofitted at MSEB 210 MW Koradi Unit VI is also satisfactory and on the date of monitoring it was achieving the guaranteed particulate emission limit of 80 mg/Nm^3. The monitored efficiency was 99.9%. The bag filter was retrofitted in two ESP paths. The other two ESP paths are operated only when the plant loads fall below 120 MW and also during start-up and shut-down periods, when maximum oil support is required. Bag Filter retrofit in Unit VI is a suitable showcase product for all future trials in India.

9. The order for bag filter retrofit at Koradi was placed on October 1995 and retrofitting work at site started on February 1996. The retrofit job was to be completed within a single boiler shutdown period of 20 weeks (5 months). The bag filter unit was commissioned on September 1997 after a delayed schedule of 14 months. The total boiler outage period was therefore extended to 85 weeks (19 months).

10. Polyacrylamide material bags (8248 Nos.) having 2400 hours of operational life was used in the bag filter. Evaporative water spray system was installed to cool the flue gases to 120^o C, before they enter the filter bags. The system and the bags failed to deliver the guaranteed operational specifications and needed frequent replacements and forced boiler shut downs. During the service period, about 30% of the originally installed polyacrylamide bags have been replaced. The achievable particulate emission limit was reported to be below 150 mg/Nm^3.

11. The bag replacement /damage problem persisted in Koradi, and hence all the 8248 polyacrylamide bags were replaced with costly Ryton (Polypropylene sulphide) bags. The Ryton bags can withstand higher temperature of 180^o C. Total bag replacement was carried out in April 2001 and the bag filter was stabilized in the third week of May when the performance monitoring was carried out. The cost of one Ryton bag is $140 compared to $50 for polyacylamide bags. The achievable emission limit was found to be below 80 mg/Nm^3.

12. The evaporative water spray system has now become redundant for Koradi Unit VI after the installation of Ryton bags. The total order value of bag filter retrofit was Rs.1300 lakhs including the cost of 8248 polyacrylamide bags (Rs.165 lakhs). The polyacrylamide bags did not perform satisfactorily and fully replaced with costly Ryton bags having 20000 hours of service life. The total cost of Ryton bags was Rs.532 lakhs.

CHAPTER - 7

SURVEY ON ESP DESIGN AND PERFORMANCE

In order to obtain relevant technical and financial information about the status of existing electrostatic precipitators in all the operating coal based power stations of the country, a questionnaire was circulated to 76 power stations. The plant wise information are given in **Annexure** A comparison of technical & financial parameters of ESP attached to TPP boilers is given in Tables 7.1-7.3. Based on the information received, following conclusion may be drawn:

1. The comparative statement of technical and financial parameters of ESP attached to less than 200 MW boilers are given in Table 7.1. Ennore I to III Units, each of 60 and 110 MW is reported to achieve particulate emission of 100 mg/Nm^3. ESP attached to boilers in Rajghat, Indraprastha, Badarpur, Bhusawal, Amarkantak, Sabarmati and Sikka thermal power stations are reported to achieve particulate emission limit of 150 mg/Nm^3. Other ESP at Talcher, Bandel, and Tanda have design efficiency of less than 99.5% and the particulate emissions are between 300 to 500 mg/Nm^3.

2. The best ESP in this category, that is, in Ennore TPS has 12 fields, multipulse energisation mode, 99.8% design efficiency with SCA of 180 to 275, gas velocity of 1 m/s and treatment time of 27 s.

3. The poor ESP performance was reported from Bandel Unit I, II and III, each of 80 MW capacity. The ESP have 8 field devoid of any pulse mode energisation, 99.4% design efficiency with SCA of 133, gas velocity of 0.9 and treatment time of 20 seconds. The fly ash resistivity at Bandel TPS was reported as 5×10^{11} ohms/cm, which is slightly higher. The ESP at Talcher Units I to IV, each of 60 MW capacity is reported to perform poorly, though it has 20 fields ESP and designed at 99.5% efficiency. The design parameters seem to be optimum except for SCA, which is quite less at 147, hence the ESP is probably undersized. The fly ash resistivity is also high at 1×10^{12} ohms/cm. The design efficiency of ESP at Tanda Unit I to IV, each of 110 MW is poor at 99.37%, hence the particulate emission is high.

4. The comparative statement of technical and financial parameters of ESP attached to greater than 200 MW but less than 500 MW boilers are given in Table 7.2. Dahanu Units I and II, each of 250 MW and Ramagundam Units I to III, each of 200 MW are reported to achieve particulate emission of 75 mg/Nm^3. ESP attached to boilers in Raichur, Kolaghat (Unit IV to VI), Mettur, Wanakbori (Unit VII), Talcher (Unit V and VI), Dadri, Singrauli and Badarpur thermal power stations are reported to achieve particulate emission limit of 150 mg/Nm^3. Other ESP at Kolaghat (Unit I to III), Bandel (Unit V), Tuticorin (Unit I to III), Wanakbori (Unit I to VI), Bhusawal (Unit I to III), Chandrapur, Koradi, Nasik and Parli TPS have design efficiency of less than 99% and the particulate emissions are between 300 to 750 mg/Nm^3.

5. The best ESP in this category, that is, in Dahanu TPS has 28 fields, semipulse energisation mode, 99.91% design efficiency with SCA of 261, gas velocity of 0.7 m/s and treatment time of 39 seconds. The other best ESP in the second category, that is, in Ramagundam TPS has 20 fields, semipulse energisation mode, 99.85% design efficiency with SCA of 148, gas velocity of 0.8 m/s and treatment time of 22 seconds. Both the ESP have negligible O&M problem. The fly ash resistivity of Dahanu is 10^{10} to10^{12} ohms/cm and Ramagundam is 8 x 10^{12} ohms/cm.

6. The poor ESP performance was reported from Chandrapur Unit I and II, each of 210 MW capacity. The ESP have 6 field multipulse mode energisation, 98.5% design efficiency with SCA of only 73.2., gas velocity of 0.9 and treatment time of 20 seconds. The other ESP at Unit III and IV, each of 210 MW capacity have 20 field multipulse mode energisation, 99.24% design efficiency with SCA of only 142.22, gas velocity of 0.75 and treatment time of 21.33 seconds. The fly ash resistivity at Chandrapur TPS was reported as 8.7 x 10^9 to 2.9 x 10^{12} ohms/cm. Poor performance of ESP at Koradi, Nashik, Parli, Bhusawal (Unit II and III), Kolaghat (Unit IV), Bandel, Tuticorin and Wanakbori is due to fundamental design problem, the design efficiency of all the ESP is below 99% and the SCA and treatment time is lower than what is required for optimum performance.

7. The comparative statement of technical and financial parameters of ESP attached to 500 MW boilers are given in Table 7.3.

8. Ramagundam TPS Unit IV to VI, each of 500 MW has 28 fields, semipulse energisation mode, 99.9% design efficiency with SCA of 222, gas velocity of 0.8 m/s and treatment time of 33 seconds. The other best ESP in the second category, that is, in Chandrapur TPS Unit VII of 500 MW has 32 fields, multipulse energisation mode, 99.88% design efficiency with SCA of 226, gas velocity of 1.0 m/s and treatment time of 21.33 seconds. Both the ESP have negligible O&M problem. The fly ash resistivity of Ramagundam is 8 x 10^{12} ohms/cm and Chandrapur is 2.9 x 10^{10} ohms/cm. The particulate emission limit in both the TPS is 70 mg/Nm^3.

9. The ESP attached to 500 MW boilers at Rihand (Unit I and II) and Singrauli (Unit VI and VII) are designed at 99.5% and 99.6% efficiency to achieve the particulate emission limit of 150 mg/Nm^3. The fundamental design parameters of SCA, gas velocity and treatment time are optimium. In Rihand TPS, the ESP has 24 fields and uses semipulse energisation mode and the SCA is 160, gas velocity is 1.25 and the treatment time is 26 seconds. In Singrauli TPS, the ESP has 28 fileds and uses multipulse energisation mode and the SCA is 165, gas velocity is 1.0 and the treatment time is 25 seconds.

10. The operational, mechanical and fundamental problems of the ESP were obtained and categorised as major, minor or negligible (none), depending on the nature and magnitude of problems stated by the power plants. The problems are also given in the comparative statements (Tables 7.1, 7.2 and 7.3).

11. The ESP capital cost is included in the boiler package and as such separate cost figures of ESP are not available. Most of the power plants were unable to provide real cost estimate of the ESP. The National Thermal Power Corporation Limited, the largest power producer of the country, confirms this statement in writing. The NTPC has provided an indicative cost figure of Rs.13.65 crores for 200 MW boiler ESP and Rs.23.05 crores for 500 MW boiler ESP (2001-02 figure).

12. The operation and maintenance cost (O&M cost) is also not calculated by most of the power plants. This is because electricity consumption, which comprise of the major operation cost, is available free of cost. The cost is mainly due to involvement of manpower and operational spares. The O&M cost of ESP is obtained from only few power stations and the figures are unrealistic and not reliable as evident from huge variations (Tables 7.1, 7.2 and 7.3).

TABLE 7.1 COMPARISON OF TECHNICAL & FINANCIAL PARAMETERS OF ESP ATTACHED TO LESS THAN 200 MW TPP BOILERS

	Name of Unit	**ESP Fields/ Energisation**	**Design efficiency (%)**	**SCA $m^2/m^3/s$**	**Gas velocity (m/s)**	**Treatment time (seconds)**	**Capital cost Rs. Lakhs**	**O&M cost Rs. Lakhs per year**	**SPM Emission (mg/Nm^3)**	**Fly ash resistivity (ohm/cm)**	**Reported problems in ESP**
1	Rajghat TPS; 1 & 2. 67.5 MW	10 Multipulse	99.77	206.4	0.56	31	--	--	150	--	Major
2	Indraprastha TPS – 5, 60 MW	10 + 6 Semipulse	99.9	190.89	0.98	19.85	265 +350 = 615	35	150	--	Major
3	Indraprastha TPS; 2 to 4, 62.5 MW	10 Semipulse	99.81	132.32	0.81	19.85	1080	35	150	--	Minor
4	Badarpur TPS 1, 2 & 3. 95 MW	8 Normal	99.6	151.87	0.80	28.8	--	--	500	7×10^9	None
5	Talcher TPS 1 to 4, 60 MW	20 Normal	99.5	146.8	0.76	22.39	3000	100	400	1×10^{12}	Major
6	Bhusawal TPS 1, 58 MW	8 Multipulse	99.77	142.85	0.54	28.5	2366	--	150	1×10^{12}	None
7	Ennore TPS 1,2 & 3, 60 MW	12 Multipulse	99.8	180	1.00	27	330	127	100	--	None
8	Bandel TPS 1,2 & 3, 80 MW	8 Normal	99.4	132.97	0.90	19.95	80	6	500	5×10^{11}	None
9	Bandel TPS 4, 80 MW	12 Normal	99.4	125.2	0.78	16.72	--	--	300	5×10^{11}	None
10	Amarkantak TPS 3 & 4, 120 MW	8 Normal	99.83	167.7	0.72	25.2	1325	132	150	--	Minor
11	Ennore TPS 4 & 5, 110 MW	12 Multipulse	99.86	275	1.00	27.00	450	1.8	100	--	None
12	Sabarmati TPS D, E & F110 MW	14 Normal	99.77	154.22	0.83	23.00	--	40	150	--	Minor
13	Sikka TPS 1, 120 MW	14 Normal	99.36	159.1	0.94	23.87	--	--	150	--	Minor
14	Sikka TPS 2, 120 MW	12 Normal	99.79	218.3	0.82	33.00	--	--	150	--	Minor
15	Tanda TPS 1 to 4, 110 MW	14 Normal	99.37	159.84	--	28.98	--	--	300	--	Major

TABLE 7.2 COMPARISON OF TECHNICAL & FINANCIAL PARAMETERS OF ESP ATTACHED TO GREATER THAN 200 MW BUT SMALLER THAN 500 MW THERMAL POWER PLANT BOILERS

	Name of Unit	**ESP Fields/ Energisation**	**Design efficiency (%)**	**SCA $m^2/m^3/s$**	**Gas velocity (m/s)**	**Treatment time (seconds)**	**Capital cost Rs. Lakhs**	**O&M cost Rs. Lakhs per year**	**SPM Emission (mg/Nm^3)**	**Fly ash resistivity (ohm/cm)**	**Reported problems in ESP**
1	Raichur TPS 1& 2; 210 MW	12 Normal	99.4	147.32	0.87	22.1	--	--	130	8.7 x 10^9	None
2	Raichur TPS 3 to 6; 210 MW	12 Normal	99.78 99.83	227.53 209.37	0.79 0.86	34.13 31.40	--	--	150 150	8.7 x 10^9	None
3	Raichur TPS 5 & 6	12 Normal	99.82	226.8	0.79	34.18	--	--	150	8.7 x 10^9	None
4	Panipat TPS 5; 210 MW	14 Multipulse	99.82	166.22	--	26.7	--	--	100	--	None
5	Kolaghat TPS 1 to 3, 210 MW	16 Semipulse	98.5	150	1.00	20.00	289	--	750	10^{10}	Major
6	Kolaghat TPS 4, 210 MW	12 Semipulse	99.7	165	0.70	25.70	--	--	150	10^{10}	Major
7	Kolaghat TPS 5 & 6, 210 MW	10 Semipulse	99.7	171.6	0.70	25.7	--	--	150	10^{10}	Major
8	Bandel TPS 5, 210 MW	12 Semipulse	98.0	81.32	1.06	10.19	100	8	500	--	None
9	Tuticorin TPS 1 to 3, 210 MW	20 Normal	98.5	109.44	1.05	13.68	500	2.5	500	--	Major
10	Mettur TPS 1 to 4, 210 MW	24 Semipulse	99.64	143.64	1.00	21.55	370	3.5 t0 7.5	150	--	Major
11	Wanakbori 1 to 3, 210 MW	20 Semipulse	99.23	140.4	--	--	--	40	250	--	Minor
12	Wanakbori 4 to 6, 210 MW	24 Semipulse	99.60	152.2	0.84	19.05	--	40	200	--	Minor
13	Wanakbori 7, 210 MW	28 Semipulse	99.76	380.22	0.55	57.00	--	40	150	--	Minor
14	Dahanu TPS 1 & 2, 250 MW	28 Semipulse	99.91	261.18	0.69	39.00	2366	--	75	10^{10} to 10^{12}	Minor

	Name of Unit	ESP Fields/ Energisation	Design efficiency (%)	SCA $m^2/m^3/s$	Gas velocity (m/s)	Treatment time (seconds)	Capital cost Rs. Lakhs	O&M cost Rs. Lakhs per year	SPM Emission (mg/Nm^3)	Fly ash resistivity (ohm/cm)	Reported problems in ESP
15	Bhusawal TPS 2 & 3, 210 MW	20 Normal	99.0	111.85	1.03	13.98	--	65	300	10^{12}	Major
16	Talcher TPS 5 & 6, 210 MW	14 Semipulse	99.78	175.6	1.15	--	9000	200	150	10^{12}	Major
17	Ramagundam 1 to 3, 200 MW	20 Semipulse	99.85	147.68	0.81	22.15	--	--	70	8×10^{12}	None
18	Dadri TPS 1 to 4, 210 MW	28 Semipulse	99.9	214.48	0.84	32.18	700	5.5	150	10^{9}	None
19	Singrauli TPS 1 to 5, 200 MW	12 Multipulse	99.6	138.52	0.92	17.3	350	15	150	--	Major
20	Badarpur TPS 4 & 5, 210 MW	20 Multipulse	99.0	115.0	0.93	17.24	2000	10	150	7×10^{9}	Minor
21	Budge Budge 1& 2, 250 MW	14 Multipulse	99.86	--	--	12	--	--	100	10^{9} to 10^{10}	None
22	Chandrapur 1 & 2, 210 MW	6 Multipulse	98.5	73.2	--	--	--	--	750	8.7×10^{9}	Major
23	Chandrapur 3 & 4, 210 MW	20 Multipulse	99.24	142.22	0.75	21.33	--	--	350	9.5×10^{9}	Major
24	Chandrapur 5 & 6, 210 MW	24 Multipulse	99.87	167.96	0.90	25.20	--	--	300	2.9×10^{10}	Major
25	Koradi TPS 5, 200 MW	20 Normal	98.5	132.74	1.1	11.33	--	--	381	--	Major
26	Koradi TPS 7, 210 MW	20 --	99	132.74	1.1	16.59	--	--	248	--	Major
27	Nasik TPS 3, 210 MW	24 --	98.5	106.48	--	--	--	--	188	--	--
28	Parli TPS 3 & 4, 210 MW	20 --	98.5 98.9	109.6 114.3	--	--	--	--	421 275	--	--
29	Parli TPS 4, 210 MW	10 --	93.5	133.33	--	--	--	--	265	--	--

TABLE 7.3 COMPARISON OF TECHNICAL & FINANCIAL PARAMETERS OF ESP ATTACHED TO 500 MW TPP BOILERS

	Name of Unit	**ESP Fields/ Energisation**	**Design efficiency (%)**	**SCA $m^2/m^3/s$**	**Gas velocity (m/s)**	**Treatment time (seconds)**	**Capital cost Rs. Lakhs**	**O&M cost Rs. Lakhs per year**	**SPM Emission (mg/Nm^3)**	**Fly ash resistivity (ohm/cm)**	**Reported problems in ESP**
1	Singrauli TPS 6 & 7, 500 MW	28 Mulipulse	99.6	164.57	1.0	25.2	1440	32.3	150	--	Minor
2	Rihand TPS 1 & 2, 500 MW	24 Semipulse	99.5	160.00	1.25	26.00	--	3.9	150	--	None
3	Ramagundam 4 to 6, 500 MW	28 Semipulse	99.9	221.9	0.81	33.33	--	--	70	8×10^{12}	None
4	Chandrapur 5 & 6, 500 MW	24 Multipulse	99.87	167.96	0.90	25.2	--	--	100	8.7×10^{9}	None
5	Chandrapur 7, 500 MW	32 Multipulse	99.88	226.00	1.0	21.33	--	--	70	2.9×10^{10}	None

CHAPTER - 8

COST BENEFIT ANALYSIS

The cost benefit analysis is based on the cost of equipment, erection, auxiliary requirement, operation and maintenance and pay back period, if any. The cost of environmental benefits is also considered. The cost benefit study is done for the following three scenarios:

1. Retrofitting of existing ESP only.
2. Bag filter as a replacement of existing ESP.
3. Bag filter for new units.

8.1 Cost Aspects of ESP

The fly ash collected from the ESP has no commercial value (though it has some utility value) hence there is no pay back period. The installation of ESP in a thermal power plant is mainly due to environmental consideration and to a certain extent it reduces the wear and tear of ID fans. The exact capital cost of ESP is not available because it is generally included in the boiler package. Very few thermal power plants could provide the capital cost of ESP. The cost figures are not reliable. The O&M costs provided by many thermal power plants were highly unrealistic with wide variations. These unrealistic estimates are evident from the following cost figures obtained from various power plants during the field studies and questionnaire survey.

S. No.	Name of the unit	Capacity	Capital cost (Rs. Lakhs)	O & M cost (Rs. Lakhs)
1	Ennore TPS	60 MW	330	127
2	Indraprastha TPS	60 MW	615	35
3	Amarkantak TPS	120 MW	1325	132
4	Ennore TPS	110 MW	450	1.8
5	Badarpur TPS	210 MW	2000	10
6	Dahanu TPS	250 MW	2366	--
7	Dadri TPS	210 MW	700	5.5
8	Singrauli TPS	200 MW	350	15
9	Mettur TPS	210 MW	310	5.5
10	Singrauli TPS	500 MW	1440	32.3
11	Rihand TPS	500 MW	--	3.9

NTPC has provided Rs. 1365 lakhs an indicative figure of capital cost for 200-210 MW boiler ESP. The O&M cost for 200-210 MW unit has been calculated and used in the cost benefit analysis.

O&M Costing

The Operation & Maintenance (O&M) cost in running the ESP is mainly dependent on the following heads:

- Energy cost
- Manpower cost
- Cost of ESP parts and spares
- Interest
- Depreciation
- Return on equity
- Net savings and payback period

The electrical energy required to energize the ESP fields is included in the auxiliary power consumption of the plant. Neither the electricity is metered nor any payment is made towards the energy charges. Therefore, the energy costing is not available in any of the power plant.

There are two ways in which approximate energy charges can be calculated. One method is by using auxiliary power consumption. The auxiliary power consumption in a coal fired thermal power plant is 9% to 9.5% of the total power generated (range depends upon the nature of boiler feed pumps; entirely motor driven or motor + turbine driven). Approximately 10% of the auxiliary power consumption is attributed to ESP operation. Another method is by using actual wattage consumed, that is, Voltage in each field and Ampere current provided. However, both the Voltage and Amperes fluctuates widely and no pattern is available in any of the power plants. Therefore the auxiliary power consumption method has been found to be more reliable to provide a realistic estimate of energy charges.

A 210 MW unit consumes 20 MW as auxiliary power consumption. Out of which 2 MW (2000 KW) is used to operate the ESP. Therefore 2000 KW x 8760 hours will be the kwh (17520000 unit) energy consumption for ESP in a year. The energy cost will be Rs. 350 lakhs per annum @ Rs. 2 per unit electricity cost.

It can be broadly said that nine technical persons in three-shift operation is required to operate the ESP (3 x 3 shift) in a 210 MW TPP. The manpower cost for one technical person is about Rs.3.0 lakhs per person per annum. Therefore, approximately Rs.27.0 lakhs is required as manpower cost for normal power plant.

About 3% of the capital cost is attributed towards the cost of operational spares. Therefore the cost of spares per year for an ESP of 210 MW unit will be Rs.41 lakhs. (3% of Rs.1365 lakhs = Rs.41lakhs)

Several lenders with different lending rates provide finances to establish the power plant. International financial institutions charge 5% to 8% interest rates. Domestic financial institutions charge 8% - 10% interest rate. The current depreciation value of the ESP is estimated at 7.5% of the capital cost. Assuming that the interest rate and depreciation are more or less similar, this component may be taken as compensated towards against each other.

The return on equity of the ESP is considered as nil. Similarly the net savings and pay back period of an ESP is also considered as nil.

8.2 Cost Aspects of Bag Filter

In India, only one unit of 210 MW has retrofitted bag filter in the existing two ESP paths. The other two ESP paths have been retained for use during emergency conditions.

The exact capital cost of a new bag filter (for uses in coal based power plant) is not available. The capital cost of retrofitting bag filter in a 210 MW unit is approximately Rs. 1300 lakhs. The capital cost includes cost of polyacrylamide fibre bags.

O&M Costing

The O&M costing parameters for bag filter is also not available. The retrofit case under consideration at Koradi is still undergoing performance guarantee test. However, the O&M cost for Bag Filter can be approximately estimated based on principles stated above.

Owing to higher pressure drop in Bag Filter compared to ESP (4 times), the energy charges to operate a Bag Filter will be higher. As per earlier estimate, the energy charges for 210 MW unit ESP is Rs.350 lakhs per annum. Therefore, the energy charges for 210 MW unit Bag Filter will be Rs.700 lakhs per annum.

The manpower cost for operating the Bag filter will be similar to ESP at Rs.27.0 lakhs per annum.

The cost of spares per year for a Bag Filter of 210 MW unit will be Rs.39 lakhs. (3% of Rs.1300 lakhs = Rs.39 lakhs). The Ryton bags need to be replaced after every 20000 operating hours, that is, after every 28 months. The cost of 8248 Ryton bags will be about Rs. 550 lakhs. Therefore, Rs. 235 lakhs will be required every year to replace the Ryton bags in a bag filter [1 Ryton bag is US $140].

Similar to ESP, the interest and depreciation cost of Bag Filter will be compensated against each other. Similarly the return on equity, net savings and pay back period of a Bag Filter are also considered as nil.

8.3 Comparison of ESP and Bag Filter

The cost benefit analysis statement for three cases in 210 MW unit, namely, retrofitting of existing ESP with bag filter, bag filter as a replacement of existing ESP and new bag filter is given below. It can be seen from the table that the capital cost of retrofitting bag filter in existing ESP is more or less comparable with the cost of new ESP. Capital cost of bag filter as replacement of existing ESP is also comparable with new ESP, because only some of the civil foundations, metal casings and electrical fittings can be reused. Capital cost of new bag filter is approximately 25% higher than the capital cost of new ESP.

The O&M of bag filter is prohibitively high because of higher energy consumption and need for periodic replacement of costly Ryton bags.

Retrofitting Bag Filter in existing ESP can derive no significant environmental benefits. It can only be derived if new Bag Filter, or bag filter as replacement of new ESP, designed for achieving 50 mg/Nm^3 particulate matter emission limit, are installed.

Comparative Statement of Three Scenarios vis-à-vis ESP (all values in lakhs Rs.)

S. No.	Parameters	ESP	Bag Filter Retrofit in ESP	Bag Filter as replacement of existing ESP*	New Bag Filter*
1	Capital cost	1365	1300	1430	1625
2	Energy charges	350	700	700	700
3	Manpower charges	27	27	27	27
4	Operational spares	41	39 + 235 (for filter bag replacement)	43 + 235 (for filter bag replacement)	49 + 235 (for filter bag replacement)
5	Interest, depreciation, return on equity, pay back period	Nil	Nil	Nil	Nil
6	Environment benefits	Can achieve upto 75 mg/Nm^3	Can achieve upto 75 mg/Nm^3	Can achieve upto 50 mg/Nm^3	Can achieve upto 50 mg/Nm^3
7	Outlet particle size (less than 10 μ)	35% - 40%	34%	34%	34%

Note :

* Expected values (based on communication with power plant operators and designers)

8.4 Evaluation of Alternate Scenarios

Based on the contents of earlier chapters and above experience, the following three scenarios has been evaluated.

Retrofitting of existing ESP only – This scenario is not very encouraging given the experience at only one power plant in India, where the bag filter has been retrofitted in the existing ESP. The capital investment of retrofitting a bag filter is similar to installing a new ESP. Moreover the operation and maintenance expenses are very high for bag filters. The boiler is required shut down for several months, so that retrofitting work can be completed. Several components of the existing ESP become redundant and sold at scrap value. The following major work is envisaged during the retrofitting schedule.

- Removal of entire roof of ESP, plates, wires, rectifiers and electrical controls
- Addition of internal pulse jet component
- Addition compressed air cleaning system and gas conditioning system
- Addition of access platforms, ladders, doors and bafflings
- Addition of cleaning system components and cleaning controls
- Addition of filters and cages
- Replacement of ID fans

In fact, during the retrofitting work, only the existing space, civil foundations and ESP outer cages are utilised. Remaining everything is to be replaced, which are sold at scrap value. After retrofitting work, huge O&M expenses are incurred due to frequent bag replacement. Increased and skilled supervision of all controls is also required to maintain the design performance of bag filter.

Bag Filter as a replacement of existing ESP – New generation ESP is capable of achieving similar particulate emission limits as that of bag filter. Hence replacement of existing ESP that are performing poorly with bag filter has no rational justification. Existing ESP can be replaced with new ESP to save on the O&M cost and reliability.

In one similar case of Indraprastha Power Station Unit V (60 MW), located in the heart of New Delhi, the existing ESP was performing very poorly (particulate emission around 750 mg/Nm^3). There were 10 fields (5 series, 2 paths) in the ESP and the SCA was 132.32. The cost of the ESP was Rs. 265 lakhs (1985 price). The boiler could not be shut down for long periods and the space available in the plant was very less. It was decided to increase the ESP fields to 16 by adding 6 fields and thereby increasing the SCA to 190.88. In 1994, the job was awarded to ABB for an estimated price of Rs.350 lakhs. The job was completed and ESP was stabilised in April 2001. Monitoring of the ESP was conducted during the in-depth study and the SPM emission result obtained is 89 mg/Nm^3.(at operating load of 26 MW, ie., 46% of rated load) The performance guarantee was for 100 mg/Nm^3. This case illustrates that retrofitting poor ESP with additional ESP series fields can improve the efficiency to achieve the stipulated emission limit in a cost-effective manner.

Bag Filter for New Units – No new bag filter has been installed in any of the coal-based power plant of the country. The World Bank has dictated universal particulate emission limit of 50 mg/Nm^3 in its new series of environmental guidelines, without considering the local meteorological and site conditions and cost-benefit analysis. The emission limit of World Bank is probably more oriented towards catering to USA market of bag filter manufacturers. The World Bank Group is a major lending agency for new power plant developers. Incidentally, other European and Japanese lenders are not insisting on 50 mg/Nm^3 particulate emission limits. In the present economic scenario of the country, the World Bank emission limit is of little relevance because almost all of the USA funded coal based private power projects have failed to achieved financial closure.

Indian power plants have tall stacks of order of 220 m and 275 m, the construction cost of which is of the order of Rs.1200 lakhs and Rs.1400 lakhs respectively. This investment, which is almost equal to that of an ESP, is essential to take care of dispersion of SO_2 and NOx emissions and cannot be dispensed with as of now. Indian environmental legislation has prescribed minimal national standard of 150 mg/Nm^3 for SPM emissions from coal based power plants. The State regulatory authorities prescribe stringent particulate emission standard, if the situation demands so, and so far have prescribed stringent limit up to 75 mg/Nm^3 (Maharastra). In view of above, the requirement of 50 mg/Nm^3 particulate matter has to be rationally justified for Indian conditions, before it is stipulated for implementation.

Having designed ESPs that are capable of achieving 75 mg/Nm^3, Indian ESP manufacturers are prepared to design ESP that are capable of achieving 50 mg/Nm^3. In this scenario, it is prudent that the choice of installing bag filters or ESP for new coal based power plant should be left to the power plant developers.

CHAPTER - 9

CONCLUSION AND RECOMMENDATIONS

9.1 Conclusion

Based on the field studies, questionnaire survey and literature referred, the comparison between ESP and Bag Filter technology for controlling fly ash emissions is given below:

S. No.	Parameters	ESP	Bag Filter
1	Philosophy	Designed to achieve the set efficiency, hence depends on consistent coal quality and boiler load	Designed for constant emission output irrespective of the frequent changes in coal quality and boiler load
2	Sensitivity	Not so sensitive to temperature, composition of flue gases and dust particles.	Extremely sensitive to higher temperature, SO_3, oil carry over, water vapour, chemical composition of dust and flue gases, abrasion, erosion
3	Fly ash resistivity	Performance is sensitive to fly ash resistivity. At resistivity higher than 10^{11}, the efficiency drops significantly.	Performance not sensitive to fly ash resistivity. The efficiency is good at higher resistivity of 10^{11} and 10^{12}.
4	Removal Efficiency	Can remove particles of micron and sub-micron range.	Can remove particles of micron and sub-micron range.
5	SPM emission limit achieved	As low as 75 mg/Nm^3	As low as 75 mg/Nm^3
6	SPM emission limit further achievable	As low as 50 mg/Nm^3	As low as 50 mg/Nm^3
7	Pressure drop across the system	Low pressure drop of the order of 1 inch WC	High pressure drop of the order of 4 to 8 inches WC
8	Energy consumption	Relatively lower	Extremely higher
9	Cleaning mechanism	Mechanical Rappers	Compressed air, hence air compressor required
10	Flue gas conditioning	Not required	Separate conditioning device required like evaporative water spray system

S. No.	Parameters	ESP	Bag Filter
11	Emergency situations	Performs reasonably during start-up, shut down and low load conditions, when heavy oil support is required in the boiler	Is not effective during start-up, shut down and low load conditions when heavy oil support is required in the boiler. Additional ESP is required to take care of such emergency situations.
12	Capital and O&M cost	Capital cost of ESP and Bag Filter are similar but ESP has lower O&M cost	Bag filter has relatively higher O&M cost because the entire bags are replaced periodically.
13	Construction	Simple construction with indigenous materials like steel plates and wires	Complex construction with imported materials like fabric bags
14	Operation	Simple operation, met with the existing power plant operators	Complex operation, requires high quality supervision
15	Maintenance	Easy maintenance, maintenance cost is also lower than bag filter	Difficult maintenance schedules, maintenance cost is extremely high due to frequent replacement of costly imported bags.
16	Technology availability	Time tested technology by Indian manufacturers and equipment suppliers. A number of Indian companies are manufacturing ESP.	Technology not proven in power plants with huge volume of gas laden with dust, Imported equipment and foreign suppliers.
17	After Sales Service	Indigenous	To depend upon foreign manufacturers
18	Experience	Wide experience	Limited experienced at only one power plant, that too ridden with problems, right from the commissioning stage
19	Environmental benefits	The environmental benefits achieved through ESP and Bag filter are similar in magnitude because both ESP and Bag filter technology can achieve the particulate emission limit of 75 mg/Nm^3.	No additional environmental benefits compared to ESP. No proven reduction in outlet dust particles of size less than 10μ.

Based on the project findings, the following conclusions are drawn.

1. ESP technology for control of particulate emission from coal-fired boilers is well established and the Indian ESP manufacturers have succeeded in achieving emission limit of 75 mg/Nm^3. The O&M staff of Indian thermal power plants are experienced with the technology and have satisfactory job knowledge on the subject. The ESP equipment is indigenous and does not depend on spares and parts of foreign origin. The capital cost of ESP is acceptable to the users. The O&M cost are quite low because the energy component is included as auxiliary power consumption. Most of the new generation ESP attached to power plants has pulse mode energisation, adequate specific surface area and treatment time and are therefore, complying to MINAS.

2. ESP attached to older power plants, mostly below 210 MW capacity, are not achieving MINAS due to lower design efficiency and low specific surface area and treatment time exposure. Most of the older ESP does not have pulse energisation. Increase in the number of series fields will provide adequate SCA and treatment exposure and expected to improve the performance. 60 MW capacity Unit V of Indraprastha Power Station has increased its SCA from 132.32 to 190.89 by adding 6 fields. The capital cost increased by Rs. 615 lakhs due to this modification. The modified ESP is achieving MINAS of 150 mg/Nm^3. Other non-performers can emulate such example and comply with MINAS.

3. Five different capacity units of power stations were monitored for ESP performance study. The operators were given sufficient time to optimise the design parameters. Four ESP attached to Unit II 67.5 MW – Rajghat TPS, Unit V-60 MW Indraprastha TPS, Unit V-210 MW Badarpur TPS and Unit VII-500 MW Chandrapur TPS performed as per the designed efficiency. ESP attached to Unit II-250 MW Budge Budge TPS did not performed as per the designed efficiency probably due to four non-functional fields.

4. The questionnaire survey revealed that most of the new generation ESP complied with MINAS. New ESP (post 1988) attached to TPS at Raichur, Panipat, Kolaghat, Mettur, Wanakbori, Dahanu, Talcher, Badarpur, Bhusawal, Ennore, Amarkantak, Sabarmati, Ramagundam, Dadri, Singrauli, Chandrapur, Rihand, Sikka, Rajghat and Indraprastha are reported to comply with MINAS. Old ESP (pre 1988) attached to Tanda, Bandel, Tuticorin, Koradi, Nashik, Parli, Talcher, Kolaghat, Wanakbori, Bhusawal and Chandrapur did not comply with MINAS.

5. The reasons for poor performance of ESP were identified and almost all of them reported high resistivity fly ash as the fundamental reason for non.performance. Other major reasons cited are poor gas flow, overloaded by excessive gas flow and dust concentration, distorted electrodes, process upsets and re-entrainment.

6. Experience have shown that high fly ash resistivity is one of the most pervasive reason for poor performance of ESP. The reasons are fundamental and must be dealt with by logical scientific procedures. ESP manufacturers and users must not ignore rudimentary fundaments. Both theory and practice proves that ESP design should be coordinated with fly ash resistivity in order to obtain the expected efficiency in new plants. In old plants suspected of having resistivity problem, in-situ resistivity measurements should be done along with through system analysis of overall process and raw materials.

7. Methods for overcoming or coping with high resistivity problem in ESP includes time tested methods like flue gas conditioning, correcting gas flow, increasing series fields and SCA and improving electrical energisation.

8. Technical details of bag filter installed in MSEB-Koradi Unit VI of 210 MW capacity has been thoroughly studied. The bag filter performance was monitored and found to achieve the designed efficiency of 80 mg/Nm^3.

9. The order for Koradi bag filter retrofit was placed on October 1995 and retrofit job was completed with a boiler outage of 85 weeks. The bag filter was commissioned in September 1997. The bags were made of polyacrylamide (Dralon) having 2400 service hours and capable of withstanding temperature of 120^0 C. Evaporative water spray system was installed for gas conditioning and air compressors for pulse jet cleaning. The bag filter was retrofitted in two ESP paths. The total capital investment was Rs.1300 lakhs (1994 price). The bags gave consistent problem and got damaged. In the total service hours available, 30% of the bags (out of total 8248 bags) needed replacement. The cost of one imported polyacrylamide bag is $50. After three years, all the polyacrylamide bags were replaced with costlier Ryton bags (polypropylene sulphide) capable of withstanding temperature of 180^0 C. The cost of one Ryton bag is $ 140 and the service life is 20,000 operating hours. The use of Ryton bags made the use of evaporative water spray system redundant. The performance of Ryton bags is yet to be verified.

10. Prima facie, it appears that bag filter has no distinct advantage over ESP. Bag filter is highly sensitive to high temperature, chemical attack, oil carry-over, flame carry-over, erosion and abrasion to which ESP is tolerant. ESP is sensitive to low and high fly ash resistivity to which bag filter is tolerant.

11. The capital cost of ESP and Bag Filter is comparable. The pressure drop across bag filter is 3 to 4 times that of ESP and therefore, bag filter consumes more energy than ESP. Unlike ESP, bag filter requires gas conditioning system, air compressor system and frequent replacement of

fabric bags. This makes the O&M cost extremely high and in the prohibitive range.

12. Under Indian conditions bag filter as a stand-alone pollution control device does not serve the purpose. During heavy oil support firing during shut-down, start-up and low load period, bag filter cannot be used. The flue gases are then diverted to the ESP to meet the emission norms. Therefore bag filter in a coal fired boiler needs to be supported by a stand-by ESP.

13. The overall environmental benefits obtained from ESP and bag filter are more or less comparable and prima facie bag filter does not have any additional advantage over ESP in terms of environmental benefits.

9.2 Recommendations

1. **Retrofitting of existing ESP with Bag Filter** – May not recommended because there are other cost-effective and reliable methods to improve the performance of existing ESP.

2. **Bag Filter as Replacement to Existing ESP** – May not recommended because the existing ESP parts will become redundant and sold at scrap value. The option is not cost-economic.

3. **Bag Filters for New Units** –Selection of use of bag filters or ESP in new power plants is left to the discretion of project developers. Both technologies are comparable and capable to meet the desired objectives.

ANNEXURE

Detailed information of various Thermal Power Plants in India

Raichur Thermal Power Station, KPCL, Raichur, Karnataka

Capacity	Stack Height	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit I & II 210 MW	2 stacks of 135 m	Yes	30	130	99.4%	No major problems in ESP except minor operational problems
Unit III to VI 210 MW	4 stacks of 220 m	Yes	67.5 (III) 88.4	130 (III) 150	99.78 (III) 99.83	
Total – 1260 MW	6 stacks					

ESP Design (Unit I & II)

1. Electrode arrangement – spiral with hooks of 2.7 mm dia
2. Electric power supply – Multipulse energisation
3. Number of series field – Two paths, 6 series
4. Specific collection area – 147.32 m^2/m^3/s
5. Gas velocity inside ESP– 0.87 m/s
6. Plate configuration – 39 rows per field, 8 plates in each row
7. Aspect Ratio – 2.13
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 22.1 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – 69
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- 8.7 x 10^9 ohm-cm

12. Collecting electrode spacing (mm)- 300 mm

13. Electrode Rapping - Mechanical hammer rappers

14. Corona electrode rapping mechanism- Available

15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Screen sheets at ESP inlet

ESP Design (Unit III & VI)

1. Electrode arrangement – spiral with hooks of 2.7 mm dia

2. Electric power supply – Multipulse energisation

3. Number of series field – Two paths, 6 series

4. Specific collection area – 209.37 to 227.53 $m^2/m^3/s$

5. Gas velocity inside ESP– 0.79 to 0.86 m/s

6. Plate configuration – 61 rows per field, 6 plates per row, plates 0.75 m length and 12.5 m height

7. Aspect Ratio – 2.16

8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 34.13 seconds

9. High tension sections (per $1000m^3$ of gas flow rate) – 67.4

10. Migration velocity of particles (designed)- Not known

11. Resistivity of Particles- Not known

12. Collecting electrode spacing (mm)- 300 mm

13. Electrode Rapping - Mechanical hammer rappers

14. Corona electrode rapping mechanism- Available

15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP- Screen sheets at ESP inlet

Most probable reasons stated for under performance of ESP

Fundamental problems	**Mechanical problems**	**Operational problems**
➢ None	➢ Excessive dust deposition on collecting electrodes and corona electrodes (sometimes)	➢ Full or overflow hoppers sometimes encountered ➢ Shorted corona sections (sometimes)

Costing Figures – Not available

Panipat Thermal Power Station, HPGCL, Panipat, Haryana

Capacity	**Stack Height**	**ESP**	**Inlet dust conc. (g/Nm^3)**	**Outlet dust conc. (mg/Nm^3)**	**Design efficiency**	**Fundamental problems**
Unit I to IV 110 MW	2 stacks	Yes	Not known	Not known	--	No problems in ESP
Unit V 210 MW	1 stacks	Yes	44.7	100	99.82	
Total – 650 MW	3 stacks					

ESP Design (Unit V)

1. Electrode arrangement – Not known
2. Electric power supply – Multipulse energisation
3. Number of series field – Two paths, 7 series
4. Specific collection area – 166.22 $m^2/m^3/s$
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – Not known
6. Plate configuration – not known
7. Aspect Ratio – 3.87
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 26.7 seconds
9. High tension sections (per $1000m^3$ of gas flow rate) – not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- not known
12. Collecting electrode spacing (mm)- 300 mm
13. Electrode Rapping - Mechanical hammer rappers
14. Corona electrode rapping mechanism- Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Screen sheets at ESP inlet

Most probable reasons stated for under performance of ESP

Fundamental problems	Mechanical problems	Operational problems
➢ None	➢ None	➢ None

Coal characteristics

Total moisture	Ash	Volatile matter	Fixed carbon	Sulphur	GCV Kcal/kg
6.9%	38.5%	19.1%	35.48%	0.3%	4155

Fly ash characteristics

Unburnt carbon	Silica	Total oxides	Aluminum oxide	Sodium oxide	Sulphur trioxide	Calcium oxide	Potassium oxide
4.7%	58%	85.5%	-	--	--	--	--

Costing Figures – Not available
O&M cost – Rs.6 lakhs per annum for 210 MW ESP.

Amarkantak Thermal Power Station, MPEB, Shahdol, MP

Capacity	Stack Height	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit III & IV 120 MW	1 stack of 120 m	Yes	90	150	99.83%	Insufficient or unstable rectifier equipment
Total – 290 MW	Unit I is 30 MW and Unit II is 20 MW					

ESP Design (Unit III & IV)

1. Electrode arrangement – Not known
2. Electric power supply – Not known
3. Number of series field – Two paths, 4 series
4. Specific collection area – 167.7 $m^2/m^3/s$
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.715 m/s
6. Plate configuration – Total plates is 2160, height 13.5m & length 750 mm
7. Aspect Ratio – 0.055
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 25.2 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- not known
12. Collecting electrode spacing (mm)- 300 mm
13. Electrode Rapping – Tumbling hammers mounted on horizontal shaft. One drop hammer per row of collecting electrode.
14. Corona electrode rapping mechanism- Not Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Guide vanes, splitters and screens are provided at the ESP inlet.

Most probable reasons stated for under performance of ESP

Fundamental problems	**Mechanical problems**	**Operational problems**
➢ Insufficient or unstable rectifier equipment	➢ Poor electrode alignment ➢ Vibrating or swinging corona wires ➢ Distorted collecting plates ➢ Excessive dust deposition on electrodes	➢ Shorted corona sections

Coal characteristics

Total moisture	**Ash**	**Volatile matter**	**Fixed carbon**	**Sulphur**	**GCV Kcal/kg**
7.2%	26.1%	--	--	0.8%	4749

Fly ash characteristics

Unburnt carbon	**Silica**	**Iron oxide**	**Aluminum oxide**	**Sodium oxide**	**Sulphate**	**Calcium oxide**	**Potass-ium Oxide**
--	67.3%	10.9%	16.0%	1.98%	0.1%	2.7%	Nil

Costing Figures – Rs. 13.25 crores
O&M cost – Rs.13.2 lakhs per annum for 120 MW ESP (Unit III & IV).

Kolaghat Thermal Power Station, WBPDCL, Kolaghat, WB

Capacity	**Stack Height**	**ESP**	**Inlet dust conc. (g/Nm^3)**	**Outlet dust conc. (mg/Nm^3)**	**Design efficiency**	**Fundamental problems**
Unit I to III 210 MW	3 stacks of 120 m	Yes	50.6	750	98.5%	The ESPs have all the problems stated in the questionnaire
Unit IV to VI 210 MW	3 stacks of 220 m	Yes	50.6	150	99.7%	
Total – 1260 MW	6 stacks					

ESP Design (Unit I to III)

1. Electrode arrangement – In between collecting plates
2. Electric power supply – semipulse ergergisation
3. Number of series field – 8 series
4. Specific collection area – 150 $m^2/m^3/s$
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 1.0 m/s
6. Plate configuration –height 24 ft. & length 9 feet
7. Aspect Ratio – 1.1 to 1.4
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 20.0 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- 10^4 to 10^{10} ohm-cm
12. Collecting electrode spacing (mm)- 300 mm
13. Electrode Rapping – Magnetic impulse rappers

14. Corona electrode rapping mechanism- Not Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Not known

ESP Design (Unit I to III)

1. Electrode arrangement – In between collecting plates
2. Electric power supply – semipulse ergergisation
3. Number of series field – 8 series
4. Specific collection area – 150 $m^2/m^3/s$
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 1.0 m/s
6. Plate configuration –height 24 ft. & length 9 feet
7. Aspect Ratio – 1.1 to 1.4
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 20.0 seconds
9. High tension sections (per $1000m^3$ of gas flow rate) – not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- 10^4 to 10^{10} ohm-cm
12. Collecting electrode spacing (mm)- 300 mm
13. Electrode Rapping – Magnetic impulse rappers
14. Corona electrode rapping mechanism- Not Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Not known

ESP Design (Unit IV)

1. Electrode arrangement – In between collecting plates
2. Electric power supply – semipulse ergergisation
3. Number of series field – 6 series
4. Specific collection area – 165 $m^2/m^3/s$
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.7 m/s
6. Plate configuration –height 12 m & length 4.8 m
7. Aspect Ratio – 1.1 to 1.4
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 25.7 seconds

9. High tension sections (per 1000m^3 of gas flow rate) – not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- 10^4 to 10^{10} ohm-cm
12. Collecting electrode spacing (mm)- 300 mm
13. Electrode Rapping – Mechanical hammer
14. Corona electrode rapping mechanism- Not Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Not known

ESP Design (Unit V & VI)

1. Electrode arrangement – In between collecting plates

2. Electric power supply – semipulse ergergisation

3. Number of series field – 5 series

4. Specific collection area – 171.6 m^2/m^3/s

5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.7 m/s

6. Plate configuration –height 12.5 m, length 3.6 m

7. Aspect Ratio – 1.1 to 1.4

8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 25.7 seconds

9. High tension sections (per 1000m^3 of gas flow rate) – not known

10. Migration velocity of particles (designed)- Not known

11. Resistivity of Particles- 10^4 to 10^{10} ohm-cm

12. Collecting electrode spacing (mm)- 300 mm

13. Electrode Rapping – Mechanical hammer

14. Corona electrode rapping mechanism- Not Available

Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Not known

Most probable reasons stated for under performance of ESP

Fundamental problems	**Mechanical problems**	**Operational problems**
➢ All problems stated in the questionnaire	➢ All problems stated in the questionnaire	➢ All problems stated in the questionnaire

Coal characteristics

Total moisture	**Ash**	**Volatile matter**	**Fixed carbon**	**Sulphur**	**GCV Kcal/kg**
8.2%	46.4%	20.6%	26.6%	--	3261

Fly ash characteristics

Unburnt carbon	**Silica**	**Iron oxide**	**Aluminum oxide**	**Sodium oxide**	**Sulphur**	**Calcium oxide**	**Potassium Oxide**
1%	61.9 %	2.9%	31%	1.02%	40 mg/kg	0.3%	0.8

Costing Figures – Rs. 2.89 crores for units I, II and III

O&M cost – Not available

ESP cost for Units IV, V and VI are not available.

Bandel Thermal Power Station, WBSEB, Tribeni, WB

Capacity	Stack Height	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit I to IV 80 MW	4 stacks of 60 m	Yes	25	300	99.4%	The ESPs have none of the problems stated in the questionnaire
Unit V 210 MW	1 stack of 120 m	Yes	51	500	98%	
Total – 530 MW	5 stacks					

ESP Design (Unit I to III)

1. Electrode arrangement – 6 plates are arranged in each row per field for collecting electrode. 54 Spiral electrodes with hooks in the frame forming one row for emitting electrode.
2. Electric power supply – Microprocessor based
3. Number of series field – 4 series
4. Specific collection area – 132.97 $m^2/m^3/s$
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.903 m/s
6. Plate configuration – corrugated plate type
7. Aspect Ratio – 1.07
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 19.95 seconds
9. High tension sections (per $1000m^3$ of gas flow rate) – 0.1516
10. Migration velocity of particles (designed)- 4.09 cm/s
11. Resistivity of Particles- 5×10^{11} ohm-cm
12. Collecting electrode spacing (mm)- 300 mm
13. Electrode Rapping – Maechanical hammer rappers

14. Corona electrode rapping mechanism- Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Perforated gas distribution screens with rapping, flow splitters, baffles provided based on flow model study.

ESP Design (Unit IV)

1. Electrode arrangement – Flat plate type collecting electrode and Mast type emitting electrode
2. Electric power supply – semipulse ergergisation
3. Number of series field – 6 series
4. Specific collection area – 125.20 $m^2/m^3/s$
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.78 m/s
6. Plate configuration – Rigid flat plate, 12.2 m height, 2.2 m length, 2mm thick
7. Aspect Ratio – 1.08
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 16.92 seconds
9. High tension sections (per $1000m^3$ of gas flow rate) – 0.72
10. Migration velocity of particles (designed)- 4.09 cm/s
11. Resistivity of Particles- 5×10^{11} ohm-cm
12. Collecting electrode spacing (mm)- 270 mm
13. Electrode Rapping – mechanical hammer rappers
14. Corona electrode rapping mechanism- Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Perforated gas distribution screens with rapping, flow splitters, baffles provided based on flow model study.

ESP Design (Unit V)

1. Electrode arrangement – 9 collecting plates in each row, 33 rows per field. 36 spiral emitting electrode in one row, 2.5 mm dia. and 1152 electrodes per field
2. Electric power supply – semipulse ergergisation
3. Number of series field – 4 path 3 series per path
4. Specific collection area – 81.32 $m^2/m^3/s$
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 1.06 m/s
6. Plate configuration – Corrugated plate
7. Aspect Ratio – 1.95
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 10.19 seconds
9. High tension sections (per $1000m^3$ of gas flow rate) – 0.0098
10. Migration velocity of particles (designed)- 4.09 cm/s
11. Resistivity of Particles- 5×10^{11} ohm-cm

12. Collecting electrode spacing (mm)- 85 to 150 mm
13. Electrode Rapping – mechanical hammer rappers
14. Corona electrode rapping mechanism- Not Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Gas flow distributor and deflector for symmetrical and uniform flow. 2 set of perforated plates at ESP inlet.

Most probable reasons stated for under performance of ESP – No problem

Coal characteristics

Total moisture	**Ash**	**Volatile matter**	**Fixed carbon**	**Sulphur**	**GCV Kcal/kg**
5.8%	32.09%	25.6%	36.6%	0.5	4669

Fly ash characteristics

Unburnt carbon	**Silica**	**Iron oxide**	**Aluminum oxide**	**Sodium and potassium oxide**	**Sulphate**	**Calcium oxide**
2.2%	60%	7.8%	21.7%	4.2%	0.35%	2.78%

Costing Figures – Rs. 0.8 crores for units I, II, III & IV

O&M cost – Rs.6 lakhs per annum for each ESP

Costing Figures – Rs. 1.0 crore for unit V.

O&M cost – Rs.8 lakhs per annum for ESP

Questionnaire No.6

Tuticorin Thermal Power Station, TNEB, Tuticorin, TN

Capacity	Stack Height	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit I to III 210 MW	2 stacks of 122 m	Yes	33	500	98.5%	High resistivity particles, poor gas flow, re-entrainment of collected particles, inadequate rapping
Unit IV to V 210 MW	Information not provided					
Total – 1050 MW						

ESP Design (Unit I to III)

1. Electrode arrangement – Row type
2. Electric power supply – Intermittent charging
3. Number of series field – 5 series, 4 path
4. Specific collection area – 109.44 m^2/m^3/s (110.7 for Unit III)
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 1.053 m/s (0.775 for Unit III)
6. Plate configuration – Vertical plate
7. Aspect Ratio – 1.0 to 1.5
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 13.68 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – Not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- 10^{15} ohm-cm
12. Collecting electrode spacing (mm)- 250 mm
13. Electrode Rapping – Maechanical hammer rappers
14. Corona electrode rapping mechanism- Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Not known

Most probable reasons stated for under performance of ESP

Fundamental problems	Mechanical problems	Operational problems
➢ High resistivity particles ➢ Re-entrainment of	➢ Poor electrode alignment ➢ Vibrating or swinging	➢ Full or overflow hoppers ➢ Shorted corona sections

Fundamental problems	**Mechanical problems**	**Operational problems**
collected particles - Poor gas flow - Inadequate rapping	corona wires - Distorted collecting plates - Excessive dust deposition on electrodes - Air leakage from hoppers, shells or ducts	- ESP overloaded due to excessive gas flow - ESP overloaded by excessive dust concentration - Process upsets (poor combustion, steam leaks, etc.)

Coal characteristics

Total moisture	**Ash**	**Volatile matter**	**Fixed carbon**	**Sulphur**	**GCV Kcal/kg**
6.17%	42%	20.68%	31.1%	0.4%	3550

Fly ash characteristics

Unburnt carbon	**Silica**	**Iron oxide**	**Aluminum oxide**	**Sodium oxide**	**SO_3**	**Calcium oxide**	**Potassium Oxide**
--	55.8%	4.82%	30.55%	0.64%	0.26%	1.45%	1.9%

Costing Figures – Not known

O&M cost – Rs.2.5 lakhs per annum for each ESP.

Questionnaire No.7

Mettur Thermal Power Station, TNEB, Mettur Dam, TN

Capacity	Stack Height	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit I to IV 210 MW	1 stack of 130m & 1 stack of 220 m	Yes	42.5	150	99.64%	High resistivity particles, gas velocity too high
Total – 840 MW						

ESP Design (Unit I to IV)

1. Electrode arrangement – Spiral with hook 2.7 mm dia, vertically parallel arrangement
2. Electric power supply – Semi-pulse energisation
3. Number of series field – 6 series, 4 pass
4. Specific collection area – 143.64 m^2/m^3/s
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 1.0 m/s
6. Plate configuration – 12.5 m height, 400 mm length
7. Aspect Ratio – 16815.6 to 12.5
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 21.55 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – Not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- Not known
12. Collecting electrode spacing (mm)- 150 mm
13. Electrode Rapping – Maechanical hammer rappers
14. Corona electrode rapping mechanism- Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Not known

Most probable reasons stated for under performance of ESP

Fundamental problems	Mechanical problems	Operational problems
➢ High resistivity particles ➢ Ghas velocity too high	➢ Vibrating or swinging corona wires ➢ Distorted collecting plates ➢ Excessive dust deposition on electrodes ➢ Air leakage from hoppers, shells or ducts	➢ Shorted corona sections ➢ ESP overloaded due to excessive gas flow ➢ ESP overloaded by excessive dust concentration

Coal characteristics

Total moisture	**Ash**	**Volatile matter**	**Fixed carbon**	**Sulphur**	**GCV** **Kcal/kg**
10.8%	46.4%	22.3%	27.18%	0.6%	3580

Fly ash characteristics

Unburnt carbon	**Silica**	**Iron oxide**	**Aluminum oxide**	**Sodium oxide**	**SO_3**	**Calcium oxide**	**Potassium** **Oxide**
0.6%	52.9%	6.48%	25.94%	--	0.68%	1.96%	--

Costing Figures – Rs.3 Crores (Unit I and II) Rs.3.7 Crores (Unit III and IV)

O&M cost – Rs.3.5 lakhs per annum for Unit I and IV, Rs. 7.5 Lakhs per annum for Unit II and III).

Questionnaire No.8

Ennore Thermal Power Station, TNEB, Ennore, TN

Capacity	Stack Height	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit I & II 60 MW	1 stack of 80 m	Yes	70	100	99.86%	High resistivity particles
Unit III to V 110 MW	2 stacks of 80 m	Yes				
Total – 450 MW	Particle resistivity not known					

ESP Design (Unit I to V)

1. Electrode arrangement – 1.6 mm cold rolled MS plate and shaped in one piece by roll forming
2. Electric power supply – Multipulse energisation
3. Number of series field – 6 series, 2 path
4. Specific collection area – 180 m^2/m^3/s (275 for Unit III, IV and V)
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 1.0 m/s
6. Plate configuration – Shaped in one piece by roll forming
7. Aspect Ratio – 37.75m to 15 m (Unit I and II) 37.5 m to 15.8 m (Unit III, IV and V)
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 27 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – Not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- Not known
12. Collecting electrode spacing (mm)- 300 mm
13. Electrode Rapping – Maechanical hammer rappers
14. Corona electrode rapping mechanism- Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Uniform

Most probable reasons stated for under performance of ESP

Fundamental problems	Mechanical problems	Operational problems
➢ High resistivity particles	➢ None	➢ None

Coal characteristics

Total moisture	Ash	Volatile matter	Fixed carbon	Sulphur	GCV Kcal/kg
9.5%	45.6%	20.6%	26.7%	0.5%	3376

Fly ash characteristics

Unburnt carbon	Silica	Iron oxide	Aluminum oxide	Sodium oxide	SO_3	Calcium oxide	Potassium Oxide
--	57.9%	2.69%	33.54%	0.46%	0.13%	0.65%	0.87%

Costing Figures – Rs. 3.3 Crores for Unit I and II, Rs.4.5 Crores for Unit III, IV and V

O&M cost – Rs.1.27 lakhs per annum for Unit I and II, Rs. 1.77 lakhs per annum for Unit III, IV and V

Questionnaire No.9

Sabarmati Thermal Power Station, AEC, Ahmedabad, Gujarat

Capacity	Stack Height	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit D, E and F 110 MW	3 stacks of 90 m	Yes	18-19	150	99.4%	High resistivity particles
Unit C 60 MW	1 stack of 90 m	Yes	13	100	99.77%	
Total – 390 MW	Resistivity of particles not known					

ESP Design (Unit D)

1. Electrode arrangement – 45 rows per field
2. Electric power supply – Variable charging pulse energiser
3. Number of series field – 4 series, 2 path
4. Specific collection area – 124.76 m^2/m^3/s
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.923 m/s
6. Plate configuration – plates of 9 m height, 400 mm width
7. Aspect Ratio – Not known
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 15.6 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – 658188 cu.m/hour
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- Not known
12. Collecting electrode spacing (mm)- 250 mm

13. Electrode Rapping – Maechanical hammer rappers

14. Corona electrode rapping mechanism- Available

15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Perforated plates, 2 sets at ESP inlet

ESP Design (Unit E and F)

1. Electrode arrangement – 45 rows per field
2. Electric power supply – Variable charging pulse energiser
3. Number of series field – 7 series, 2 path
4. Specific collection area – 154.22 $m^2/m^3/s$
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.83 m/s
6. Plate configuration – plates of 9 m height, 400 mm width
7. Aspect Ratio – Not known
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 23 seconds
9. High tension sections (per $1000m^3$ of gas flow rate) – 197.2 cu.m/seconds
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- Not known
12. Collecting electrode spacing (mm)- 250 mm
13. Electrode Rapping – Maechanical hammer rappers
14. Corona electrode rapping mechanism- Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Perforated plates, 2 sets at ESP inlet

Most probable reasons stated for under performance of ESP

Fundamental problems	Mechanical problems	Operational problems
➢ High resistivity particles	➢ Vibrating or swinging corona wires ➢ Excessive dust deposition on electrodes	➢ None

Coal characteristics

Total moisture	Ash	Volatile matter	Fixed carbon	Sulphur	GCV Kcal/kg
6-8%	15 - 22%	23-25%	18-56%	0.2-0.4%	5800-6250

Fly ash characteristics

Unburnt carbon	Silica	Iron oxide	Aluminum oxide	Sodium oxide	SO_3	Calcium oxide	Potassium Oxide
--	65-71%	6-8.5%	20-22%	0.08-1.2%	--	0.55-0.75%	0.04 to 1.26

Costing Figures – Not known

O&M cost – Rs.40 Lakhs per annum per ESP

Questionnaire No.10

Wanakbori Thermal Power Station, GEB, Tharsa, Kheda, Gujarat

Capacity	**Stack Height**	**ESP**	**Inlet dust conc. (g/Nm^3)**	**Outlet dust conc. (mg/Nm^3)**	**Design efficiency**	**Fundamental problems**
Unit I to III 210 MW	3 stacks of 150 m	Yes	30-60	250	99.23%	Undersized ESP
Unit IV to VI 210 MW	3 stacks of 150 m	Yes	30-60	200	99.6%	
Unit VII	1 stack of 220 m	Yes	40-65	150	99.76	
Total – 1470 MW	Resistivity of particles not known					

ESP Design (Unit I, II and III)

1. Electrode arrangement – 45 rows per field, 20 field, 360 electrodes per field, emitting electrode – spiral hooks, 2.7 mm dia, 1408 spirals in each field, 28160 in each ESP
2. Electric power supply – Semi pulse energisation
3. Number of series field – 5 series, 4 path
4. Specific collection area – 140.4 m^2/m^3/s
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 360 m^3/s
6. Plate configuration – plates of 9 m height, 3.2 m length, width 400 mm. 7200 plates per ESP
7. Aspect Ratio – Not known
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- Not known
9. High tension sections (per 1000m^3 of gas flow rate) – Not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- Not known
12. Collecting electrode spacing (mm)- 250 mm; Plate wire spacing 75 mm
13. Electrode Rapping – Maechanical hammer rappers

14. Corona electrode rapping mechanism- Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Perforated plates, 2 sets at ESP inlet

ESP Design (Unit IV, V and VI)

1. Electrode arrangement – 38 rows per field, 24 field, 304 collecting electrodes per field, emitting electrode – spiral hooks, 2.7 mm dia, 11848 spirals in each field, 28416 in each ESP
2. Electric power supply – Semi pulse energisation
3. Number of series field – 6 series, 4 path
4. Specific collection area – 152.2 $m^2/m^3/s$
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – (0.84 m/s) 326 m^3/s
6. Plate configuration – plates of 9 m height, 3.2 m length, width 400 mm. 7296 plates per ESP
7. Aspect Ratio – Not known
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 19.05 seconds
9. High tension sections (per $1000m^3$ of gas flow rate) – Not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- Not known
12. Collecting electrode spacing (mm)- 300 mm
13. Electrode Rapping – Maechanical hammer rappers
14. Corona electrode rapping mechanism- Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Perforated plates, 2 sets at ESP inlet

ESP Design (Unit VII)

1. Electrode arrangement – 77 rows per field, 28 field, 462 electrodes per field, emitting electrode – spiral hooks, 2.7 mm dia, 4104 spirals in each field, 57456 in each ESP
2. Electric power supply – Semi pulse energisation
3. Number of series field – 7 series, 4 path
4. Specific collection area – 380.22 $m^2/m^3/s$
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 340 m^3/s (0.552 m/s)
6. Plate configuration – plates of 13.5 m height, 750 mm length, 6468 plates per ESP
7. Aspect Ratio – Not known
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 57.065 seconds
9. High tension sections (per $1000m^3$ of gas flow rate) – Not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- Not known
12. Collecting electrode spacing (mm)- Plate wire spacing 150 mm
13. Electrode Rapping – Maechanical hammer rappers

14. Corona electrode rapping mechanism- Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Perforated plates, 2 sets at ESP inlet

Most probable reasons stated for under performance of ESP

Fundamental problems	Mechanical problems	Operational problems
➢ Undersized ESP	➢ None	➢ Shorted corona sections ➢ ESP overloaded due to high dust concentration ➢ Full or overflow hoppers

Coal characteristics

Total moisture	Ash	Volatile matter	Fixed carbon	Sulphur	GCV Kcal/kg
9.6%	36.8%	22.19%	31.39%	0.4-0.6%	3690

Fly ash characteristics

Unburnt carbon	Silica	Iron oxide	Aluminum oxide	Sodium oxide	Sulphur as SO3	Calcium oxide	Potassium Oxide
0.8%	63%	10.7%	12.9%	--	1.1%	8.7%	--

Costing Figures – Not known

O&M cost – Rs.40 Lakhs per annum per ESP

Questionnaire No.11

Sikka Thermal Power Station, GEB, Sikka, Jamnagar, Gujarat

Capacity	**Stack Height**	**ESP**	**Inlet dust conc. (g/Nm^3)**	**Outlet dust conc. (mg/Nm^3)**	**Design efficiency**	**Fundamental problems**
Unit I 120 MW	1 stack of 100 m	Yes	46	150	99.36%	Insufficient or unstable rectifier equipment
Unit II 120 MW	1 stack of 130 m	Yes	72.7	150	99.79%	
Total 240 MW						

ESP Design (Unit I)

1. Electrode arrangement – Collecting electrodes : 8 x 45 collecting electrodes per field and 7 fields in series per path
2. Electric power supply – 70 KV rectifiers, 800 mA
3. Number of series field – 7 series, 2 path
4. Specific collection area – 159.1 m^2/m^3/s
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.94 m/s
6. Plate configuration –Length 400 mm
7. Aspect Ratio – Not known
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 23.87 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – Not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- Not known
12. Collecting electrode spacing (mm)- 300 mm
13. Electrode Rapping – Mechanical hammer rappers

14. Corona electrode rapping mechanism- Available

15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – GD screens at inlet and outlet

ESP Design (Unit II)

1. Electrode arrangement – Collecting electrodes : 6 x 35 collecting electrodes per field.
2. Electric power supply – 70 KV rectifiers, 1200 mA
3. Number of series field – 6 series, 2 path
4. Specific collection area – 218.3 $m^2/m^3/s$
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.82 m/s
6. Plate configuration –Length 750 mm
7. Aspect Ratio – Not known
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 33 seconds
9. High tension sections (per $1000m^3$ of gas flow rate) – Not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- Not known
12. Collecting electrode spacing (mm)- 300 mm
13. Electrode Rapping – Mechanical hammer rappers
14. Corona electrode rapping mechanism- Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – GD screens at inlet and outlet

Most probable reasons stated for under performance of ESP

Fundamental problems	**Mechanical problems**	**Operational problems**
➢ Insufficient or unstable rectifier equipment	➢ None	➢ ESP overloaded (at full load)

Coal characteristics

Total moisture	Ash	Volatile matter	Fixed carbon	Sulphur	GCV Kcal/kg
8%	34.8%	22.9%	35%	--	4208

Fly ash characteristics

Unburnt carbon	Silica	Iron oxide	Aluminum oxide	Sodium oxide	SO3	Calcium oxide	Potassium Oxide
--	61.7 %	7.2%	25.4%	0.51%	0.98%	0.1%	0.41%

Costing Figures – Not known

O&M cost – Not known

Questionnaire No.12

Dahanu Thermal Power Station, BSES, Thane, Maharastra

Capacity	Stack Height	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit I and II 250 MW	2 stacks of 275.3 m	Yes	58	75	99.91%	High resistivity particles, re-entrainment of particles.
Total – 500 MW						

ESP Design (Unit I and II)

1. Electrode arrangement – 24 field. Collecting electrodes : 35 rows of collecting electrodes per field, 210 electrodes per field, 5040 electrodes per boiler.
2. Emitting electrodes : spiral with hooks, 2.7 mm dia, 54 electrodes in the frame forming one row, 1836 electrodes per field, length of electrode per field is 10300 m.
3. Electric power supply – Semi puylse energisation, 1000 KW power, 500 KW corona power
4. Number of series field – 6 series, 4 path
5. Specific collection area – 261.18 $m^2/m^3/s$
6. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.69 m/s
7. Plate configuration – Height 13.5 m, Length 750 mm
8. Aspect Ratio – 2.75 : 1
9. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 39 seconds
10. High tension sections (per $1000m^3$ of gas flow rate) – Not known
11. Migration velocity of particles (designed)- Not known
12. Resistivity of Particles- 10^{10} to 10^{12} ohm/cm
13. Collecting electrode spacing (mm)- 300 mm
14. Electrode Rapping – Mechanical hammer rappers

15. Corona electrode rapping mechanism- Available

16. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – 2 sets of perforated plates at inlet of ESP and 2 sets of U shaped thin plates.

Most probable reasons stated for under performance of ESP

Fundamental problems	**Mechanical problems**	**Operational problems**
➢ High resistivity particles ➢ Re-entrainment of collected particles	➢ Gas sneakage through hoppers and around ESP zones.	➢ None

Coal characteristics

Total moisture	**Ash**	**Volatile matter**	**Fixed carbon**	**Sulphur**	**GCV Kcal/kg**
13.14%	26.97%	26.14%	33.75%	0.43	4314

Fly ash characteristics

Unburnt carbon	**Silica**	**Iron oxide**	**Aluminum oxide**	**Sodium oxide**	**Sulphate**	**Calcium oxide**	**Pota-ssium Oxide**
0.69	61.2%	10.6%	16.1%	0.06%	1.2%	10.1%	0.05%

Costing Figures – Rs.23.66 Crores per ESP (Excluding civil engineering)

O&M cost – Not known

Questionnaire No.13

Bhusawal Thermal Power Station, MSEB, Bhusawal, Maharastra

Capacity	Stack Height	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit I 58 MW	1 stack of 60 m	Yes	22-27	150	99.77%	High resistivity particles, Undersize ESP
Unit II and III 210 MW	2 stacks of 90 m	Yes	27-30	300	99.0%	
Total 478 MW	NO ESP problem reported for Unit I ESP.					

ESP Design (Unit I)

1. Electrode arrangement – Suspended collecting plates and discharged spiked strips
2. Electric power supply – Multi pulse energisation, 440 V input
3. Number of series field – 4 series, 2 path
4. Specific collection area – 142.85 m^2/m^3/s
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.538 m/s
6. Plate configuration – Suspended corrugated type
7. Aspect Ratio – 1.13
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 28.5 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – Not known
10. Migration velocity of particles (designed)- 25 m/s
11. Resistivity of Particles- 10^{12} ohm/cm
12. Collecting electrode spacing (mm)- 400 mm
13. Electrode Rapping – Mechanical hammer rappers
14. Corona electrode rapping mechanism- Available

15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – specially designed flap type perforated plates

ESP Design (Unit II)

1. Electrode arrangement – Suspended collecting plates . Emitting spiral electrodes with hook.
2. Electric power supply – Multi pulse energisation, 440 V input
3. Number of series field – 5 series, 4 path
4. Specific collection area – 111.85m^2/m^3/s
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 1.03 m/s
6. Plate configuration – 39 rows, 351 collecting electrodes per field, total 7020 electrodes
7. Aspect Ratio – 2.22
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 13.98 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – 0.0168
10. Migration velocity of particles (designed)- 1.03 m/s
11. Resistivity of Particles- 10^{12} ohm/cm
12. Collecting electrode spacing (mm)- 125 mm plate wire spacing
13. Electrode Rapping – Mechanical hammer rappers
14. Corona electrode rapping mechanism- Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – 2 sets of perforated plates

ESP Design (Unit III)

1. Electrode arrangement – 304 collecting electrode plates per field, 1184 emitting electrodes per field.
2. Electric power supply – Pulse mode provision not available
3. Number of series field – 5 series, 4 path
4. Specific collection area – 121.92 m^2/m^3/s
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.875 m/s
6. Plate configuration – Total length of electrode per field – 6820 m. Height 9 m, length 400mm
7. Aspect Ratio – 2.22
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 18.3 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – 0.0159
10. Migration velocity of particles (designed)- 0.875 m/s
11. Resistivity of Particles- 10^{12} ohm/cm
12. Collecting electrode spacing (mm)- 150 mm

13. Electrode Rapping – Mechanical hammer rappers
14. Corona electrode rapping mechanism- Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – 2 sets of perforated plates

Most probable reasons stated for under performance of ESP

Fundamental problems	**Mechanical problems**	**Operational problems**
➢ High resistivity particles ➢ ESP is undersized	➢ Poor electrode alignment	➢ Shorted corona sections ➢ ESP overloaded by excessive dust concentration ➢ ESP overloaded by excessive gas flow

Coal characteristics

Total moisture	**Ash**	**Volatile matter**	**Fixed carbon**	**Sulphur**	**GCV Kcal/kg**
7%	30%	27%	35%	--	3700

Fly ash characteristics

Unburnt carbon	**Silica**	**Iron oxide**	**Aluminum oxide**	**Sodium oxide**	**SO_3**	**Calcium oxide**	**Potassium Oxide**
0.5	67%	10.6%	22%	0.5%	1%	3%	1%

Costing Figures – Rs.8.8 Crores (Unit I) Unit II and III ESP cost not available

O&M cost – Rs.31.7 Lakhs (Unit I) Rs.61.9 Lakhs (Unit II) Rs.65 Lakhs (Unit III)

Questionnaire No.14

Bhusawal Thermal Power Station, MSEB, Bhusawal, Maharastra

Capacity	Stack Height	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit I 58 MW	1 stack of 60 m	Yes	22-27	150	99.77%	High resistivity particles, Undersize ESP
Unit II and III 210 MW	2 stacks of 90 m	Yes	27-30	300	99.0%	
Total 478 MW	NO ESP problem reported for Unit I ESP.					

ESP Design (Unit I)

1. Electrode arrangement – Suspended collecting plates and discharged spiked strips
2. Electric power supply – Multi pulse energisation, 440 V input
3. Number of series field – 4 series, 2 path
4. Specific collection area – 142.85 m^2/m^3/s
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.538 m/s
6. Plate configuration – Suspended corrugated type
7. Aspect Ratio – 1.13
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 28.5 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – Not known
10. Migration velocity of particles (designed)- 25 m/s
11. Resistivity of Particles- 10^{12} ohm/cm
12. Collecting electrode spacing (mm)- 400 mm
13. Electrode Rapping – Mechanical hammer rappers
14. Corona electrode rapping mechanism- Available

15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – specially designed flap type perforated plates

ESP Design (Unit II)

1. Electrode arrangement – Suspended collecting plates . Emitting spiral electrodes with hook.
2. Electric power supply – Multi pulse energisation, 440 V input
3. Number of series field – 5 series, 4 path
4. Specific collection area – 111.85m^2/m^3/s
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 1.03 m/s
6. Plate configuration – 39 rows, 351 collecting electrodes per field, total 7020 electrodes
7. Aspect Ratio – 2.22
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 13.98 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – 0.0168
10. Migration velocity of particles (designed)- 1.03 m/s
11. Resistivity of Particles- 10^{12} ohm/cm
12. Collecting electrode spacing (mm)- 125 mm plate wire spacing
13. Electrode Rapping – Mechanical hammer rappers
14. Corona electrode rapping mechanism- Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – 2 sets of perforated plates

ESP Design (Unit III)

1. Electrode arrangement – 304 collecting electrode plates per field, 1184 emitting electrodes per field.
2. Electric power supply – Pulse mode provision not available
3. Number of series field – 5 series, 4 path
4. Specific collection area – 121.92 m^2/m^3/s
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.875 m/s
6. Plate configuration – Total length of electrode per field – 6820 m. Height 9 m, length 400mm
7. Aspect Ratio – 2.22
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 18.3 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – 0.0159
10. Migration velocity of particles (designed)- 0.875 m/s
11. Resistivity of Particles- 10^{12} ohm/cm
12. Collecting electrode spacing (mm)- 150 mm
13. Electrode Rapping – Mechanical hammer rappers

14. Corona electrode rapping mechanism- Available
16. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – 2 sets of perforated plates

Most probable reasons stated for under performance of ESP

Fundamental problems	**Mechanical problems**	**Operational problems**
➢ High resistivity particles ➢ ESP is undersized	➢ Poor electrode alignment	➢ Shorted corona sections ➢ ESP overloaded by excessive dust concentration ➢ ESP overloaded by excessive gas flow

Coal characteristics

Total moisture	**Ash**	**Volatile matter**	**Fixed carbon**	**Sulphur**	**GCV Kcal/kg**
7%	30%	27%	35%	--	3700

Fly ash characteristics

Unburnt carbon	**Silica**	**Iron oxide**	**Aluminum oxide**	**Sodium oxide**	**SO3**	**Calcium oxide**	**Potassium Oxide**
0.5	67%	10.6%	22%	0.5%	1%	3%	1%

Costing Figures – Rs.8.8 Crores (Unit I) Unit II and III ESP cost not available

O&M cost – Rs.31.7 Lakhs (Unit I) Rs.61.9 Lakhs (Unit II) Rs.65 Lakhs (Unit III)

Questionnaire No.15

Tanda Thermal Power Station, NTPC, Dist. Ambedkarnagar (UP)

Capacity	**Stack Height**	**ESP**	**Inlet dust conc. (g/Nm^3)**	**Outlet dust conc. (mg/Nm^3)**	**Design efficiency**	**Fundamental problems**
Unit I to IV 110 MW	2 stacks of 120 m	Yes	41.9	263.6	99.37%	The ESP problems are being studied by NTPC
Total 440 MW						

ESP Design (Unit I to IV)

1. Electrode arrangement – Spiral with hooks
2. Electric power supply – Pulse energisation not available, 415 V input
3. Number of series field – 7 series, 2 path
4. Specific collection area – 159.84 $m^2/m^3/s$
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 201.8 m3/s
6. Plate configuration – Flat strengthened at edge
7. Aspect Ratio – 3.2/9
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 28.98 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – Not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- Not known
12. Collecting electrode spacing (mm)- Not known
13. Electrode Rapping – Mechanical hammer rappers

14. Corona electrode rapping mechanism- Available

15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Screens

Most probable reasons stated for under performance of ESP – Not identified

Coal characteristics

Total moisture	Ash	Volatile matter	Fixed carbon	Sulphur	GCV Kcal/kg
2.6%	45.7%	17.7%	34%	0.4	3890

Fly ash characteristics

Unburnt carbon	Silica	Iron oxide	Aluminum oxide	Sodium oxide	SO_3	Calcium oxide	Potassium Oxide
12.08	52%	5.3%	23%	0.57%	--	3%	1.23%

Costing Figures – Not available

O&M cost – Not available

Questionnaire No.16

Rihand Thermal Power Station, NTPC, Rihand

Capacity	Stack Height	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit I & II 500 MW	1 stack of 225 m	Yes	80-90	150	99.5%	No problems in ESP
Total 1000 MW						

ESP Design (Unit I and II)

1. Electrode arrangement – Mast type discharge electrode, plate type collecting electrode
2. Electric power supply – Semi pulse energisation, 60 KV , 1100 mA
3. Number of series field – 6 series, 4 path
4. Specific collection area – 160 m^2/m^3/s
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 1.25 m/s
6. Plate configuration – 31.5m x 5 m
7. Aspect Ratio – 2.2
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 26 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – 2 sections per field
10. Migration velocity of particles (designed)- Not available
11. Resistivity of Particles- Not available
12. Collecting electrode spacing (mm)- Not available
13. Electrode Rapping – Mechanical hammer rappers
14. Corona electrode rapping mechanism- Available

15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Honeycomb GD screens at inlet of each pass

Most probable reasons stated for under performance of ESP - No problem

Coal characteristics

Total moisture	**Ash**	**Volatile matter**	**Fixed carbon**	**Sulphur**	**GCV Kcal/kg**
11.2%	35.1%	25.6%	28.1%	0.44	3870

Fly ash characteristics

Unburnt carbon	**Silica**	**Iron oxide**	**Aluminum oxide**	**Sodium oxide**	**SO_3**	**Calcium oxide**	**Potassium Oxide**
0.03	65.6%	10%	21%	0.27%	Traces	0.11%	0.87%

Costing Figures – Not available

O&M cost – Rs.3.9 lakhs per annum per ESP

Questionnaire No.17

Talcher Thermal Power Station, NTPC, Talcher, Orissa

Capacity	Stack Height	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit I to IV 60 MW	2 stacks of 60 m	Yes	50-60	400	99.5%	High resistivity particles, Insufficient number of corona sections, undersize ESP
Unit V and VI 210 MW	1stack of 120 m	Yes	50	150	99.78%	
Total 460 MW						

ESP Design (Unit I to IV)

1. Electrode arrangement – Parallel plate with duratrode as emitting electrode
2. Electric power supply – Pulse energisation not available
3. Number of series field – 5 series, 2 path
4. Specific collection area – 146.8 m^2/m^3/s
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.762 m/s
6. Plate configuration – Not available
7. Aspect Ratio – 1.47
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 22.39 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – Not known
10. Migration velocity of particles (designed)- 0.1912 m/s
11. Resistivity of Particles- 10^{12} ohm/cm
12. Collecting electrode spacing (mm)- 305 mm
13. Electrode Rapping – Magnetic impulse type

14. Corona electrode rapping mechanism- Available

15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – GD screens and deflection plates

ESP Design (Unit V and VI) [Old + Retrofit]

1. Electrode arrangement – Parallel plates . Emitting electrodes helical spring.
2. Electric power supply – Semi pulse energisation
3. Number of series field – 8 series
4. Specific collection area – 97 + 78.6 $m^2/m^3/s$
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 1.15 m/s
6. Plate configuration – Parallel plates with baffles
7. Aspect Ratio – 1.6 (old) 1.33 (retrofit)
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- Not available
9. High tension sections (per $1000m^3$ of gas flow rate) – Not available
10. Migration velocity of particles (designed)- 0.2142 m/s
11. Resistivity of Particles- 10^{12} ohm/cm
12. Collecting electrode spacing (mm)- 250 (Old) 400 mm (retrofit)
13. Electrode Rapping – Mechanical tumbling hammer
14. Corona electrode rapping mechanism- Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Splitters and guide valves, screen deflection plates

Most probable reasons stated for under performance of ESP

Fundamental problems	**Mechanical problems**	**Operational problems**
➢ High resistivity particles ➢ Insufficient number of corona sections ➢ ESP is undersized	➢ Excessive dust deposits on collecting electrodes and corona electrodes	➢ ESP overloaded by excessive dust concentration

Coal characteristics

Total moisture	**Ash**	**Volatile matter**	**Fixed carbon**	**Sulphur**	**GCV Kcal/kg**
--	38%	25%	28%	0.5	3500

Fly ash characteristics

Unburnt carbon	**Silica**	**Iron oxide**	**Aluminum oxide**	**Sodium oxide**	**SO_3**	**Calcium oxide**	**Potassium Oxide**
--	62%	4%	29%	--	Traces	0.6%	--

Costing Figures – Rs.30 Crores per ESP for Unit I, Unit II, Unit III and Unit IV Rs.90 Crores per ESP for Unit V and Unit VI

O&M cost – Rs.100 Lakhs per annum per ESP for Unit I, Unit II, Unit III and Unit IV, Rs.200 Lakhs per annum per ESP for Unit V and Unit VI

Questionnaire No.18

Ramagundam Thermal Power Station, NTPC, Ramagundam, AP

Capacity	**Stack Height**	**ESP**	**Inlet dust conc. (g/Nm^3)**	**Outlet dust conc. (mg/Nm^3)**	**Design efficiency**	**Fundamental problems**
Unit I to III 200 MW	1 stack of 225 m	Yes	62	70	99.85%	No problems
Unit IV to VI 500 MW	3 stacks of 220 m	Yes	42	70	99.9%	
Total 2100 MW	NO ESP problem reported for Unit I ESP.					

ESP Design (Unit I to III)

1. Electrode arrangement – Suspended collecting plates and spiral emitting electrodes
2. Electric power supply – Semi pulse energisation
3. Number of series field – 5 series, 4 path
4. Specific collection area – 147.68 $m^2/m^3/s$ (16 fields)
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.813 m/s
6. Plate configuration – 0.905 m width, 13.5 m height
7. Aspect Ratio – 1.67
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 22.15 seconds
9. High tension sections (per $1000m^3$ of gas flow rate) – Not known
10. Migration velocity of particles (designed)- 25 m/s
11. Resistivity of Particles- 8×10^{12} ohm/cm
12. Collecting electrode spacing (mm)- 300 mm
13. Electrode Rapping – Mechanical hammer rappers

14. Corona electrode rapping mechanism- Available

15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Screens, flow splitters.

ESP Design (Unit IV to VI)

1. Electrode arrangement – Suspended collecting plates . Emitting spiral electrodes with hook.
2. Electric power supply – semi pulse energisation
3. Number of series field – 6 series, 4 path
4. Specific collection area – 221.9 $m^2/m^3/s$
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.81 m/s
6. Plate configuration – Ht. 12.5 m 750 mm width
7. Aspect Ratio – 2.16
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 33.33 seconds
9. High tension sections (per $1000m^3$ of gas flow rate) – Not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- 8×10^{12} ohm/cm
12. Collecting electrode spacing (mm)- 300 mm plate wire spacing
13. Electrode Rapping – Mechanical hammer rappers
14. Corona electrode rapping mechanism- Available

15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Screens, splitters

Most probable reasons stated for under performance of ESP – No problem

Coal characteristics

Total moisture	**Ash**	**Volatile matter**	**Fixed carbon**	**Sulphur**	**GCV Kcal/kg**
10.65%	35.35%	23.6%	30.9%	0.55%	3927

Fly ash characteristics

Unburnt carbon	**Silica**	**Iron oxide**	**Aluminum oxide**	**Sodium oxide**	**SO_3**	**Calcium oxide**	**Potassium Oxide**
--	61.6%	3.7%	19.6%	0.23%	0.11%	3.26%	0.85%

Costing Figures – Not known

O&M cost – Not known

Questionnaire No.19

Dadri Thermal Power Station, NTPC, Dadri, UP

Capacity	Stack Height	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit I to IV 210 MW	4 stacks of 220 m	Yes	40-50	150	99.9%	High resistivity particles, Velocity not equal in all passes / path
Total 840 MW						

ESP Design (Unit I to IV)

1. Electrode arrangement – Suspended collecting plates and spiral emitting electrode
2. Electric power supply – Semi pulse energisation
3. Number of series field – 6 series, 4 path
4. Specific collection area – 214.48 $m^2/m^3/s$
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.839 m/s
6. Plate configuration – Ht. 13.5 m width 750 mm 144 collecting plates per field
7. Aspect Ratio – 2.67
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 32.18 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – Not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- 10^9 ohm/cm
12. Collecting electrode spacing (mm)- 300 mm
13. Electrode Rapping – Mechanical hammer rappers
14. Corona electrode rapping mechanism- Available
15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Screens

Most probable reasons stated for under performance of ESP

Fundamental problems	Mechanical problems	Operational problems
➢ High resistivity particles ➢ Velocity not equal in all passes	➢ None	➢ None

Coal characteristics

Total moisture	**Ash**	**Volatile matter**	**Fixed carbon**	**Sulphur**	**GCV** **Kcal/kg**
8.5%	36%	24%	31.3%	0.52	3930

Fly ash characteristics

Unburnt carbon	**Silica**	**Iron oxide**	**Aluminum oxide**	**Sodium oxide**	**SO_3**	**Calcium oxide**	**Potassium** **Oxide**
--	60%	5.2%	27%	--	0.3%	2%	--

Costing Figures – Rs.6.965 Crores per ESP

O&M cost – Rs.5.5 Lakhs per ESP

Questionnaire No.20

Singrauli Thermal Power Station, NTPC, Singrauli, UP

Capacity	Stack Height	ESP	Inlet dust conc. (g/Nm^3)	Outlet dust conc. (mg/Nm^3)	Design efficiency	Fundamental problems
Unit I to V 200 MW	3 stack of 220 m	Yes	51.83	150	99.6%	No fundamental problems except occasional re-entrainment of collected particles
Unit VI and VII 500 MW	2 stacks of 220 m	Yes	73.5	150	99.6%	
Total 2000 MW						

ESP Design (Unit I to V)

1. Electrode arrangement – Vertical collecting and emitting electrode
2. Electric power supply – Multi pulse energisation 1560 KW
3. Number of series field – 6 series, 2 path (5 old + 1 retrofitted)
4. Specific collection area – 138.52 m^2/m^3/s
5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 0.924 m/s
6. Plate configuration – 38 rows x 8 plates x 304 electrodes
7. Aspect Ratio – Not available
8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 17.312 seconds
9. High tension sections (per 1000m^3 of gas flow rate) – Not known
10. Migration velocity of particles (designed)- Not known
11. Resistivity of Particles- Not known
12. Collecting electrode spacing (mm)- 150 mm

13. Electrode Rapping – Mechanical hammer rappers

14. Corona electrode rapping mechanism- Available

15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Perforated plates

ESP Design (Unit VI and VII)

1. Electrode arrangement – Vertical

2. Electric power supply – Multi pulse energisation, 4000 KW

3. Number of series field – 7 series, 4 path

4. Specific collection area – 164.57 $m^2/m^3/s$

5. Gas velocity inside ESP (gas velocity x cross section area of ESP) – 1.0 m/s

6. Plate configuration – 65 rows, 9 plate in each row x 16380 plates

7. Aspect Ratio – Not available

8. Treatment time (time taken by the flue gas to pass through the length of the collecting electrode zone)- 25.2 seconds

9. High tension sections (per $1000m^3$ of gas flow rate) – Not known

10. Migration velocity of particles (designed)- Not known

11. Resistivity of Particles- Not known

12. Collecting electrode spacing (mm)- 150 mm

13. Electrode Rapping – Mechanical hammer rappers

14. Corona electrode rapping mechanism- Available

15. Gas Flow Distribution means to achieve uniform/symmetrical flow inside the ESP – Perforated plates

Most probable reasons stated for under performance of ESP

Fundamental problems	**Mechanical problems**	**Operational problems**
➢ Occasional re-entrainment of collected particles	➢ Occasional vibrating or swinging corona wires ➢ Occasional air leakage into hoppers , shells or gas ducts	➢ Full or overflow hoppers (sometimes) ➢ Shorted corona sections (sometimes)

Coal characteristics

Total moisture	Ash	Volatile matter	Fixed carbon	Sulphur	GCV Kcal/kg
18.8%	28.8%	22.7%	29.7%	0.34%	3830

Fly ash characteristics

Unburnt carbon	Silica	Iron oxide	Aluminum oxide	Sodium oxide	SO_3	Calcium oxide	Potassium Oxide
1.18%	62.9%	5.4%	22.3%	1.23%	0.4%	3.26%	0.46%

Costing Figures – Rs.3.5 Crores per ESP (Unit I to Unit V)

O&M cost – Rs.15 Lakhs per annum (Unit I to Unit V)

Costing Figures – Rs.13.4 Crores per ESP (Unit VI to Unit VII)

O&M cost – Rs.32.3 Lakhs per annum (Unit VI to Unit VII)