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PARTICULATE CONTROL STRATEGIES

FOR INCINERATION

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ABSTRACT

This paper discusses various particulate emission control strategies that can be employed for Municipal Solid Waste (MSW), Municipal Sewage Sludge, and Industrial Waste Incineration facilities. An example will be given of a particulate control installation that successfully cleans off-gases from an incinerator at a large photographic products plant.

Data supporting a theoretical model of Wet Electrostatic Precipitator (WESP) performance at a reduced flow will be presented. It is proposed this model could be used in adjusting EPA reporting parameters for reduced plant operation.

INTRODUCTION

In the United States, regulations for controlling the combustion/incineration of hazardous wastes in boilers and industrial furnaces, as well as existing and planned regulations for certain metals and organic compounds, are becoming increasingly stringent.

In addition, the fine fraction of particulate matter is now recognized as having a considerable detrimental effect on human health. Fine or submicron particulate can be harmful to one's health because of its size and possible chemical properties. A scientific review by the EPA concluded that "fine particles, which penetrate deeply into the lungs, are more likely than coarse particles to contribute to health effects."¹ This is especially dangerous when toxic heavy metals and/or gaseous components such as dioxins, which have condensed on the particles, are present in this size range. Most of the conventional air pollution control technologies are unable to remove or have difficulty removing fine particulate at acceptable energy levels, so alternative techniques have been developed.

In the early 1900s, Frederick G. Cottrell showed that an electrostatic precipitator (ESP) could successfully collect sulphuric acid mist in a 5,000 ACFM unit.² The design was subsequently modified to operate in a wet environment applied on a commercial scale (250,000 ACFM) to collect lead and zinc oxide fumes. Since that time, the design has been refined and used extensively in the nonferrous metallurgical industry to collect a variety of submicron fumes.

In the last two decades, the Acid Mist Precipitator has been used to collect submicron particles in other applications, where it is commonly called a WESP, including coke ovens, blast furnaces, wood dryers, power boilers, sewage sludge, and hazardous waste incinerators.³

It has been shown in studies on waste treatment incinerators that the WESP is particularly suited to collect submicron particulate ($<0.6 \mu\text{m}$) and heavy metals to meet the stringent EPA regulations now in place.⁴ The WESP has become a vital pollution control technology to meet more stringent air emissions standards. This paper discusses a series of stack emission tests conducted after the installation of a new air pollution control system, which included a WESP at Kodak's Kings Landing multiple hearth incinerator. Results of testing at Kodak's B-218 rotary kiln incinerator are also discussed briefly at the end of the paper. An approved alternate monitoring method to demonstrate compliance with hazardous waste incinerator operating requirements is also discussed.

POLLUTION CONTROL STRATEGIES

Gaseous pollutants can be absorbed, condensed, altered chemically, or thermally oxidized (combustion or catalytic processing). The removal of particulate and small droplets is carried out by one or more of the following mechanisms: gravity separation, centrifugal separation, inertial impaction, interception, diffusion, thermal and electrical precipitation, and agglomeration.

Others have presented detailed discussions of the various conventional air pollution control technologies employing these principles.^{5,6,7} Scrubbers can collect fine particulate, but only at excessively high energy costs. As the particulate approaches the submicron size range, a Venturi Scrubber becomes uncompetitive with other methods.

Fabric filters encounter significant challenges when used for incineration. While they are able to remove fine particulate, the main disadvantage of fabric filters is that they must operate at temperature ranges above the dewpoint, thus being unable to remove uncondensed vapors and gaseous pollutants. They cannot be used to collect sticky or moist particulate, which can adhere to and blind the fabric.

Although dry ESPs can be used, their size and cost become excessive for high efficiency collection of submicron particulate. They are also at a major disadvantage for high resistivity applications and applications where re-entrainment losses become significant, i.e., extremely low outlet loadings. A WESP treats a saturated gas stream and will generally have the advantage of a smaller footprint because of the reduced gas volume compared to that of the expanded gas at higher temperatures in a dry ESP.

PRINCIPLE OF WESP OPERATION

WESP operation is similar to that of a dry ESP, such that particulate-laden flue gases enter the unit through a gas distribution or baffle screen. This distribution device serves two purposes:

- ◆ To reduce pressure losses in the rather abrupt throttling, which occurs when the flow is decelerated to normal precipitator velocities (0.5–1.8 m/s); and
- ◆ To ensure uniform cross-sectional gas flow at the entrance to the precipitator.

Next, the gases pass between plates/rows or tubes, which are grounded collecting electrodes. A negative potential is applied to emitting electrodes, which are positioned in a parallel array between the collecting electrodes.

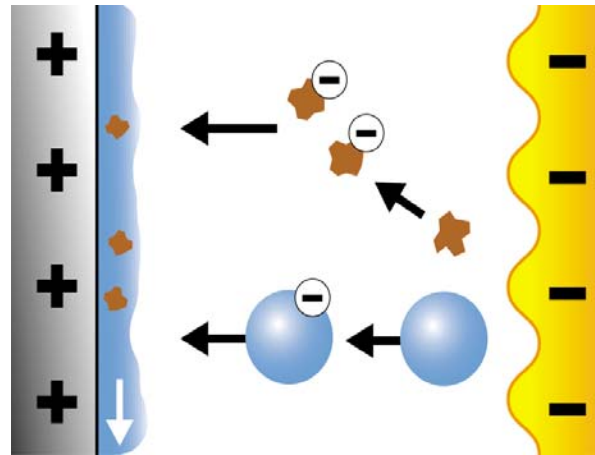


Figure 1 – How an ESP Works

If a sufficiently high voltage differential exists across the electrodes, the electrical breakdown of the gas surrounding the discharge electrodes results in a corona discharge. Gas ions formed in the corona move rapidly under the influence of the electric field toward the collecting electrode. Their charge is transferred to the solid and liquid particles by collision with them and in the case of fine particulate, the transfer of charge also occurs by diffusion of the ions from the region of corona and subsequent attachment to the particles. The action of the electric field between the electrodes causes the particles to move towards and deposit upon the collecting electrodes, where a liquid film is utilized to continuously remove particles.

WESP CONFIGURATION ALTERNATIVES

The two most common types of WESP configuration arrangements are plate and tubular. Most conventional dry ESPs use an array of vertically hung parallel plates or modules with the gas passing through the unit horizontally. This design has also been modified for WESPs; however, there are certain disadvantages in this arrangement. It has been found that in applications involving sticky dust, increased water sprays are required to avoid sticky organic buildup on the plates. Increased water spraying leads to increased flashover (reduced performance and spark erosion) and the need for larger water treatment facilities. In addition, a mist eliminator is usually required to avoid droplet carryover at the outlet. In a conventional vertical flow WESP, the sticky organics are collected on a water film that flows down the tubes.

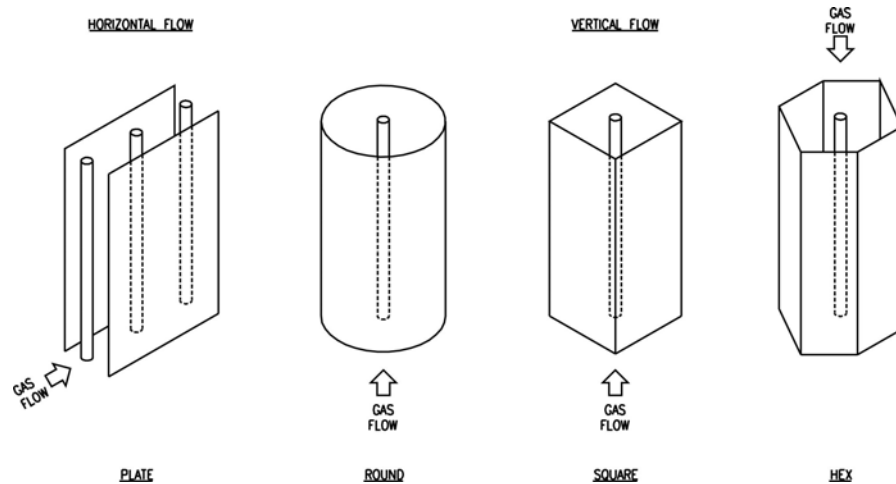


Figure 2 – Configuration Alternatives

One of the major disadvantages of the round tube design is the large footprint required, especially in larger units where the spacing between tubes must be increased to allow for additional stiffening. One way of overcoming this large footprint is the use of rectangular tubes; however, there are disadvantages in that it is difficult to keep the walls properly wetted, especially in the corners where buildup can occur.

A major user of WESPs in the nonferrous metallurgical industry, INCO Ltd., first proposed using a hexagonal (hex) tube design in a patent application in 1982.⁸ One of the main features of the design is that it combines the benefits of the space savings provided by a square unit and at the same time more closely approximates the corona occurring in a round tube.

The hex tube design also has a material savings in that both sides of the tube are used as a collecting surface. It is not necessary to seal each individual tube; minor exchange of gas flow from one to the other will not detract from performance as it would in a round tube unit. In addition, the outer perimeter of the unit can be used as the shell, thus avoiding the necessity of having a vessel within which the tubes must be mounted. The SonicKleen WESP, employing both a hex tube and vertical down flow configuration, was considered to be the optimal configuration by Kodak and was selected for the Kings Landing facility (see Figure 3) in 1994.



Figure 3 – TurboSonic SonicKleen WESP

TREATMENT PLANT LAYOUT

The pollution control equipment installed at the Kings Landing facility in 1994 was designed to clean off-gases from an existing BSP/Envirotech multiple hearth sludge incinerator. The incinerator burns sludge that results from the adjacent industrial wastewater treatment process.

The objective of the air pollution control devices (APCD) was to limit the emissions to the atmosphere to meet Federal RCRA (40 CFR Part 264) and New York State (6 NYCRR Part 373) hazardous waste incinerator regulations. The incinerator had an existing system consisting of a Venturi and Tray Scrubber; however, it was not adequate to handle the volume of off-gases resulting from the installation of a new Secondary Combustion Chamber (SCC) and was removed by Kodak to make room for the new devices. The installation of a new SCC was considered necessary to meet the destruction removal efficiency for organics and carbon monoxide in the off-gases from the multiple hearths (See Figure 4).

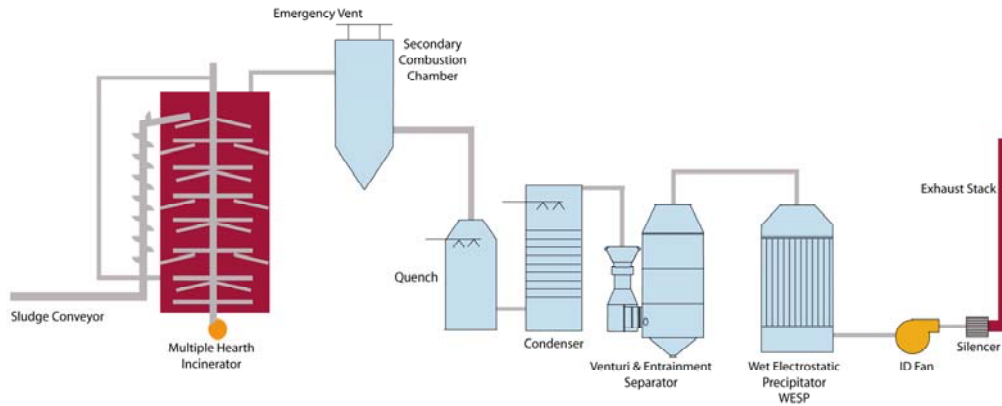


Figure 4 – Schematic Of Kings Landing APCD

The installation is described as follows:

- ◆ A Quench tower to cool the combustion products from the SCC to the saturation temperature;
- ◆ A Separator or Direct Contact Cooler (DCC), providing condensation nucleation of the fine particulate by cooling the gas below the saturation temperature;
- ◆ A Venturi Separator style wet scrubber; and
- ◆ A down flow hexagonal WESP to remove submicron sized metals and particulates.

The treated gases exit the WESP through an induced draft (ID) fan for release to the atmosphere through a new stack.

The single casing down flow WESP has a similar configuration as that illustrated in Figure 3, using 85 tubes @ 13', with a 1.17 KVA (DC) Transformer Rectifier Set. The design inlet gas flow was 20,500 ACFM @ 105 °F, -60 WG with each of the heavy metals and particulate inlet load to the WESP specified in Table 1 below.

Table 1

Material	Lbs/hr
HCl	0.518
SO ₂	1.193
As	0.819
Cd	0.034
Cr+6	0.071
Pb	0.474
Ni	0.052
Particulate	0.03 gr/DSCF

EMISSIONS TESTING RESULTS

Two sets of emissions tests are discussed in this report. The first set was conducted before the upgrade in 1992 under typical operation using the sludge that existed on the day of the test. The second set is from a Trial Burn conducted in 2001, except the mercury results are from a later Comprehensive Performance Test (CPT) conducted in 2002. These 2001–2002 tests were conducted under worst case conditions, including maximum gas flow and feed rates, minimum APCE water flow rates, and WESP-specific power, with maximum temperature for the metals test and minimum temperature for the DRE and THC tests. Metal solutions were fed in addition to the sludge to create a maximum metals feed rate for the metals test.

Results of emissions testing before and after the upgrade are summarized below and compared to the Hazardous Waste Combustor Maximum Achievable Control Technology (HWC MACT) interim emissions standards, which were effective in 2003. As is shown in Table 2, following the upgrade all emissions met the HWC MACT standards.

Table 2 – Emission Test Results

Emission Category (units)	HWC MACT Emission Standard (Effective 2003)	Trial Burn and CPT Test Results (2001-2002)(Worst case conditions, max metals feed rate)	Pre-1994 upgrade (1992)(Not tested at maximum metals feed rate)
Particulate (gr/DSCF)	0.015	0.0033	0.025
HCl/Cl ₂	77	<0.145	-
Carbon Monoxide (ppm)	100	1.6	-
Total Hydrocarbons (ppm)	10	1.4	-
Low Volatile Metals (As, Be, Cr) (ug/m ³)	97	11.6	74
Semi-Volatile Metals (Pb, Cd) (ug/m ³)	240	227	2700
Dioxin/Furans- TEQ (ng/m ³)	0.4	0.00061	-
Mercury (ug/m ³)	130	61	19
DRE- chlorobenzene (%)	99.99	>99.9999	-
DRE- toluene (%)	99.99	>99.9987	-

*All standards except DRE are corrected to 7% O₂.

Metals removal efficiencies before and after the upgrade are shown in Table 3. This table shows the dramatic increase in metals removal efficiency following the 1994 upgrade.

Table 3 – Pre and Post Upgrade Results

Metal	2001 Trial Burn Removal %	1992 Pre-Upgrade Removal %	Ratio of emissions after the upgrade to before the upgrade based on removal efficiencies
Antimony	99.96	88.89	0.0037
Arsenic	99.91	85	0.0058
Barium	99.98	99.88	0.14
Beryllium	99.97	94.55	0.0053
Cadmium	97.95	81.82	0.11
Chromium	99.97	95	0.0063
Lead	99.11	82.05	0.050
Nickel	99.99	96.14	0.0038
Silver	99.92	98.79	0.063
Zinc	99.87	84.67	0.0084

EMISSIONS MODELING RESULTS

Following the 1994 upgrade, Kodak conducted eight sets of tests with three runs under each test condition to determine the impact of different variables in order to minimize emissions. Using this collection of data, a predictive linear model was created using a partial least squares linear modeling program (developed by Charles Heckler, Kodak statistician) to predict the impact of varying operating conditions. The model results for lead and cadmium removal efficiency are shown in Table 4. Correlations are moderate at about 0.75. These models can only be used to simulate emissions near the range of operating conditions used in the test series, because most variables do not have a linear impact on emissions, particularly over a wider range of conditions.

Table 4 – Correlation Coefficients

Predicted Compound	Correlation of Actual & Predicted Emissions	Y Intercept	#3 Hearth Temp (F)	Venturi Pressure Drop (in of water)	Ash Feed Rate (lb/hr)	Chlorine Feed rate (lb/hr)	Stack Gas Air Flow Rate (ACFM)	Specific Power (VA/1000 ACFM)
Pb RE %	0.78	102.968	-0.00188	0.0134	-0.00359	-0.00344	-0.0000226	0.00259
Cd RE %	0.75	104.430	-0.00353	0.0299	-0.000744	-0.0170	-0.0000507	0.00576

Current HWC MACT standards require that all conditions are the same or better than the conditions run during the Trial Burn/CPT. This model shows that not only will this facility meet the emissions standards when all operating conditions are the same or better than the conditions run during the trial burn, but that emissions standards can be met even when some operating conditions are less stringent than those occurring during the Trial Burn/CPT. This model allows prediction of whether a particular variation in operating conditions outside the permitted range would cause the emissions to exceed the standard. This model confirms that increasing specific power positively improves removal efficiency.

WESP SPECIFIC POWER ALTERNATIVE MONITORING PETITION

As part of the Trial Burn approval, the agency required that the multiple hearth WESP maintain the same voltage or power that was maintained during the Trial Burn/CPT testing. Although Kodak maximizes WESP power input using the automatic control system, power will still vary with gas conditions. This forced Kodak to reduce the power output to the WESP during the Trial Burn/CPT test. However, Kodak did not want to unnecessarily limit power, so an Alternative Monitoring Petition was submitted requesting a specific power limit (power/air flow rate) instead of simply a power limit, so operating limits could be met by lowering air flow rate if gas conditions caused a power reduction. Because specific power is the key to WESP design, it is a better predictor of WESP performance than power alone. Specific power is defined as the WESP secondary power/gas flow rate.

WESP removal is typically determined by the well-known Deutsch Equation,² which states that:

$$\eta = 1 - \exp(-Aw/Q) \quad (1)$$

where

A = WESP collection area,
w = particle migration velocity,
Q = gas flow rate through the WESP, and
 η = collection capacity

Particle migration velocity can be estimated by the following equation:²

$$w = kP/A \quad (2)$$

where

P = power input to the WESP (secondary power), and
k = a constant based on the characteristics of the WESP

Inserting equation (2) into equation (1) gives

$$\text{WESP removal} = 1 - \exp(-kP/Q)$$

Based on this equation, if kP/Q is constant, removal is constant. If kP/Q increases, then removal will increase. Therefore, if there is a minimum kP/Q limit based on the Trial Burn/CPT average, then performance will always be better than or equal to the removal efficiency demonstrated during the CPT. Because only P/Q is variable for a given WESP, a P/Q minimum limit ensures that performance will always be better than or equal to the removal efficiency during the CPT. Therefore, Kodak proposed that the WESP performance be based on the rolling hour average specific power, P/Q , established as the average of the test run averages during the Trial Burn/CPT.

The Agency approved this petition, but required the automatic controller to maximize voltage and a minimum power set at 85% of the WESP power level during the Trial Burn/CPT maximum test. Kodak has been able to meet those requirements 100% of the time since the September 2003 compliance date.

B-218 INSTALLATION RESULTS COMPARED TO REGULATIONS

Kodak also operates a rotary kiln hazardous waste incinerator at Building 218 at the Kodak Rochester site. This unit consisted of a rotary kiln, SCC, adiabatic Quench Tower, Venturi Scrubber and Separator, and two ID Fans in series, complete with silencers discharging to a common stack. In order to meet the new MACT waste incinerator regulations, complete replacement of the existing APCS was completed.

The flow sheet of the new system installed in 2001 is presented in Figure 5 below.

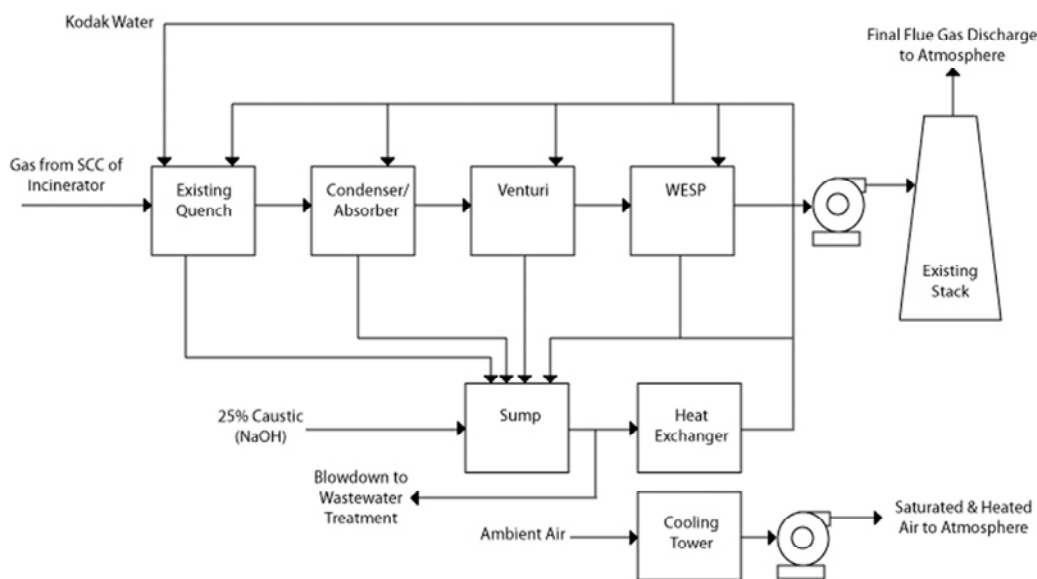


Figure 5 – Upgrade Of B-218 APCS Equipment

The WESP performance data from the Kings Landing unit was useful in confirming the sizing of this much larger installation. Kodak again chose a SonicKleen design, supplied by TurboSonic. The unit was designed for 71,133 ACFM saturated gas, at 111 °F, with a design pressure of -55" WG. Rather than supplying one or two large units, which would be difficult to ship, four units were supplied. Each unit comprised of 169 15' hex tubes, constructed of 316L SS. The WESP installation was arranged in two trains, each comprising of two WESPs in series (See Figure 6).



Figure 6 – SonicKleen WESP on B-218 Rotary Kiln

The test results, shown in Table 5, met all standards including both the interim HWC MACT standards that were effective in 2003 and the final HWC MACT standards that are effective in 2008.

Table 5 – B-218 Emission Standards And Test Results

Pollutant	Interim Standard (63.1203)		Final Standard (63.1219)	MH-TB CPT	218 Trial Burn Testing
PM*	0.015	gr/dscf	0.013	0.0033	0.0037
SVM	240	ug/dscm	230	220	<9
LVM	97	ug/dscm	92	12	<15
Hg	130	ug/dscm	130	79	<37
Cl	77	ppmv	32	0.14	<0.4
D/Fs wet	0.4	TEQ ng/m3	0.4	0.0034	0.21
CO	100	ppmv	100	5	N/A
THC	10	ppmv	10	N/A	<1
DRE	99.99	%	99.99	>99.999	>99.999

*All standards except DRE are corrected to 7% O₂.

CONCLUSIONS

The installation of the TurboSonic WESPs at the Kodak incinerators in Rochester have successfully allowed Kodak to continuously meet both current and future standards.

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