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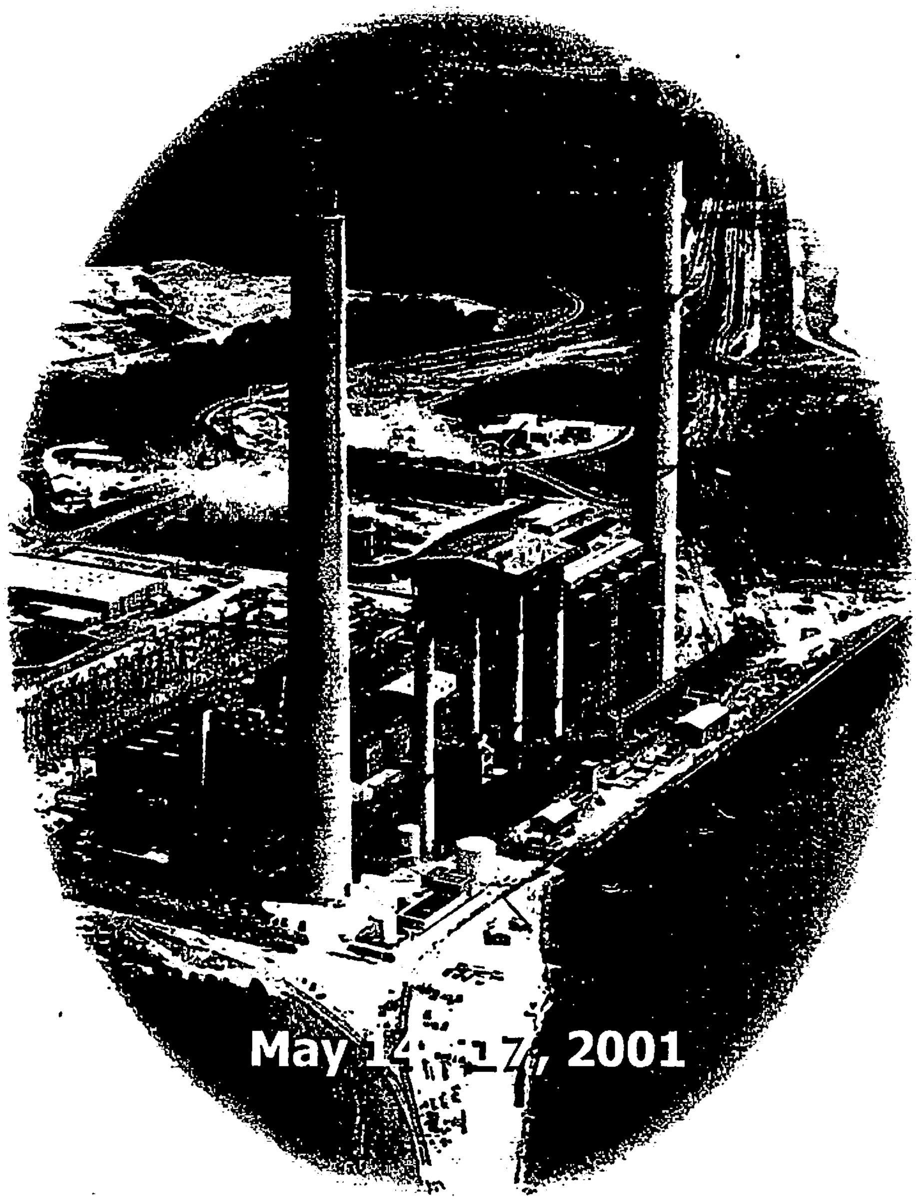

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INCINERATION FACILITY EMPLOYS WET ESP POLUTION CONTROL TECHNOLOGY TO MEET NEW EPA MACT MULIT-POLLUTANT STANDARDS

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Abstract

Eastman Chemical Company, Tennessee Eastman Division wished to upgrade its existing incineration facilities to meet future anticipated MACT regulations, which will be in effect on September 30, 2002. The wastes generated at Tennessee Eastman are primarily high BTU, organic materials that can be effectively managed through combustion. For disposal of these wastes, Tennessee Eastman operates three incineration units, a liquid chemical destructor and two rotary kilns. In addition, Tennessee Eastman co-manages some high BTU wastes and biological wastewater treatment sludges in coal fired boilers used to produce steam and electricity for the facility.

Introduction

Wastes disposed at the three incineration facilities vary in BTU, ash, chlorine and metals content. There are over 2000 active waste streams compiling the waste profile. Additionally, approximately 300,000 solid waste containers and over 20 million pounds of general trash and other loose bulk solid waste are disposed annually. Thermal incineration is a proven technology for the efficient destruction of hazardous wastes that are generated as a by-product of chemical manufacturing and similar industrial processes.

However, while incineration is often the preferred method for waste disposal, the process has the potential to produce such undesirable air pollutants as:

- Products of incomplete combustion (hydrocarbons & carbon monoxide)
- Particulate material (ranging from 0.01 to 100+ micron in size)
- Halogen gases (hydrogen chloride & chlorine)
- Heavy metals (semi-volatile, low volatility & mercury)
- Poly-chlorinated organic compounds (dioxins & furans)

In considering the severely toxic nature of these pollutants on human health and the environment, the US EPA has recently enacted a set of MACT ("Maximum Achievable Control Technology") standards for hazardous waste combustors, which are designed to minimize release of those pollutants to the atmosphere.

While control of hydrocarbon and carbon monoxide emissions must be addressed within the incinerator envelope, through more efficient combustion, the other regulated pollutants must be removed from the exhaust gas by other means. Therefore, a properly designed and operated Air Pollution Control System (APCS) must be incorporated as an integral part of the incineration system.

The APCS can become very complex and expensive, since it must incorporate multiple, highly sophisticated Air Pollution Control Devices (APCD) to achieve the low allowable discharge levels for the pollutants regulated under the new MACT standards.

One technology, that can provide the required level of removal efficiency for all of the non-combustion controlled pollutants is a Wet Scrubber/Wet Electrostatic Precipitator combination.
Wet scrubbing is a well-known and accepted technology for abatement of halogen gases and coarse particulate material and is an integral component of any "wet" pollution control train. Abatement of sub-micron particulate (including adsorbed metals and organics), however, requires a more sophisticated device to achieve the required reduction. Although many technologies exist that will provide adequate efficiency for one

or several of the targeted pollutants, the Wet Electrostatic Precipitator is perhaps the single wet device that can address fine particulate, heavy metals and dioxin/furan compounds simultaneously. [1]

Theoretical Aspect of Wet Electrostatic Precipitation

The wet electrostatic precipitation process can be divided into three fundamental steps:

- Charging of particles and water droplets
- Collection of charged particles and water droplets on the surface of collector
- Removal of collected particles from the surface of the collector for disposal by intermittent or continuous washing

Charging Mechanism

Charging of the particles occurs by two distinct particle-charging mechanisms:

a) Field charging (of primary importance for particles greater than 0.5 micron), where particles are charged by the bombardment of negative ions moving from the ionizing electrode towards the collecting wall

b) Diffusion charging (more important for particles smaller than 0.2 micron), which occurs because of the thermal random motion of the sub-micron particles and their collision with negative ions

In the intermediate size range between 0.2 and 0.5 micron both charging mechanisms are important. In field charging, the intensity of the electrical field, the total surface area of the particles and their dielectric properties play a major part in the process. In ion diffusion charging, the operating current, the ions mobility (a function of temperature) and the gas velocity in the precipitator are the most important factors. This leads to the conclusion, that for applications with a substantial portion of particles below 0.5 micron, the operating current and residence time become significant design factors.

Collection Mechanism

As soon as the particles and droplets acquire some charge, they will be influenced by the field in the precipitator and will begin their migration towards the collecting wall by the Coulomb force and resisted by inertial and viscous forces. For sub-micron particles, inertial forces are insignificant and the particle attains the velocity determined by the equilibrium between Coulomb and Stokes forces. This velocity is known as the migration velocity (*w*). Particle trajectory towards collection surface is not a vector sum of migration velocity and gas velocity. In reality particle motion is dominated by gas turbulence and particle collection becomes a matter of probability when particle enters the laminar boundary region where the Coulomb force is effective. The probability or efficiency of particle capture is increasing with the higher migration velocity which in turn depends upon operating corona power. After the particle or liquid droplet is contacting the collection surface of the Wet ESP the probability of reentrainment is minimal

Removal Mechanism

In a Wet Electrostatic Precipitator (WESP), collected particles are removed from the surface of the collector by liquid irrigation. The mechanism for delivery of the liquid is different for various WESP designs.

In conventional WESP's, the washing liquid is sprayed from the top in down-flow designs and from the bottom in up-flow designs. Each of these methods has the potential to reduce the WESP efficiency due to increased sparking from the water sprays or incomplete irrigation of the collection surface, resulting from clogged spray nozzles. In the conventional down flow WESP the final separation of the liquid droplets from the moving gas is accomplished by gravity that really doesn't work for small droplets, that can be generated by the sparking at the bottom of the collector.

In contrast, the condensing type of WESP is continuously self-cleaning, with an even moisture distribution across the entire collecting surface. Clean water, condensed from the saturated process gas, forms a liquid film on the collection surfaces, eliminating the need for troublesome spray nozzles and excessive treatment of the recycle liquid [2].

Estimating WESP Efficiency

The exponential Deutsch-Anderson equation is extensively used as a design basis for predicting the performance of a single-stage dry precipitator. Field experience has shown that, with little modification, the same equation can also be applied to wet precipitators. In fact, since wet ESP's are immune to such problems like resistivity, back corona and secondary reentrainment, the calculated values of migration velocity W are much closer in wet ESP's to the empirical values of W or so-called precipitation rate parameter

In its simplest form, the Deutsch-Anderson equation is given as:

$$\text{Eff} = 1 - \text{Exp}\,(-Aw/V) \qquad (1)$$

The collecting electrode surface area, *A*, and volumetric flow rate, V, are calculated from the known geometry of the WESP and the process design data. The drift, or migration, velocity, *W*, is generally determined from data collected on similar applications, pilot testing, or in the absence of such empirical data, the migration velocity is calculated for a given particle size, intensity of electrical field, corona current density and viscosity of the gas.

From Figure 1a for duct precipitators,

$$\frac{A}{V} = \frac{2Lh}{2Shv} = \frac{L}{Sv} \qquad (2)$$

So,

$$\text{Eff}_{DP} = 1 - \text{Exp}\,(-Lw/Sv) \qquad (3)$$

From Figure 1b for tubular precipitators,

$$\frac{A}{V} = \frac{2\pi RL}{\pi R^2 v} = \frac{2L}{Rv} \qquad (4)$$

Therefore,

$$\text{Eff}_{TP} = 1 - \text{Exp}\,(-2Lw/Rv) \qquad (5)$$

Comparison of Equations (3) and 5 shows: [3]

- For a given efficiency a tubular precipitator may be operated at twice the gas velocity of a duct precipitator of equal electrode length and inter-electrode spacing.
- For a given gas flow (volumetric flow rate) efficiency of the duct precipitator is independent of duct spacing.
- For a given volumetric flow rate, efficiency of a tubular precipitator increases with increase in tube diameter

For the project at hand the Condensing WESP™ of two (2) pass arrangement was installed. For condensing WESP the Deutsch-Anderson equation can be presented as:

$$\text{Eff} = 1 - \text{Exp}\,(-AK_c\,W/v)$$

TABLE 1-1
PERFORMANCE TEST RESULTS

Constituent	Performance Test Emissions [1,2] (average of 3 runs)	MACT Performance Requirement	Croll-Reynolds Performance Agreement
Particulate matter	0.0026 gr/dscf	0.015 gr/dscf	0.015 gr/dscf
Hydrogen chloride/chlorine	3.8 ppmdv (as HCl/Cl_2 combined)	77 ppmdv (as HCl/Cl_2 combined)	75 ppmdv (as HCl/Cl_2 combined)
Low-volatility metals (including arsenic, beryllium, and chromium) [3]	< 42.9 µg/dscm for As, Be, Cr combined	97 µg/dscm for As, Be, Cr combined	55 µg/dscm for As, Be, Cr combined
Semi-volatile metals (including cadmium and lead) [4]	< 5.14 µg/dscm for Cd and Pb combined	240 µg/dscm for Cd and Pb combined	100 µg/dscm for Cd and Pb combined
Dioxins / furans (tetra-octa PCDD/PCDF congeners) [5]	< 0.0107 ng TEQ/dscm	0.4 ng TEQ/dscm	0.2 ng TEQ/dscm

Notes:

1. All concentrations are corrected to 7% O_2.

2. "<" indicates that at least one fraction of the sampling train was less than the detection limit for one or more compounds.

3. The possible range of the average LVM emissions was 40.1 – 44.6 µg/dscm at 7% O_2. The lower value in the range does not consider fractions reported as "non-detect" (i.e., non-detect = 0). The higher value in the range includes fractions reported as "non-detect" (i.e., non-detect = the detection limit).

4. The possible range of the average SVM emissions was 3.66 – 5.35 µg/dscm at 7% O_2. The lower value in the range does not consider fractions reported as "non-detect" (i.e., non-detect = 0). The higher value in the range includes fractions reported as "non-detect" (i.e., non-detect = the detection limit).

5. Emissions results for dioxins/furans includes fraction reported as "non-detect" for conservativism (i.e., non-detect = the detection limit).

Where:

Kc – empirical coefficient reflecting the influence of thermal forces on the submicron particle. The temperature differential between hot saturated gas and cold wall of he collecting surface of the WESP is providing two mechanisms:

Thermophoresis will take place when the gas temperature on opposite sides of a particle differ. Gas molecules on the warmer side have a higher kinetic energy, and so they'll strike the particle with more force than will molecules on the cooler side. This unbalanced striking force causes the particle to move away from the warmer temperature zone towards cold collecting surface. The velocity at which the particle moves depends on the temperature gradient across the particle, the relative thermal conductivities of the gas, particle, density and viscosity of the gas.

Diffusiophoresis will take place in the vicinity of cold wall of the collector when the partial water vapor pressure in the carrier gas is greater that the water vapor pressure at the surface of the water droplets of scrubbing liquid. In this case, water vapor will condense into the droplets. A bulk motion of gas toward the droplets is created to replace the condensed vapor. This gas movement sweeps the particle toward the droplet and impinges the particle upon the droplet.

Velocity Distribution

Velocity through the precipitator is the only flow parameter involved in the Deutsch-Anderson equation and assumes even flow distribution. In practice, however, this condition is very difficult to achieve. Non-uniform gas flow can affect the precipitator performance by scouring the collection surface in localized regions of high gas velocity and by reducing performance due to the exponential relation between efficiency and the gas flow. Poor gas flow distribution can decrease the precipitator efficiency by as much as 20 to 30%. For single stage units, Dry ESP 1/10 or 1/16 scale model studies are usual. Such expensive studies are rarely undertaken for the vertical tubular WESP's. Various air distribution devices are used in the WESP's. Also, well-engineered equipment layout can also materially contribute to the efficient air flow distribution in the precipitator.

By combining a WESP with a low-energy scrubber, located in the inlet or bottom section, the additional benefit derived from such an arrangement will be the improved gas distribution through the marble bed, packed bed or *similar scrubber. (Fig. 2)*

Electrical Energization

Electrical energization is a very important factor in the design of the WESP. Unlike Dry ESP's, the power input into the WESP's is not limited by the resistivity of the dry cake of accumulated particles on the collection surface. A wet ESP requires lower voltage peaks and can have much higher average voltage.

It is a well established fact that migration velocity, and therefore efficiency, of the WESP is directly proportional to the corona power (the product of the operating secondary voltage and the operating corona current) [3]. Since efficiency of particulate removal is in effect a probability of capture, the uniform distribution of a corona current density within an ionizing section of the WESP becomes a very important design parameter. Theory and practice has demonstrated that the best uniformity of corona discharge can be achieved in the round tubular WESP. Plate design WESP's are compensating the lack of the uniformity by extensive surface area of collection usually at least double of a round tubular WESP.

During normal operation, corona power is limited by internal sparks between the ionizing electrodes and the collecting tubes. Since the WESP efficiency is directly proportional to the electrical power conveyed to the moving gas, each time a spark occurs, the voltage, and consequently the particulate collection efficiency, is reduced.

In a WESP, for a given set of gas flow conditions and fine particle concentration, the sparking rate is a function of:

- Gas Velocity
- Concentration of entrained liquid droplets
- Quality of the WESP components assembly(mainly alignment of electrodes)
- Selection of high voltage power supply to match both WESP geometry and the physical size.

The power level and efficiency of a WESP can be dramatically increased by properly designing the automatic voltage control system and current limiting reactor (CLR) [4]. While the industry average seldom goes beyond 40% conduction, the proper selection of the transformer-rectifier (T/R), automatic voltage controller (AVC) and automatic current-limiting reactor (ACLR), can deliver up to 86% conduction (the maximum theoretically possible) (Fig. 3).

Corona Current Suppression

For Hazardous Waste Combustor applications, where the majority of particles entering the WESP are below 0.5 micron, and the total concentration of these particles are likely to be 1.0 gr/acf or higher, the geometry of the WESP internals, as well as the design of the high-voltage power supply, becomes very important in order to achieve high removal efficiency.

Corona suppression can occur with a medium concentration of fine particles or with a heavy concentration of large particles. Since the particles are being charged to the same polarity as the gas ions, this combination has the tendency to reduce the electric field at the discharge electrode and, in some cases involving very high concentration, may reduce the corona current by a factor of 50 or more. This phenomenon is known as corona current suppression.

Although corona current suppression (or corona quenching) can dramatically lower the power input into the WESP, it does not necessarily diminish the particulate removal efficiency to the same extent. This is true since in addition to the current reduction, the space charge effect increases the operating voltage in the vicinity of the collector [3].

Certain criteria should be met in order to prevent the deterioration of removal efficiency in the presence of a space charge effect. The level of current suppression that will be experienced in a particular application is related to the surface area of the suspended particles per unit volume of gas and designed corona current density within the WESP ionizing section (Fig. 4).

It is important to note that the higher the corona current density with clean gas conditions the lower will be the damaging effect of corona current suppression on the removal efficiency.

Several options are available to the designer of the WESP when corona current suppression may be a factor for a waste incinerator exhaust.

- Reduce the inlet loading of large particulate to the WESP, through the use of a prescrubbing section.
- Provide a method of sub-cooling of the flue gas, below adiabatic saturation, in order to take advantage of the effects of flux force condensation on particle growth and their subsequent collection by mechanical means.
- Design the discharge electrode and the inter-electrode spacing to provide the lowest possible corona starting voltage and the highest possible corona current density.
- Select the optimum residence time (i.e. gas velocity) in the WESP to insure the maximum possible particle charging under suppression conditions
- Provide at least two (2) passes (fields) with independent power supplies for each pass.

In the case of two passes in the WESP, with independent, high voltage power supplies for each pass, efficiency of 99.99% can be maintained even in the presence of current suppression. The first pass will operate in "suppressed" conditions at a somewhat reduced efficiency level, but it will condition the gas for the second pass, which will operate at its full design potential. With proper design, the total efficiency of the system, despite the reduced corona current in the first pass, is very high and directly proportional to the combined (total) operating power from both high voltage power supplies.

Conclusions

1. The tubular, up-flow, condensing WESP is providing the necessary efficiency of 99.99% to permit existing Hazardous Waste Combustors to meet the newly enacted MACT standards. Careful consideration must be given to the design of the basic system to account for the effects of corona current suppression.

2. Properly designed prescrubbing system with subcooling is providing the liquid mist for dioxin and furans adsorption and their subsequent removal in the WESP.

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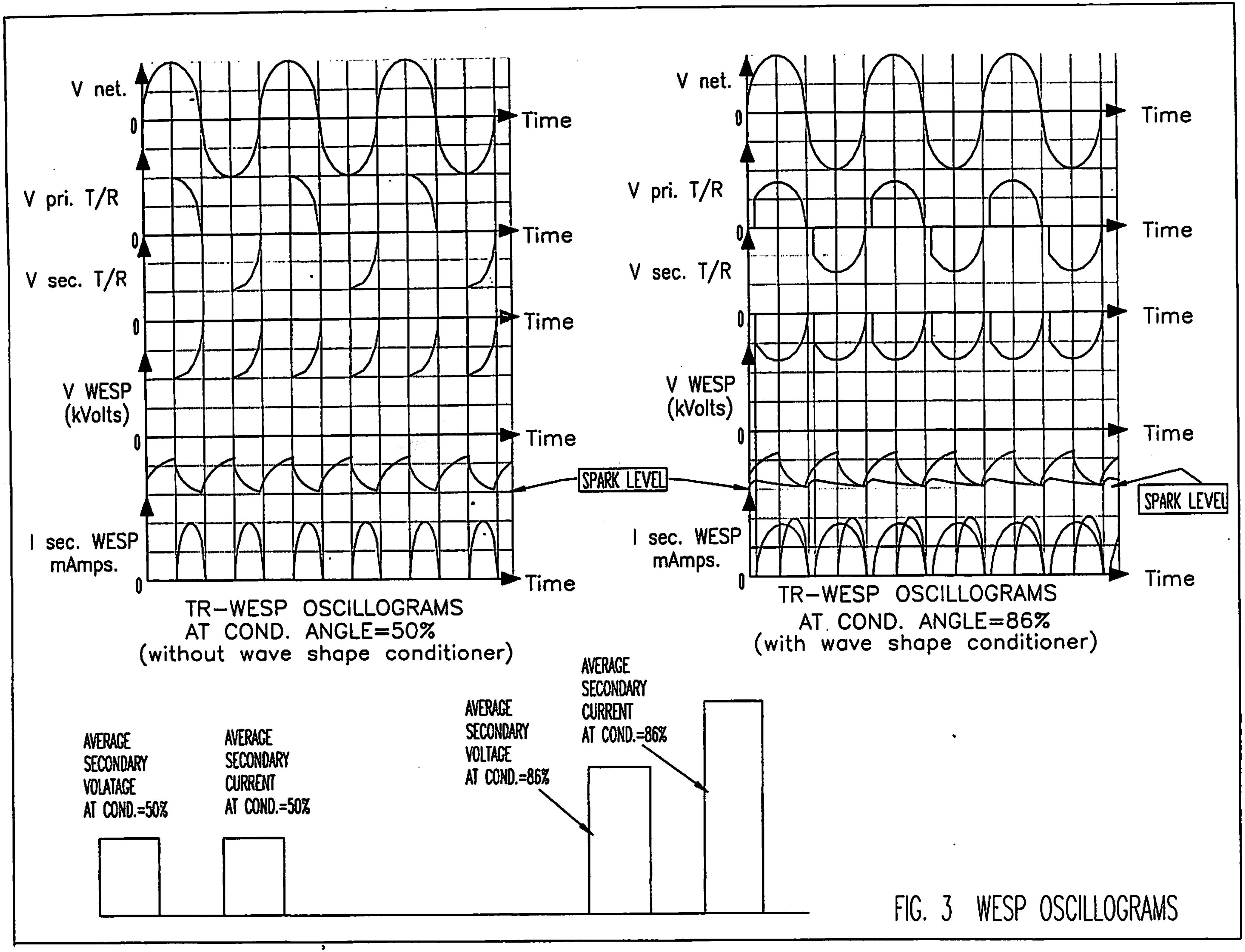

FIG. 3 WESP OSCILLOGRAMS

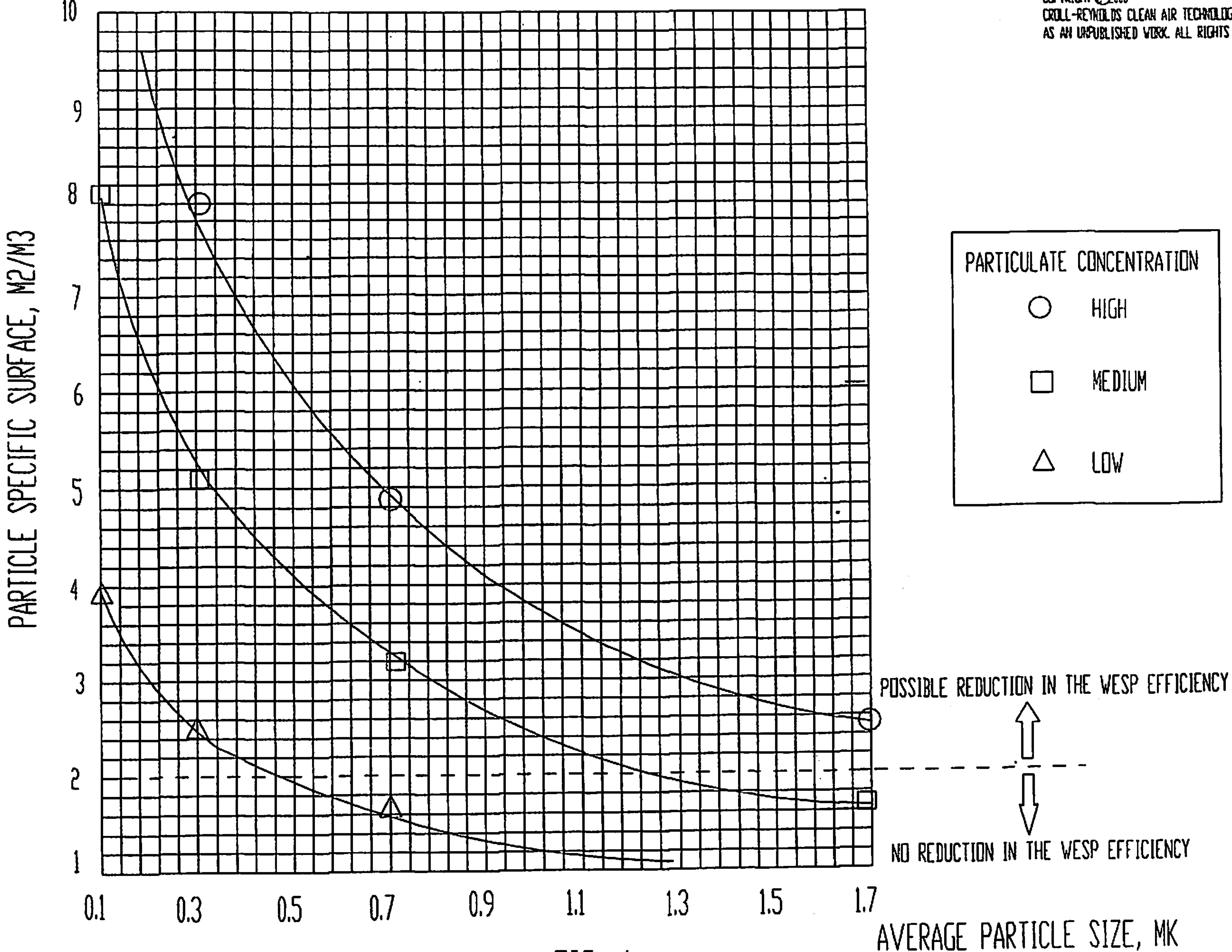
PARTICLE SPECIFIC SURFACE, M2/M3
10
9
8
7
6
5
4
3
2
1
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
1.7
AVERAGE PARTICLE SIZE, MK
PARTICULATE CONCENTRATION
HIGH
MEDIUM
LOW
POSSIBLE REDUCTION IN THE WESP EFFICIENCY
NO REDUCTION IN THE WESP EFFICIENCY

FIG. 4