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Contemporary Dust Control Techniques in Cement Industry, Electrostatic Precipitator - A Case Study

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Abstract: The case study deal with the current day problem of pollution by industrial zones in Pakistan with emphasis on the cement Industry which has been proved to be the 2nd revenue generating hub after textile sector of the Pakistan. A pilot study into the identification and available removal Techniques of particulates from the exhaust of a cement plant clinker cooler was carried out. The objective of this work was to study the performance of the each technique in detail in the removal of a particulate with a wide range of sizes, under different operational conditions and to compare the results for collection efficiency with predictions by available theoretical models. A brief and comprehensive discussion regarding design, construction and bottlenecks of each tool has been discussed to fully ascertain it's scope and usability. First part of the study identifies the various pollutants being emitted from the chimney of a specific cement plant in Pakistan and while last portion deals with the ways to curtail these pollutants.

Key words: Clinker Cooler · Collection Efficiency · Pollutants

INTRODUCTION

The priority in the cement industry is to minimize the increase in ambient particulate levels by reducing the mass load emitted from the stacks, from fugitive emissions and from other sources.

Collection and recycling of dust in the kiln gases in required to improve the efficiency of the operation and to reduce atmospheric emissions. Units that are well designed, well operated and well maintained can normally achieve generation of less than 0.2 kilograms of dust per metric ton (kg /t) of clinker, using dust recovery systems. NOx emissions should be controlled by using proper kiln design, low -NOx burners and an optimum level of excess air. NOx emissions from a dry kiln with pre heater and pre calciner are typically 1.5 kg /t of clinker, as against 4.5 Kg/t for the wet.

An electrostatic precipitator was employed, consisting of a conventional plate-wire precipitator to handle 12 000 actual cubic feet per minute (acfm) of exhaust gas. To offset the high electrical resistivity of the clinker dust, moisture was added by spraying water directly onto the clinker bed in order to alleviate the problems caused by back corona. Overall collection efficiencies in excess of 90 percent were achieved and in excess of 40 percent by the grid precipitator section alone.

MATERIALS AND METHODS

Materials: Emissions from cement works are determined both by continuous and discontinuous measuring methods, which are described in corresponding national guidelines and standards. Continuous measurement is primarily used for dust, NOx and SO_2 , while the remaining parameters relevant pursuant to ambient pollution legislation are usually determined discontinuously by individual measurements [1, 2].

The following descriptions of emissions refer to modern kiln plants based on dry process technology [3].

Climatically Relevant Gases / Carbon Dioxide: During the clinker burning process climatically relevant gases are emitted. CO_2 accounts for the main share of these gases [1, 3]. Other climatically relevant gases, such as dinitrogen

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monoxide (N_2O) or methane (CH_4), are emitted in very small quantities only [1]. CO_2 emissions are both raw material-related and energy-related. Raw material-related emissions are produced during limestone de carbonation (CaCO3) and account for about 60% of total CO_2 emissions. Energy-related emissions are generated both directly through fuel combustion and indirectly through the use of electrical power.

Dust: To manufacture 1 t of Portland cement, about 1.5 to 1.7 t raw materials, 0.1 t coal and 1 t clinker (besides other cement constituents and sulfate agents) must be ground to dust fineness during production. In this process, the steps of raw material processing, fuel preparation, clinker burning and cement grinding constitute major emission sources for particulate components. While particulate emissions of up to 3,000 mg/m^3 were measured leaving the stack of cement rotary kiln plants as recently as in the 1950s, legal limits are typically 30 mg/m^3 today and much lower levels are achievable.

Nitrogen Oxides (Nox): The clinker burning process is a high-temperature process resulting in the formation of nitrogen oxides (NOx). The amount formed is directly related to the main flame temperature (typically 1850-2000°C). Nitrogen monoxide (NO) accounts for about 95 % and nitrogen dioxide (NO_2) for about 5 % of this compound present in the exhaust gas of rotary kiln plants. As most of the NO is converted to NO_2 in the atmosphere, emissions are given as NO_2 per m³ exhaust gas..

Sulphur Dioxide (SO_2): Sulphur is input into the clinker burning process via raw materials and fuels. Depending on their origin, the raw materials may contain sulphur bound as sulphide or sulphate. Higher SO_2 emissions by rotary kiln systems in the cement industry are often attributable to the sulphides contained in the raw material, which become oxidized to form SO_2 at the temperatures between 370°C and 420°C prevailing in the kiln pre heater. Given the sulphide concentrations found e.g. in German raw material deposits, SO_2 emission concentrations can total up to 1.2 g/m^3 depending on the site location. In some cases, injected calcium hydroxide is used to lower SO_2 emissions.

Carbon Monoxide (CO) and Total Carbon [4]: The exhaust gas concentrations of CO and organically bound carbon are a yardstick for the burn-out rate of the fuels utilized in energy conversion plants, such as power stations. By contrast, the clinker burning process is a material conversion process that must always be operated with excess air for reasons of clinker quality. In concert with long residence times in the high-temperature range, this leads to complete fuel burn-up [1, 3].

The emissions of CO and organically bound carbon during the clinker burning process are caused by the small quantities of organic constituents input via the natural raw materials (remnants of organisms and plants incorporated in the rock in the course of geological history). These are converted during kiln feed preheating and become oxidized to form CO and CO_2 [4].

Dioxins and Furans (PCDD/F): Rotary kilns of the cement industry and classic incineration plants mainly differ in terms of the combustion conditions prevailing during clinker burning. Kiln feed and rotary kiln exhaust gases are conveyed in counter-flow and mixed thoroughly. Thus, temperature distribution and residence time in rotary kilns afford particularly favorable conditions for organic compounds, introduced either via fuels or derived from them, to be completely destroyed. For that reason, only very low concentrations of polychlorinated dibenzo-p-dioxins and dibenzofurans (colloquially "dioxins and furans") can be found in the exhaust gas from cement rotary kilns.

Polychlorinated Biphenyls (PCB): The emission behavior of PCB is comparable to that of dioxins and furans. PCB may be introduced into the process via alternative raw materials and fuels. The rotary kiln systems of the cement industry destroy these trace components virtually completely.

Trace Elements: The emission behavior of the individual elements in the clinker burning process is determined by the input scenario, the behavior in the plant and the precipitation efficiency of the dust collection device. The trace elements introduced into the burning process via the raw materials and fuels may evaporate completely or partially in the hot zones of the pre heater and/or rotary kiln depending on their volatility, react with the constituents present in the gas phase and condense on the kiln feed in the cooler sections of the kiln system.

Pollution Control Technique: The case study objective is to minimize the increase in ambient particulate levels by reducing the mass load emitted from the stacks, from fugitive emissions and from other sources.

Collection and recycling of dust in the kiln gases in required to improve the efficiency of the operation and to reduce atmospheric emissions. Units that are well designed, well operated and well maintained can normally achieve generation of less than 0.2 kilograms of dust per metric ton (kg /t) of clinker, using dust recovery systems. NOx emissions should be controlled by using proper kiln design, low -NOx burners and an optimum level of excess air. NOx emissions from a dry kiln with preheater and precalciner are typically 1.5 kg /t of clinker, as against 4.5 Kg/t for the wet.

Within each of the five main categories of particulate control techniques, there are many different design types [5]:

Gravity settling chamber
Mechanical collectors
Particulate wet scrubbers
Electrostatic precipitators
Fabric filters

Gravity Setting Chambers: As the name implies, this category of control devices relies upon gravity settling to remove particles from the gas stream. Gravity settling chambers are used only for very large particles in the upper end of the super coarse size range (approximately 75 micrometers and larger). The very low terminal settling velocities of most particles encountered in the field of air pollution limits the usefulness of gravity settling chambers.

Mechanical Collectors: Mechanical collectors use the inertia of the particles for collection. The particulate-laden gas stream is forced to spin in a cyclonic manner. The mass of the particles causes them to move toward the outside of the vortex. Most of the large-diameter particles enter a hopper below the cyclonic tubes while the gas stream turns and exits the tube.

A typical large-diameter cyclone system is shown in Figure 2.2.1. The gas stream enters the cyclone tangentially and creates a weak vortex of spinning gas in the cyclone body. Large-diameter particles move toward the cyclone body wall and then settle into the hopper of the cyclone. The cleaned gas turns and exits the cyclone. Large-diameter cyclones are used to collect particles ranging in diameters from one-sixteenth inch to more than 6 inches.

A small-diameter cyclone tube is shown in Figure 2.2.2. Vanes located on the inlet of each of the tubes create the spinning movement of the gas stream.

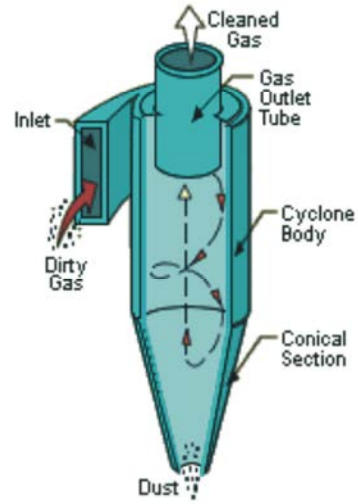


Fig. 1: Top-Inlet Large-Diameter Cyclone

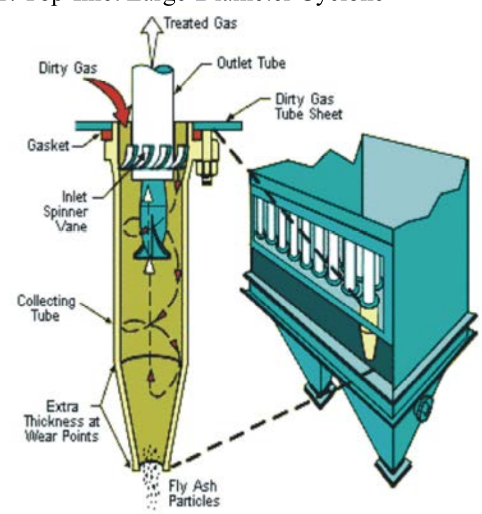


Fig. 2: Small-Diameter Multi-Cyclone Collector

Most of the commercial tubes are six, nine, or twelve inches in diameter. Due to the limited gas handling capacity of each tube, large numbers of tubes are mounted in parallel in a single collector.

The small-diameter of the cyclone tube creates more rapid spinning of the gas stream than is possible in large-diameter cyclones. Furthermore, the particles moving outward in the spinning gas stream have a relatively shorter distance to travel in a small-diameter multi-cyclone tube before they reach the cyclone body wall. These features allow small-diameter multi-cyclones to collect considerably smaller particles than large-diameter cyclones can. Small-diameter multi-cyclones, such as the one shown in Figure 2.2.2 are capable of removing particles having diameters down to 5 micrometers. Conversely, the small-diameter multi-cyclones are not generally used for very large diameter

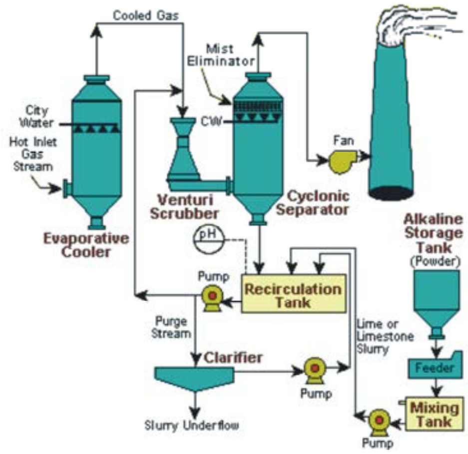


Fig. 2.9.1

material, such as one-eighth inch and above, because large particles may plug the spinner vanes in the multi-cyclone tubes.

Particulate Wet Scrubbers: There are a number of major categories of particulate wet scrubbers. The list provided below is not exhaustive (nor is it listed in order of efficiency).

Venturis
Impingement and Sieve Plates
Spray Towers

This case study discusses three of the above types of scrubbers: venturis, impingement plate scrubbers and spray towers.

Wet Scrubbing Systems: Each particulate wet scrubber vessel is part of a large and sometimes complex, wet scrubbing system. For example, Figure 2.7.1 illustrates a venturi scrubber in a scrubbing system. The evaporative cooler, located before the venturi scrubber in the system, cools the gas stream, which serves the following purpose:

It protects the construction materials of the venturi throat.

It helps to homogeneously and heterogeneously nucleate vapor phase material emitted from the process before it reaches the scrubbing system.

It prevents the water droplets from evaporating and inhibiting inertial impaction.

Many types of particulate wet scrubbers can provide high efficiency control of particulate matter. One of the main advantages of particulate wet scrubbers is that they are often able to simultaneously collect particulate matter and gaseous pollutants. Also, wet scrubbers can often be used on sources that have potentially explosive gases or particulate matter. They are compact and can often be retrofitted into existing plants with very limited space.

One of the main disadvantages of particulate wet scrubbers is that they require make-up water to replace the water vaporized into the gas stream and lost to purge liquid and sludge removed from the scrubber system. Wet scrubbers generate a waste stream that must be treated properly.

Methods: During the process of cement manufacture, considerable amount of dust is emitted at almost every stage. For control of dust emission, various emission standards are being formulated around the globe for cement industry. Since then, significant developments have taken place in terms of cement production as well as technologies.

The cement plant under the case study is of Chinese origin, which is situated in NWFP, PAKISTAN with less emphasis on dust emission control than to keep the feed rates (production) to the optimum level. However due to growing concern by the neighboring inhabitants over the regular dust bombardment and also production loss due to un-availability of any dust control equipment, a thorough discussion was held by the senior management to curtail the worsening situation and it was decided go for a best emission control equipment. Various emission control equipments available in the market were evaluated one by one in detail and finally latest, state of the art, Electro-static Precipitator System was chosen keeping in view it's justification as discussed earlier of this case study.

A brief introduction of histry, construction and operation is given below [6-9].

Electrostatic Precipitator: An electrostatic precipitator (ESP) or electrostatic air cleaner is a particulate collection device that removes particles from a flowing gas (such as air) using the force of an induced electrostatic charge [6]. Electrostatic precipitators are highly efficient filtration devices that minimally impede the flow of gases through the device and can easily remove fine particulate matter such as dust and smoke from the air stream.

Invention of the Electrostatic Precipitator: The first use of corona to remove particles from an aerosol was by Hohlfeld in 1824. However, it was not commercialized until almost a century later. In 1907 Dr. Frederick G. Cottrell applied for a patent on a device for charging particles and

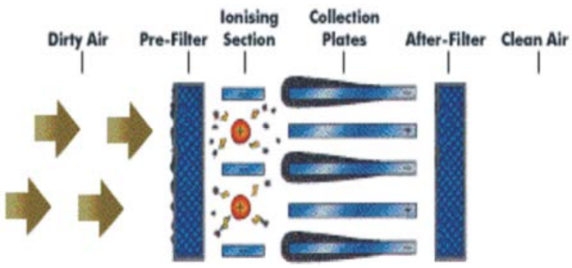


Fig. 3.1

then collecting them through electrostatic attraction- the first electrostatic precipitator. He was then a professor of chemistry at the University of California, Berkeley. Cottrell first applied the device to the collection of sulfuric acid mist emitted from various acid-making and smelting activities.

How Electrostatic Filtration Works: Electrostatic dust collectors use electrostatic charges to separate dust from the dusty air stream. A number of high voltage, direct current electrodes (carrying negative charge) are placed between grounded electrodes (carrying positive charge). The dust borne air stream is passed through the passage between the discharging (negative) electrodes and collecting (positive) electrodes. Dust particles receive a negative charge from the discharging electrodes (ionizing section) and are attracted to the positively charged grounded electrode (collection plates) and fasten on to it. Cleaning is done by rapping or vibrating the collecting electrode wherein dust particles fall away. Cleaning can be done without interrupting the flow.

The basic components of an electrostatic precipitator are (i) power supply unit (to impart high voltage, unidirectional current) (ii) an 'ionizing' section where charge is imparted to dust filled air stream (iii) cleaning system to remove dust particles and (iv) housing for the precipitator.

The Plate Precipitator: The most basic precipitator contains a row of thin wires and followed by a stack of large flat metal plates, with the plates typically spaced about 1 cm apart. The air stream flows through the spaces between the wires and then passes through the stack of plates.

A negative voltage of several thousand volts is applied between wire and plate. If the applied voltage is high enough an electric discharge ionizes the air around the electrodes. Negative ions flow to the plates and charge the gas-flow particles. The ionized particles, following the negative electric field created by the power supply, move to the grounded plates. Particles build up on the collection plates and form a layer. The layer does not collapse, thanks to electrostatic pressure (given from layer resistivity, electric field and current flowing in the collected layer).

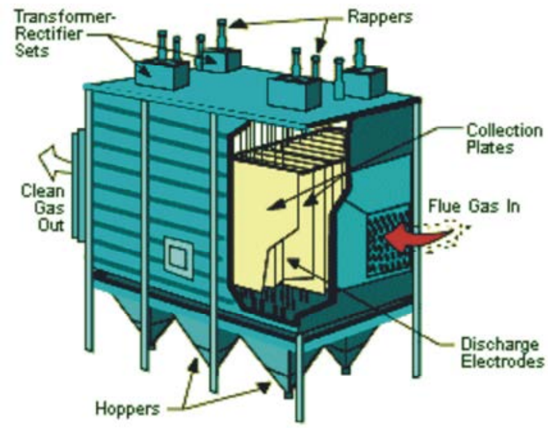


Fig. 3.2

Electrostatic Precipitators: Types of Electrostatic Precipitators.

There are three main styles of electrostatic precipitators: (1) negatively charged dry precipitators, (2) negatively charged wetted-wall precipitators and (3) positively charged two-stage precipitators. The negatively charged dry precipitators are the type most frequently used on large applications such as coal-fired boilers, cement kilns and Kraft pulp mills. Wetted-wall precipitators (sometimes called wet precipitators) are often used to collect mist and/or solid material that is moderately sticky. The positively charged two-stage precipitators are used only for the removal of mists. In the remainder of this section, the discussions will focus only on negatively charged dry precipitators because these are the most common types of precipitators.

Figure 3.2 shows the scale of a typical electrostatic precipitator used at a coal-fired boiler.

Essentially all of these units are divided into a number of separately energized areas that are termed fields. Precipitators have between three and ten fields in series along the gas flow path. On large units, the precipitators are divided into a number of separate, parallel chambers, each of which has an equal number of fields in series. There is a solid partition or physical separation between the 2 to 8 chambers that are present on the large systems.

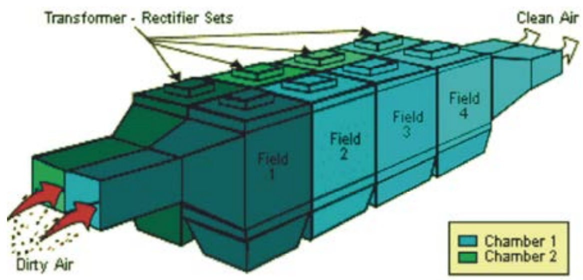


Fig. 3.3

Figure 3.3 shows a single gas passage in a typical electrostatic precipitator. A high-voltage electrical charge is applied to the small-diameter electrode shown in the center of the picture. The large vertical surfaces on both sides of the electrode are electrically grounded collection plates. The particles in the gas stream, which is moving horizontally through the unit become charged and then move to either side.

The Selection Criteria for ESP: Electrostatic precipitators can have very high efficiencies due to the electrical forces applied to the small particles. These types of collectors can be used when the gas stream is not explosive and does not contain entrained droplets or other sticky material [10].

The composition of the particulate matter is very important because it influences the electrical conductivity within the dust layers on the collection plate. Resistivity, an important concept associated with electrostatic precipitators, is a measure of the ability of the particulate matter to conduct electricity and is expressed in units of ohm-cm. As the resistivity increases, the ability of the particulate matter to conduct electricity decreases. Precipitators can be designed to work in any resistivity range; however, they usually work best when the resistivity is in the moderate range (108 to 1010 ohms-cm).

Electrostatic Precipitators: Have the following advantages.
They have high efficiencies (exceeds 99.9% in some applications)
Fine dust particles are collected efficiently
Can function at high temperatures (as high as 700 degree F – 1300 degree F)
Pressure and temperature changes are small
Difficult material like acid and tars can be collected
They withstand extremely corrosive material
Low power requirement for cleaning
Dry dust is collected making recovery of lost product easy
Large flow rates are possible

Electrostatic Precipitators: Have the following disadvantages:
High initial cost
Materials with very high or low resistivity are difficult to collect
Inefficiencies could arise in the system due to variable condition of airflow (though automatic voltage control improves collector efficiency)
They can be larger than bag houses (fabric collectors) and cartridge units and can occupy greater space
Material in gaseous phase cannot be removed by electrostatic method
Dust loads may be needed to be reduced before precipitation process (pre cleaner may be needed)

The efficiency of *electrostatic precipitators* can be increased by:

- Larger collection surface areas and lower air flow rates give more time and area for dust particles to collect.
- Increased speed of dust particles towards collection electrodes.

Performance and Efficiency Parameters: To evaluate the performance analysis of an ESP, a formula was devised by Bundy, D. S. and T. E. Hazen [3], which is given below.

$$R = 1 - e^{(-AV)}{}_d / Q$$

Notations for Inputs:

Electrodes collecting area (A) (meter^2)
Particles drift velocity (V_d) (meter/second)
Gas flow rate (Q) (meter^3/second)

Actual Data for the Particular ESP:

Electrodes collecting area (A)= 18 m2
Particles drift velocity (V_d)= 100 ~102 m/sec
Gas flow rate (Q)= 797 ~800 m^3/sec

Solution

Collection efficiency (R) = 92% ~ 99%

Table 1: Efficiency graph keeping Drift Velocity Constant

	DATA SHEET # 1							
Efficiency (%age)	99	98	97	96	95	94	93	92
Air Flow Rate (m^3/sec)	391	429	498	548	581	621	659	709

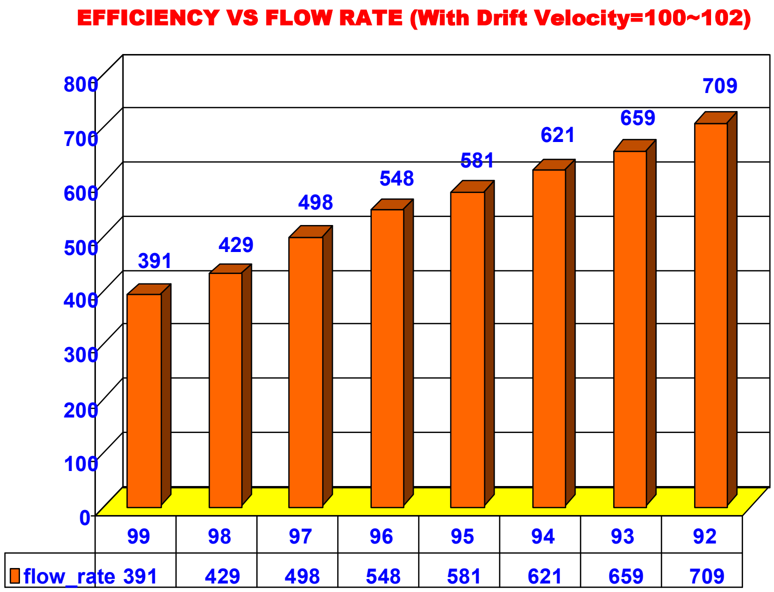
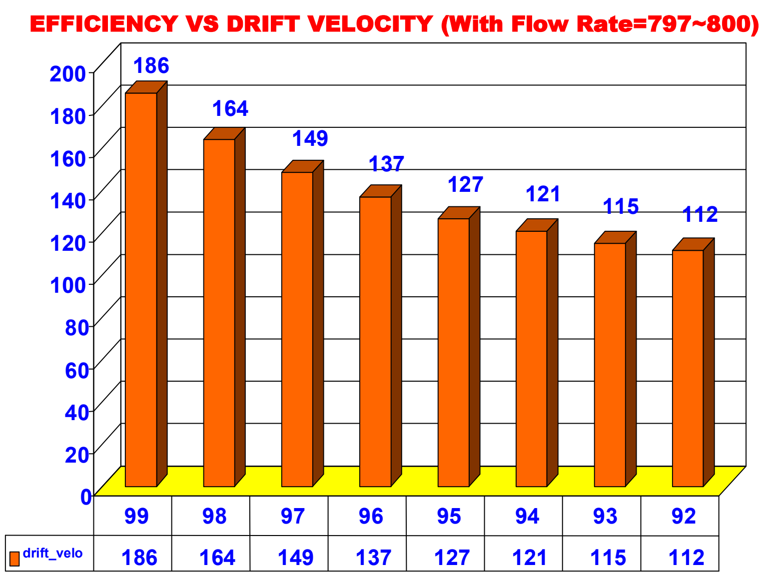


Table 2: Efficiency graph keeping Flow Rate Constant

	DATA SHEET # 2							
Efficiency (%age)	99	98	97	96	95	94	93	92
Drift Velocity (m/sec)	186	164	149	137	127	121	115	112



Change Equation: To evaluate the various unknown parameters, following change equations were devised by P. Aarne Vesilind, J. Jeffrey Peirce and Ruth F. Weiner {Ref # 3 and 4}, as given under.

$R = 1 - e^{(-AV)}{}_d / Q$ Collection efficiency estimate

$\frac{Q}{V} \ln(1-R)$ Electrodes collecting area

$Vd = -\frac{Q}{V} \ln(1-R)$ Particle drift velocity

$Q = -\frac{A\ Vd}{\ln(1-R)}$ Gas flow rate

RESULTS AND DISCUSSIONS

During this case study, different values for all the three parameters were aimed in Foxpro sub routine to check for maximum efficiency. By keeping value of electrodes collecting area fixed, data table sheets along with the corresponding bar charts were made by varying the Particles drift velocity (Vd) and Gas flow rate (Q) for optimum R value.

The data sheet # 01 shows the effect of Gas flow rate (Q) to ESP efficiency keeping Particles drift velocity (Vd) in a fixed range showing a inversely proportional relation. Similarly the data sheet # 02 shows the effect of Particles drift velocity (Vd) to ESP efficiency keeping Gas flow rate (Q) in a fixed range showing a proportional relation.

The Actual Data Is Enclosed Which Is the Soul Work of the Author. Also Before Implementation to Cement Plant, Consultation Regarding Environment Similarities Should Be Done:

CONCLUSIONS

Although the Electrostatic precipitator system was installed at the site of cement plant and in operation but the optimum efficiency could not attained due to difficulties in sorting out the proper value ranges for Particles drift velocity (Vd) and Gas flow rate (Q) as other parameters were bounded by the design. With the help of R=1-e{-AVd/g}, optimized values of Vd and Q were tabulated while keeping the electrode collecting area(A) constant, collection Efficiency in the range of 92~99% were attained.

The raw meal (semi finished product in form of dust) which was exhausted previously, added up to the production of the plant. As the total capacity of the clinker production of under study plant is 2500 TPD (Tons per day), it was estimated on the basis of physical stock taking that, by using a electrostatic precipitator equipment on the optimized operation parameters, overall collection efficiencies greater than 99 percent are possible. An estimated 8~ 10 TPH (Tons per hour) of feed lost in the form of dust /emissions from main exhaust were recovered as well as the calorific value of the pre-heating system was improved.

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