21st Century ESP Design
Synergism of Old and New Concepts

By

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INTRODUCTION

Until recently, it was believed that dust emission levels from pulverized coal fired boilers at or below 0.015 lb/Mbtu could be routinely achieved only with fabric filters. Since the turn of this century, there have been advances in electrostatic precipitator (ESP) design, along with the equipment that provides power for the process, that have substantially lowered this imaginary floor to emission levels that rival those delivered by fabric filter technology. Data provided in this paper will demonstrate the effects of thoughtful application of three (3) ESP design technologies - discharge electrode configuration, power supply type, and collecting plate spacing - into the design of two utility ESP's. The first application is on an 80 MW utility ESP rebuild, and the second, a 460 MW Coal Fired ESP Retrofit. These results exceeded expectations by a wide margin.

While this report focuses predominately upon design improvements that are relatively new to the ESP industry, it would be remiss to ignore other, more basic elements of ESP design that are essential when designing for today's low emissions standards:

Gas Flow Distribution

Many well-designed ESP's have failed to live up to performance expectations because little or no attention is paid to gas flow uniformity in upstream ductwork, through the ESP treatment zone, and at the ESP exit plane. Hard ductwork turns, insufficient or improper vaning, high expansion ratios for inlet nozzles, and improper perforated plate selection are several of the main culprits. Modern, high efficiency ESP's cannot function effectively unless the minimum flow distribution standards stipulated in ICAC EP7 are met at the ESP inlet. Extensive flow studies were performed on each of the ESP units mentioned herein using 1/12 scale physical models, which have been found to be extremely reliable in simulating actual flow conditions and allowing adjustments on the fly. On a broader scale, where multiple ESP chambers or casings are a part of the overall arrangement, it is equally important that the gas flow volume be equalized over each parallel section.

Hopper and Anti-Sneakage Baffling

Achievement of the low particulate outlet loadings noted herein would not be possible without careful attention to flue gas sneakage in the treatment zone of the ESP, and particularly in the ESP hoppers. These areas are closely monitored during the flow model testing to insure that proper baffling is installed in the ESP that properly directs the flue gas through the treatment zone, and that flow in and around the ESP hoppers is kept “quiet” to prevent reentrainment.

Electrical Sectionalization

Experience has told us that modern, high-efficiency ESP’s function well with a high degree of electrical sectionalization, which allows maximum flexibility of independent bus section energization to accommodate different operating conditions within the ESP. Each of the units highlighted in this paper are designed with maximum sectionalization.

Rapping Ratio

Several of the ESP’s mentioned in this paper are outfitted with comparatively tall collecting plates. In designing rapping systems for these, and to a lesser degree, shorter plates, careful attention must be paid to the collecting plate area rapped by each electromagnetic rapper. For each installation studied herein, the rapping ratio for the collecting electrode system is $\leq$ 1500 ft2 per rapper. Conservatism in this critical area is essential for attainment of the high particulate removal efficiencies noted herein.

ESP DISCHARGE ELECTRODE DESIGN

The ELEX/RS discharge electrode has an operating history in the U.S. dating back into the 1970’s. The characteristics and performance of this electrode have been well documented in several recent technical papers [(1)]. It is widely recognized that this electrode is among the best current distributing discharge electrodes in the industry, and typically promotes production of very high current densities. These characteristics alone lead to better overall ESP performance.

An additional feature of this electrode, as documented in a recent publication [(2)], is its adaptability to customization. This capability permits the designer to create an optimum set of electrostatic conditions in several different areas of an ESP. An example would be doubling the quantity of electrode emitter points in the inlet field(s) of an ESP, enabling production of higher current levels to overcome space charge effect, coupled with a voltage enhancing electrode configuration in the latter fields.

An additional optimization feature of the ELEX electrode is the ability to vary the tip spread of its emitter tabs. Air load tests[(3)] have demonstrated corona current density increases of as much as 44% over pipe and spike type electrodes, as illustrated in figure 3. The ability to effectively control the voltage/current relationship in each area of the ESP through variation of the emitter tip spread is a feature available only with the ELEX electrode, and is one reason for its typically superior performance.

Examples of several customization possibilities are shown in figures 1 and 2 that follow. These optimization features have been successfully employed since the late 1990's.

Figure 1 – **ELEX RDE PROFILES**

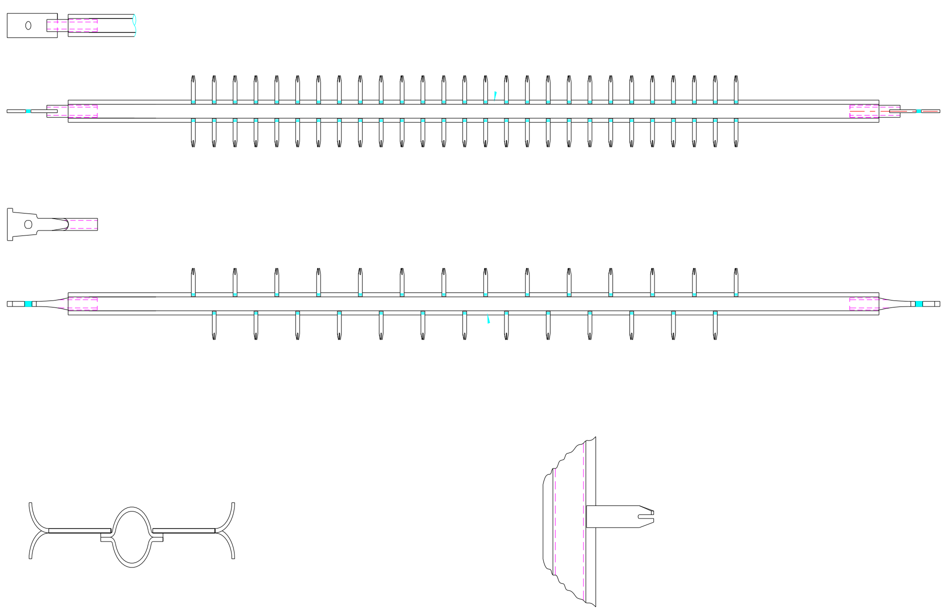
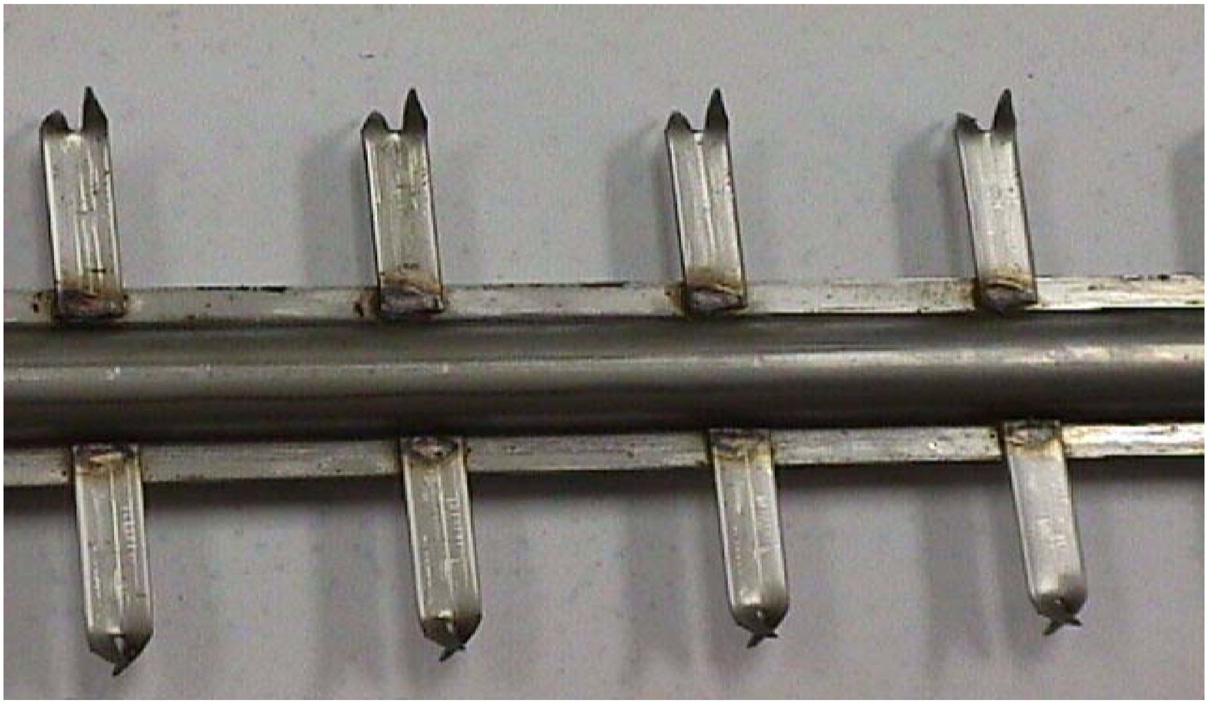


Figure 2 - Aggressive ELEX RDE



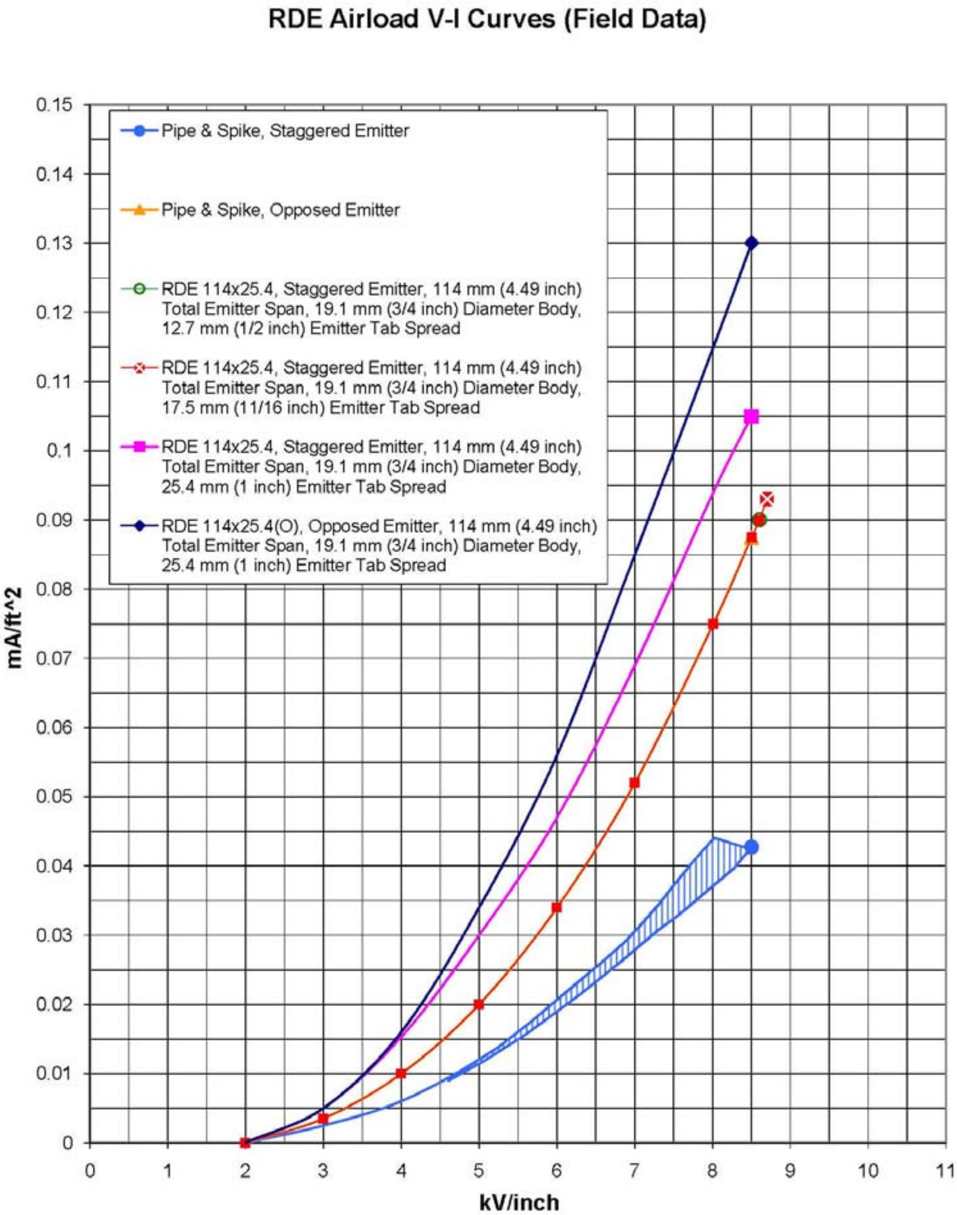


Figure 3

A recently completed retrofit of customized ELEX electrodes into an ESP with 9" collecting plate spacing achieved particulate emissions of < 0.015 lb/mmBtu with no other modifications to the ESP. Achievement of such a low emission level alone is a notable feat for an ESP. The fact that these electrodes were retrofitted into existing 9" gas passages without modification of the collecting plates makes ESP performance at this low level even more impressive. We attribute this performance to the extraordinary power density achieved using the ELEX electrode, along with the customized discharge electrode emitter configurations employed throughout the ESP.

ESP POWER SUPPLIES

A second recent advancement in ESP technology is the use of switchmode power supplies (SMPS) in lieu of conventional transformer/rectifier sets. Various forms of this technology have been studied for the past several decades, and in recent years this product has become more refined and widely accepted.

An SMPS set consists of four modules; An AC/DC module that takes three-phase input and rectifies and filters it to create a fairly smooth DC bus of approximately 650 volts DC. The next module is a DC/AC block that consists of an integrated gate bipolar transistor (IGBT) full bridge circuit, which converts the DC bus into a high frequency AC waveform. A Resonant Tank module, combined with the last AC/DC module, steps up the high frequency AC, rectifies it, and thus delivers high voltage DC to the ESP. This block, which is oil-filled, is the high frequency equivalent to a conventional 60 Hz. TR set. Several examples of various switched mode power supply configurations, as provided by NWL, are pictured in figure 4 below.

Figure 4 – Switched Mode Power Supplies

Because the AC input voltage is rectified, filtered, and then switched very quickly (25 kHz) in small packets of energy, the ripple voltage is only 3-5% of the DC voltage level as compared to 35-45% for linear 60 Hz. power supplies.

The three-phase input results in a much higher power factor (.94 vs. .63), and lower power consumed per kilowatt of power delivered to the precipitator.

In summary the major advantages in electrical performance of a switch mode power supply over a conventional TR set are:

- Improved power factor
- Increased secondary voltage and secondary current
- More efficient delivery of power to the ESP

These effects have been observed and applied on numerous occasions over the past decade or so, such that a clear trend of improved performance using SMPS in conjunction with ELEX electrodes has been established.

Several units employing the switched mode power supplies in conjunction with ELEX electrodes have started up in the past few years, all with very favorable results. Test results from a 2005 startup whereby the internals (collecting plates and discharge electrodes) of the existing ESP were completely removed and replaced, collecting plate spacing increased from 9 inches to 12 inches, and the power supplies replaced with SMPS units, resulted in a 70% improvement in opacity.

WIDE PLATE SPACING

While this design has been widely utilized in Europe and Japan for many years, it has not yet enjoyed widespread acceptance in U.S. markets. This is likely due to the relatively slow evolutionary process from the narrow plate spaced ESP's of the 70's and 80's to the more common 12" spacing of today. A myriad of reasons, such as electrode geometry, size of available power supplies, insulator design, and the need for larger electrical clearances have certainly influenced this trend. The clearance issue comes into play a great deal in rebuild situations, as many of these entail upgrading from 9" plate spacing. A number of these older designs with wire type electrodes and smaller power supplies simply did not anticipate conversion to wider plate spacing and its attendant design requirements.

One example of a successful conversion to wide plate spacing occurred at the Baldwin Station of Dynegy Midwest Generation. In 2002, the unit was retrofitted with new collecting plates and ELEX electrodes. The first four (4) fields of the 6-field ESP were designed with collecting plates spaced on 12" centers, and the last two (2) fields were designed with 16" collecting plate spacing. This arrangement replicated the original design. No test data was made available following completion of the project, but the combination of ELEX electrodes throughout the ESP with wide plate spacing in the last two fields, coupled with improved gas flow distribution, enabled the station to retire the existing flue gas conditioning system.

The examples documented above describe the evolution of the design process whereby one or more of these key design elements were incorporated into actual ESP projects. The performance results from these units have been a springboard for use of this combination on larger units.

A SMALL UTILITY APPLICATION

The first startup of a utility ESP employing all of these features occurred in July of 2008 on an 80 MW coal fired unit at the Tecumseh Generating Station of Westar Energy. In recent years, the boiler was converted to fire 8900 Btu/lb PRB coal. Particulate removal initially consisted of a mechanical dust collector. A single chamber, 3-field PC Walther European design ESP was added downstream of the dust collector in 1976. The rebuilt ESP occupies the same envelope as the existing ESP, but with American type internals. There are now six (6) mechanical fields in series, collecting plates are now spaced at 16", and the conventional TR sets have been replaced with switched mode power supplies. ESP performance has increased dramatically subsequent to the rebuild.

The Tecumseh unit represents the first start-up of a utility ESP employing SEI's new ESP design concept, whereby all three (3) design improvements discussed herein are married into a single utility ESP installation:

- Customized ELEX rigid discharge electrodes
- NWL Switched mode power supplies
- Wide (~16") collecting plate spacing

Test results, as noted earlier, are as follows:

Performance Test Results

<u>Particulate Emissions</u>

	Test 1	**Test 2**	**Test 3**
Gas Volume (ACFM)	330,721	330,614	333,408
Dust concentration (lb/hr)	1.74	3.66	4.52
Dust concentration (gr/acf)	.00061	.00129	.00263
Dust Loading (lb/mmBtu)	**.0020**	**.0042**	**.0052**

Average = 0.0038 lb/mmBtu

These results, while noteworthy under any condition, might be viewed as "tainted", due to the following:

- <u>The presence of an upstream mechanical dust collector of uncertain efficiency upstream of the ESP</u>. This has both a positive and a negative effect: While the pre-collector reduces the total dust loading to the ESP, it raises the percentage of fine particulate. In passing through the mechanical collector, the fine PRB ash becomes even finer, making high efficiency collection even more difficult. The tested PM removal efficiency of 99.71% is really quite extraordinary.
- <u>The new ESP components were retrofitted into an existing shell that may have been conservatively sized</u>. Interestingly enough, the opacity of this unit before being rebuilt typically was in the range of 15-20%, certainly not stellar performance by today's standards. During the testing of the upgraded ESP, stack opacities ranged from 0-5%, a significant improvement.

<u>A FULL SIZE UTILITY APPLICATION</u>

The most recent ESP configured in this manner is Unit #3 at the Duck Creek Station of Ameren/UE which was tested in May of 2009 and represented the first ESP competitively sized and bid using these design synergies. It was to be retrofitted on a 460 MW coal fired unit burning a PBR/Bituminous coal blend. The existing ESP was to be later retired and/or demolished. The specified particulate emissions guarantee was 0.020 lb/Mbtu, later reduced to 0.015 lb/Mbtu during negotiations after contract award. Key design requirements are summarized as follows:

Gas Volume (ACFM)	1,657,000
Gas temperature (°F)	329
Coal type	70%PRB/ 30% Bituminous blend
Target particulate emissions	0.015 lb/Mbtu
Target visible emissions	10%

The proposed ESP was sized as follows:

- **1 ESP/ 4 MF / 4 CH / 28 GP per CH / 41 ft by 12 ft PL / 16-inch GP / Custom ELEX Electrodes / SMPS**
- **SCA = 266 sq ft/kacfm, Gas Treatment Time = 10.64 sec, ESP Velocity = 4.51 fps**

Additionally, the required emissions were guaranteed according to the specification. This was the first time that the "synergy" design was "battle tested" on a new, full-size utility ESP competitive bid. It became clear after the fact that the project was won on the basis of a more cost effective ESP sizing, which ultimately translated into a lower price.

Following detail design, fabrication, and construction, the final hurdle was to have a successful performance test that would validate this advanced design. The results of the testing are summarized below:

Performance Test Results
Particulate Emissions

	Test 1	Test 2	Test 3
Gas Volume (ACFM)	1,633,339	1,681,827	1,655,579
Dust concentration (lb/hr)	10.511	9.314	8.182
Dust concentration (gr/acf)	.0015	.00135	.00115
Dust Loading (lb/mmBtu)	**.00535**	**.00435**	**.00410**

Average Particulate Emissions = 0.0047 lb/mmBtu

Opacity = 2.7%

FRACTIONAL EFFICIENCY DATA

In addition to the data above, efficiencies throughout the particle size ranges shown below were measured by a cascade impactor, and compared against similar test data from a technical paper (3) presented not long ago:

	Yi, Hao, Duan, Li, & Guo, 2006	Yi, Hao, Duan, Li, & Guo, 2006	Duck Creek
PM SIZE	**ESP**	**Fabric Filter**	**ESP**
PM	**99.89**	**99.94**	**99.91**
PM 10	**99.62**	**99.76**	**99.73**
PM 2.5	**99.16**	**99.72**	**99.63**
PM 1	**98.59**	**99.54**	**99.37**

Note that in all three cases the overall PM collection efficiency is approximately the same value. When comparing the Duck Creek ESP data against fabric filter and conventional ESP data, it is clear that the performance of the Duck Creek ESP is exceptional in the finer particle size range (PM 2.5 and PM1), and clearly represents a very favorable comparison to fabric filter performance across all particle size ranges.

CONCLUSION

Several additional utility units employing the "synergy" design will also be starting up in the coming months, with similar results anticipated. While it is fair to say that the results above exceeded our projections, the element of commercial risk must be respected when venturing beyond the contemporary limits of technology. As noted early in this paper, the emissions guarantees and accompanying results extend ESP performance projections to levels previously thought to be limited to fabric filters. These results clearly project modern ESP's into that market niche, thereby providing a cost effective alternative to current technologies.

Given this now consistent success in achieving extremely low emission levels with a 21st century design ESP, a companion solution for dealing with mercury control becomes the next step. The design of the Tecumseh rebuilt ESP dealt with that eventuality by leaving a vacant portion of one of the ESP's fields for future installation of a Toxecon II carbon injection system. However, no formal evaluation of that potential solution has been conducted to date.

REFERENCES

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