Achieving Long-Term Peak Performance For FCCU Precipitators

NEUNDORFER

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WHO IS NEUNDORFER?

Founded in Cleveland, Ohio in 1975, we have been dedicated to helping owners and operators of air quality control systems reduce emissions and improve pollution control system performance through design, modeling, consulting, product support, installation, and service.

Our highly skilled, technically oriented team is driven by an extremely inquisitive nature and desire to resolve complex issues. We use a proven process that combines in-depth analysis, experiential knowledge, and a focus on both the technical and economic challenges that are unique to each customer.

Neundorfer has extensive experience to help you in these areas:

- On-site and remote troubleshooting
- Precipitator controls tuning and optimization
- Online assessments
- Internal inspections
- Shutdown planning
- Shutdown technical direction
- Customized in-person or virtual training

Questions about your ESP?

We'll help you troubleshoot. Contact the ESP Help Desk!

Over the past 45 years of helping precipitator owners/operators in North America, we have run across quite a few precipitators. Achieving peak performance and long-term reliability is always a concern of precipitator operators.

Precipitators on Fluidized Catalytic Cracking Units (FCCU) are no different, but can be particularly challenging because they have to operate for 5-6 years, reliably and in emissions compliance, between shutdowns. The challenge is two-fold. First, what can you do to achieve consistent performance between shutdowns? Second, when we get to the shutdown, how do we identify what we need to work on so the precipitator can operate reliably for the next run period?

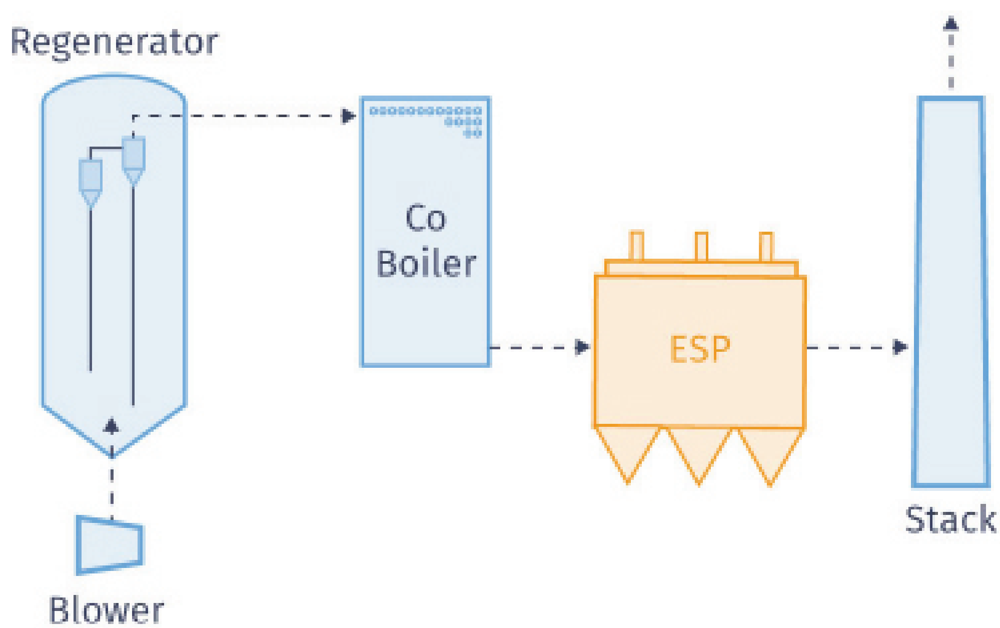
We'll present a 3-part series for FCCU precipitator operators.

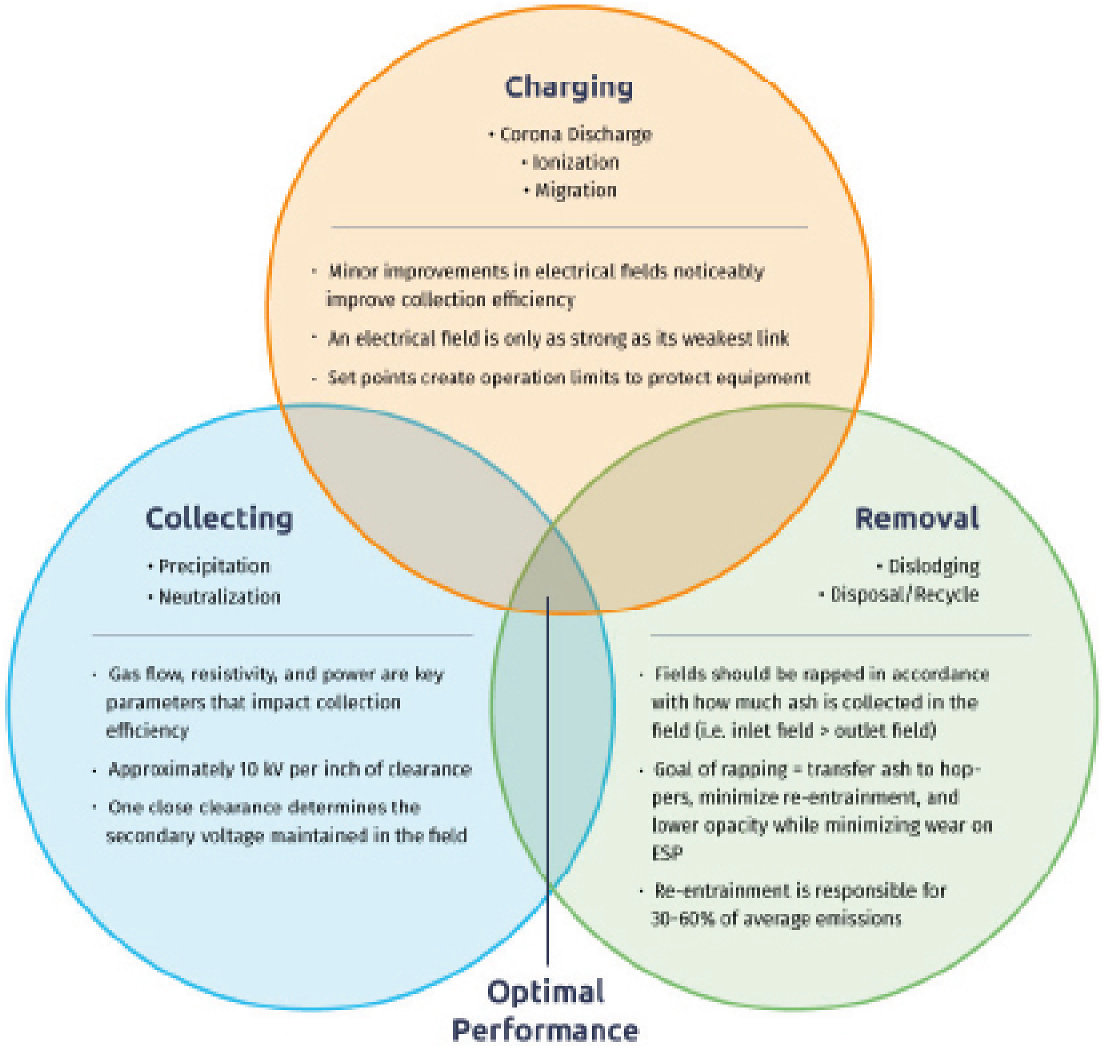
1. Discuss the three key processes of a precipitator, what are common issues and what influences precipitators on FCC units.
2. How to use precipitator data to plan your shutdowns.
3. Long term performance and reliability improvement options.

We'll present helpful tips and ideas to help you achieve long-term peak performance of your FCCU precipitator.

So, let's get started!

TYPICAL FCCU-ESP CONFIGURATION





These three processes are necessary for a properly functioning precipitator:

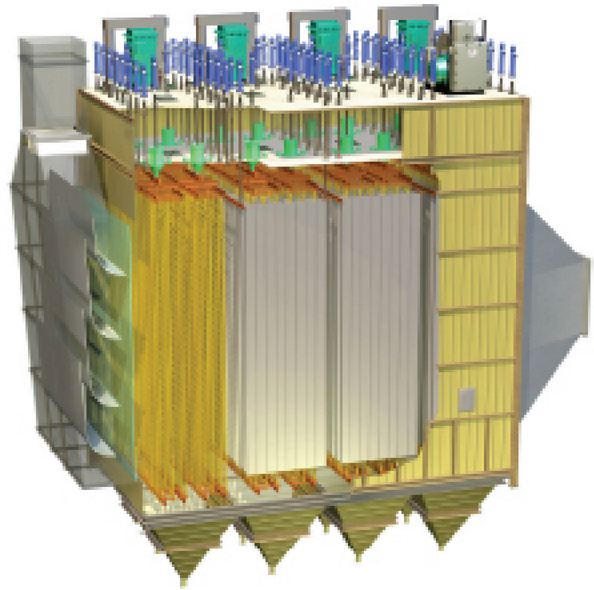
Charging: the process that creates the ions which charge the dust particle

Collecting: the process by which the charged dust particles migrate to the collection surfaces

Removal: the process that involves rapping off the collected dust particles and removing them from the precipitator.

Precipitators are not so forgiving. If one of these steps is not performing optimally, overall precipitator collection performance degrades. You cannot get away with just 2 steps working well.

Diagnosing issues with these steps can be difficult because a symptom may be the result of one or multiple issues within each of the steps that collectively contribute to poor performance.



Below is a discussion on how the three precipitator processes impact FCCU precipitator operation.

1. CHARGING

Maximize secondary voltage (kV) input and you maximize precipitator collection efficiency. Simply put, *kV is King!* Here are the major culprits to not being able to maximize kV input.

YOU'RE ONLY AS GOOD AS YOUR CLOSEST CLEARANCE

Misalignment between collecting electrodes and discharge electrodes (i.e wires, RDEs, etc) results in reducing the point at which the field wants to spark or what is referred to as spark over voltage. This results in lower kV input, along with lower secondary current (mA) input and lower overall power input (kW). Thus, maintaining good clearances is essential for efficient precipitator operation.

Remember, every one (1) inch of clearance between a plate and discharge electrode equates to 10kV. That means that close clearances degrade the available power input into the field by 10kV per inch of clearance lost. Also, depending on your plate spacing and discharge electrode geometry, current does not begin to flow until 18kV-20kV. Why is kV so important? Keep reading.

Alignment of the upper discharge electrode frames and the lower anti sway frames is critical. Removing or repairing bent/warped plates is important, however it may be easier to just remove the wire/discharge electrode(s) that is being affected.

CHECK YOUR CONTROLS

In order to get the best performance out of your precipitator, the voltage controller must be allowed to operate as close to the spark-over voltage as possible. Most controllers used today are modern, microprocessor-based controls. They are not fool proof. They depend on good feedback from the Transformer/Rectifier sets to operate properly. Issues preventing these controls from optimizing performance are:

- Control limit settings programmed lower than the T/R set nameplate
- One or more input signals are out of calibration
- Too low a spark rate set on the controller.

Solutions range from confirming controller set up matches T/R set nameplate rating, periodic checking of feedback signal calibration (yes, even on those "non calibration necessary" controls) and making sure the controls are sparking appropriately to the process.

CORONA QUENCHING

Very fine particles are formed in the catalytic process, and there are a lot of them. This large number of tiny particles have a shielding effect on the power input because; 1) they are lighter than the larger particles, 2) they partially migrate to the collecting plates, and 3) they stay entrained in the gas stream. While they are floating around, they repel other similarly charged particles (same polarity). This condition is prevalent in the inlet fields of a precipitator where the dust loading is the highest.

This condition requires more kV gain for more efficient operation. Solutions range from making sure the controls are not set below nameplate ratings (easy) to better matching T/R set output to the field (harder). Another way to increase kV is to increase the space charge effect. More on this below in the discussion around resistivity.

2. COLLECTING

Collecting is the process of getting the charged dust particle to the collecting plates. The primary influencer here for a FCC unit is gas temperature and its impact on dust resistivity.

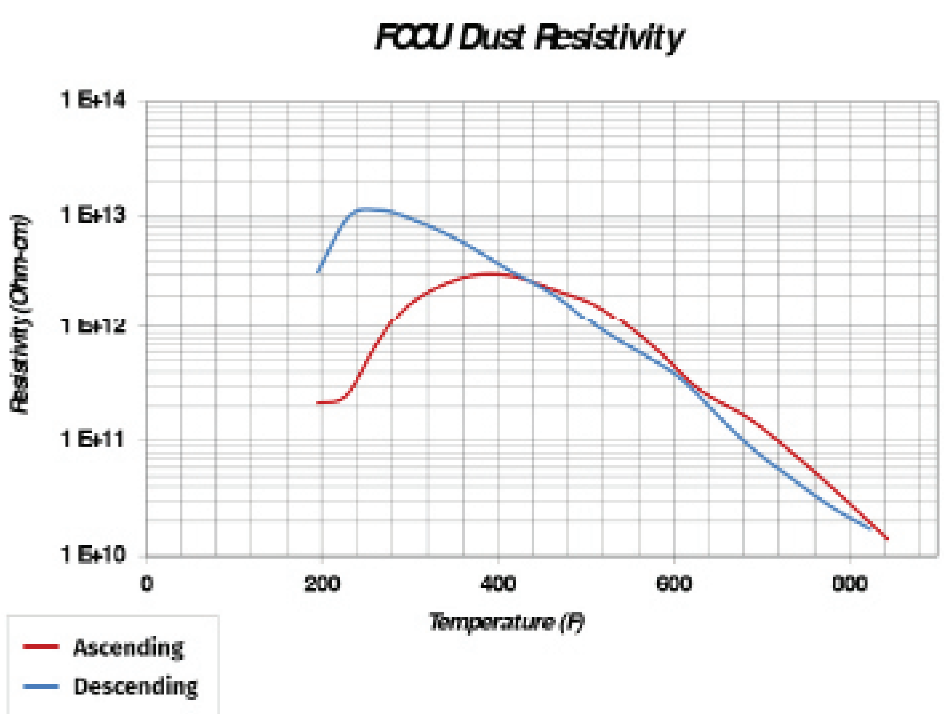
WHAT IS RESISTIVITY?

This term is most critical for the fly ash precipitator because it directly controls the levels of voltage and current observed at most installations. Resistivity, which is a characteristic of particles in an electric field, is a measure of a dust particle's resistance to transferring charge (both accepting and giving up charges). Particles can have high, moderate (normal), or low resistivity.

Resistivity also refers to the electrical resistance of the ash layer after it forms on the positive ground collecting plate. If the resistance level is high, the corona current passing through the ash layer must be generally reduced or reduced performance of the ESP will result.

The range of resistivity is primarily affected by the chemistry of the ash, moisture in the flue gas, levels of sulfur trioxide, and flue gas temperature. Resistivity effects are generally observed by the occurrence of sparking on most ESP fields at some reduced level of voltage and current. Operation in a good zone of resistivity allows the ash layer on the collector plate to bond sufficiently for optimum precipitator performance and helps to reduce the reentrainment of dust.

Dust from a FCCU is typically in the moderate to high resistivity range. An example of a graph of resistivity is below.



INFLUENCES ON RESISTIVITY

In the chart you can see how temperature influences resistivity. Gas temperatures for FCCU precipitators are typically in the 450ºF to 650ºF range. Most of the temperature comes from the catalytic process in the regenerator.

Metals content in the catalyst will also influence resistivity. As the catalyst ages, more metals are present in the catalyst, thus reducing the resisitivity as the catalyst ages.

MODIFYING RESISTIVITY

A common practice to improve baseline opacity is to reduce resisitivity by injecting Ammonia (NH_3) ahead of the precipitator. Ammonia injected ahead of the precipitator will react with the SO_2 and SO_3 in the gas stream and create ammonia sulfates and ammonia bisulfates.

These compounds have three effects; reduce the resistivity of the dust particle, agglomerate the small particles into larger ones which are easier to collect, and increase the ability of the inter-electrode space to increase kV. These increase the collection efficiency and reduce opacity. This can also help reduce opacity spiking occurrences.

3. REMOVAL

RAPPING

Once the dust is collected on the collecting plates, we have to remove it. Rappers are devices that remove the dust from the collecting plates and drop the dust in the collecting hopper.

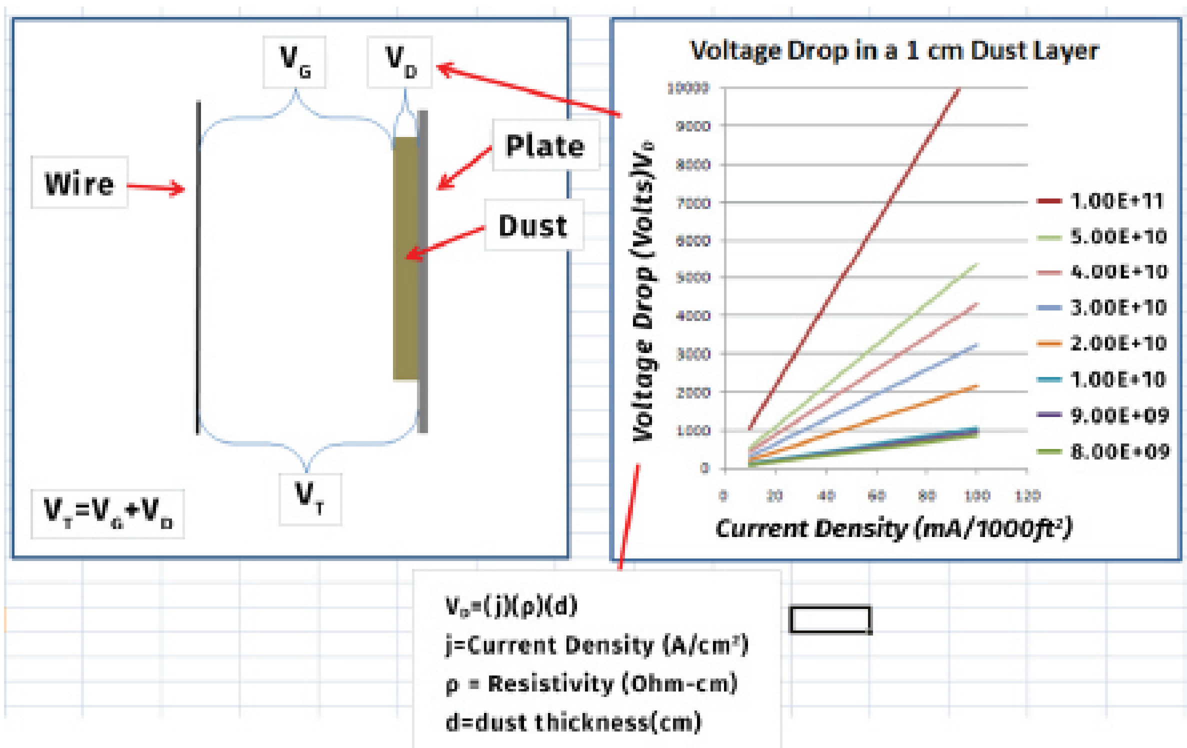
Since rapping is more "art" than "science", the solutions require time and patience. Most of the solutions revolve around assessing the rapping programs (repeat times, impact) and trial and error changes to find the optimal program. For example, Inlet field rapping repeat times may be every 4 minutes while the outlet field may only rap once a day.

Too aggressive rapping (repeat cycles, impact force) can cause the dust to be re-entrained, which leads to high emissions. Rapping too infrequently causes build-up to occur, potentially allowing crusting and a large amount of dust falling off the plates when the rapping event occurs. Both conditions cause the typical "opacity spiking" problem users experience.

RESISTIVITY IMPACTS REMOVAL TOO!

Dusts with high resistivities are a challenge for removal. These dusts are harder to remove from the collecting plate due to the higher "clamping force" associated with high resistivities. Once the charged dust reaches the grounded collecting plate, the charge on the particle is partially discharged and slowly leaked to the grounded collection plate. It is this retained charge ("clamping force") that holds the dust onto the collecting plate.

High dust resistivities result in more retained charge across the dust layer. This relationship is shown in the chart below.



Note that the injection of Ammonia (resistivity modifier) can result in "sticky" dust if optimal injection rates are not used. This dust can be very difficult for rappers to remove.

CONCLUSION

Precipitators can perform at high efficiencies over long periods of time if we pay attention to the three processes and understand what is influencing them. The things we should keep in mind all the time are:

- Secondary Voltage (kV) is King
- 10 kV per inch of clearance between discharge electrode and collecting plate
- You are only as good as your closest clearance
- Temperature is a key influencer on performance
- Keeping collecting plates clean is important, but rapping is more an art than a science.

Our next part will discuss how we can use precipitator operating data to diagnose or identify potential problems, things we can do to try to solve problems without shutting down and how to use the data to plan our future shutdowns.

INTRODUCTION

This paper is a continuation of our 3-part series on achieving long-term peak performance for FCCU precipitators. In our first part, we discussed the three key processes of a precipitator, what are common issues, and what influences precipitators on FCC units. In this part, we are going to discuss how to use precipitator data to troubleshoot problems and plan your shutdowns. Our third and final part will focus on how to improve precipitator performance.

Precipitators are sometimes seen as "black boxes". They'll take whatever you throw at them. This is far from the truth! Precipitators are specifically designed for an application. The designer was given a set of process conditions and an emissions objective, and design a "box" to achieve that objective with those conditions. As time has passed, those conditions have changed which influences the three key precipitator processes. Has your precipitator changed? No.

Precipitator data contains a wealth of information that helps us solve problems and plan our work scopes. The challenge is the data is often misunderstood and misinterpreted. Sparking, current, voltages, and power are important operating parameters, but without understanding context, it's difficult to understand what they are telling us.

Being able to use data to our advantage has many benefits. You can identify a problem before it happens. You can identify the root cause of the problem faster. You can direct your limited maintenance resources towards the items that will yield the highest reliability and performance results.

So let's talk about data! We'll try not to bore you.

COLLECTING DATA

You cannot use data unless you collect it! That's the first step. The second step is how we collect it determines how useful it is.

For example, if we are manually collecting precipitator control data on a paper sheet or spreadsheet once a shift, we really should talk about what's going on with technology this century! This data is not very useful.

Data collected in SCADA systems can be very useful. It allows multiple variables to be collected on a timely basis and can be correlated with FCCU variables that influence the precipitator.

Typical precipitator data that we want to collect is related to each Transformer Rectifier/Voltage Control.

The important variables are:

- Primary current (A)
- Primary voltage (V)
- Secondary current (mA)
- Secondary voltage (kV)
- Spark rate (SPM)

As with anything, we have to make sure the data is good. Periodically, standard Transformer/Rectifiers controls should be checked to be for calibration. Use the formula in the sidebar to verify calibration.

We also want to record/collect rapping times, purge air system operating parameters, and process variables such as gas temperatures.

FORMULA TO VERIFY CONTROL CALIBRATION

$$\frac{\text{Primary Current } (\textit{In amps}) \times \text{Primary Voltage } (\textit{In volts})}{\text{Secondary Current } (\textit{In mA}) \times \text{Secondary Voltage } (\textit{In kV})}$$

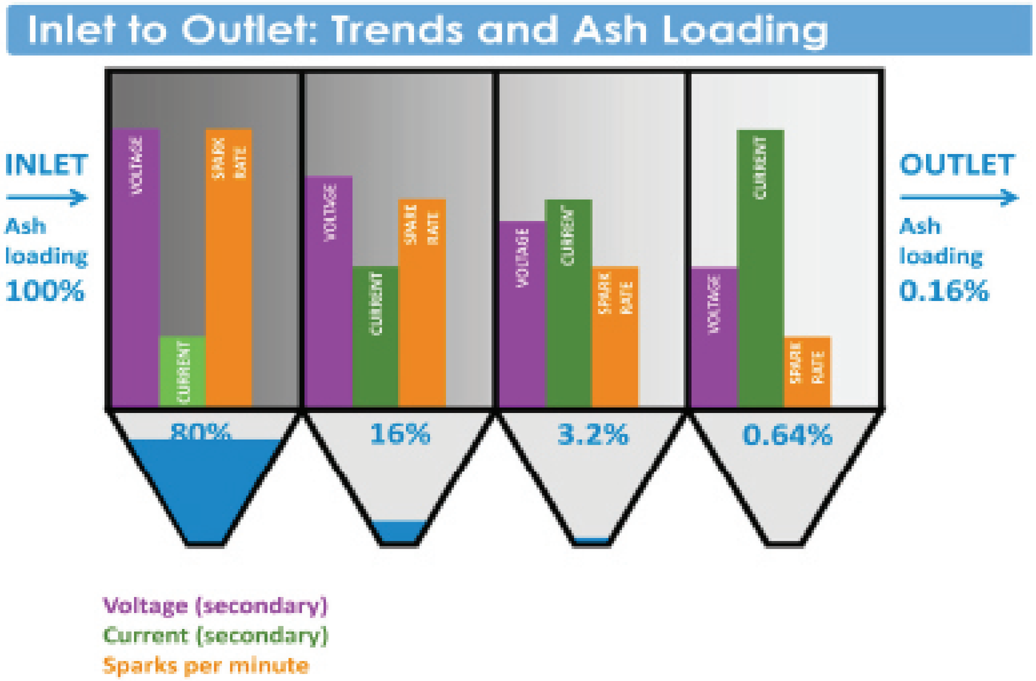
= 1.43 plus or minus 10%

For this calculation to be accurate, the conduction angle on the TR sets should be at least 90 degrees but preferably higher. If the conduction angle is high enough and the value lies outside of that range, the control should be calibrated.

USING AND INTERPRETING DATA

Once we've collected data we now want to use it to help us troubleshoot and plan our maintenance.

Trends are important. They can tell us a lot, especially whether it's a precipitator problem or something else that's influencing the precipitator. Typically, we want to see secondary current (mA), secondary voltage (kV), and actual spark rates follow the pattern below.



Most of the collection in a precipitator should occur in the first (inlet) field. This will yield a lower current, but higher voltage. As the gas stream gets cleaner as it progresses through the precipitator, the current levels increase.

Below are more examples. Figure 1 below shows precipitator data that shows an abrupt change in secondary current (mA) and secondary voltage (kV). A potential cause of this is a close clearance issue in the precipitator.

Figure 2 is an example of what data would like where there was a process influence on precipitator performance, such as a change in temperature which impacts dust resistivity.

Both of these examples result in higher than normal opacity (emissions). In figure 1, the problem is process-related. In figure 2, the solution is solved in the precipitator.

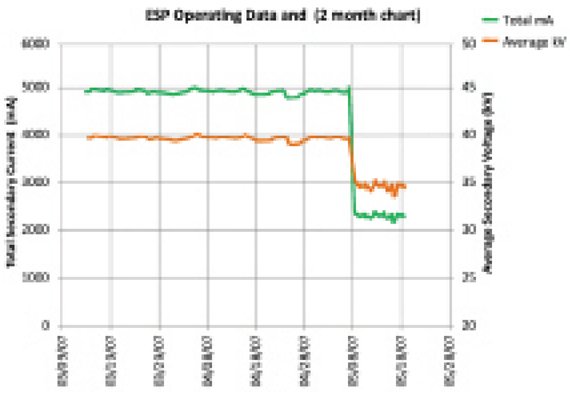


Figure 1

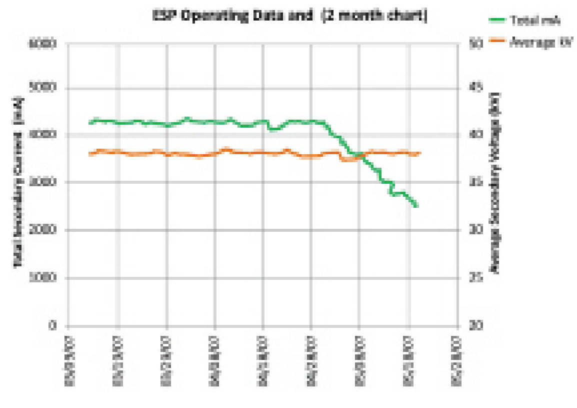
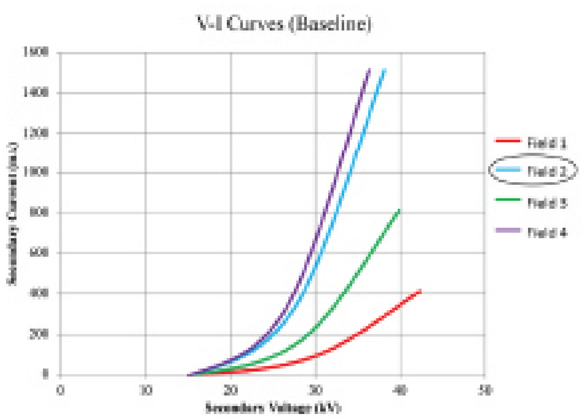
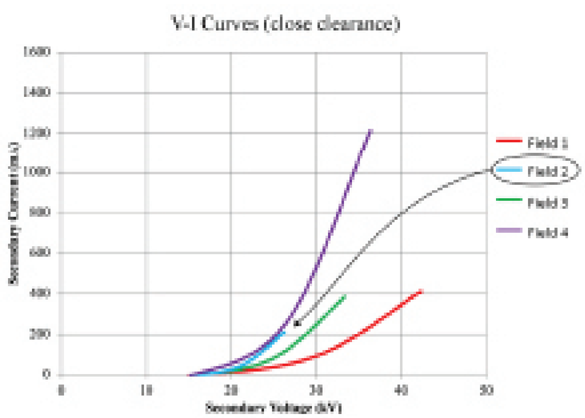


Figure 2

Voltage-Current (V-I) curves are another useful tool to help diagnose and understand what is going on in the precipitator so we can properly plan our actions. V-I curves show the relationship between the current generation and voltage. Most modern control systems can generate these curves or they can be manually generated.

Below are two examples showing V-I curves. The first one is the normal trend we expect to see. These curves can be created post-shutdown. The second set of curves indicates one field (the second) has a close clearance as indicated by the lower level of secondary current. We would also expect to see higher sparking on this field.





PLANNING

With an FCCU precipitator, you have a chance to get it right once every 5-6 years (depending on your shutdown schedules). In between shutdowns, if something were to happen, you have a very short window to solve a problem. Let the data lead you!

A good evaluation of operating data should be done as part of the scope of work development and budgeting process for your major shutdowns. The data can tell you what issues to expect.

The data can also tell you what to target during an internal inspection of the precipitator. This is especially important with an FCCU precipitator since you may not have had the opportunity to get inside the precipitator before the shutdown.

The first day or two of the shutdown is when you can do an inspection to help you finalize your shutdown scope of work. The data will tell you (or the inspector) what to expect or where to focus the attention first.

The data can help you identify issues with:

- Close clearances
- Dirty discharge electrodes
- Dirty collecting plates
- Dirty insulators
- Process influences on the precipitator
- Rapper failures
- Dust hopper evacuation issues

CONCLUSION

Precipitator operating data can tell you a lot about how the precipitator is performing and can lead you to what is causing the problems you are experiencing. This will help you be more effective in diagnosing the problem and create a solution faster. The data is especially useful when we are trying to plan for shutdowns and to prioritize our inspection plans.

The analysis of data may seem a little daunting. You have tools at your disposal (i.e. SCADA) that can be used to help you organize and interpret it. Neundorfer has developed on-line and off-line tools specifically for precipitator data evaluation. Please contact our HelpDesk if you need assistance.

INTRODUCTION

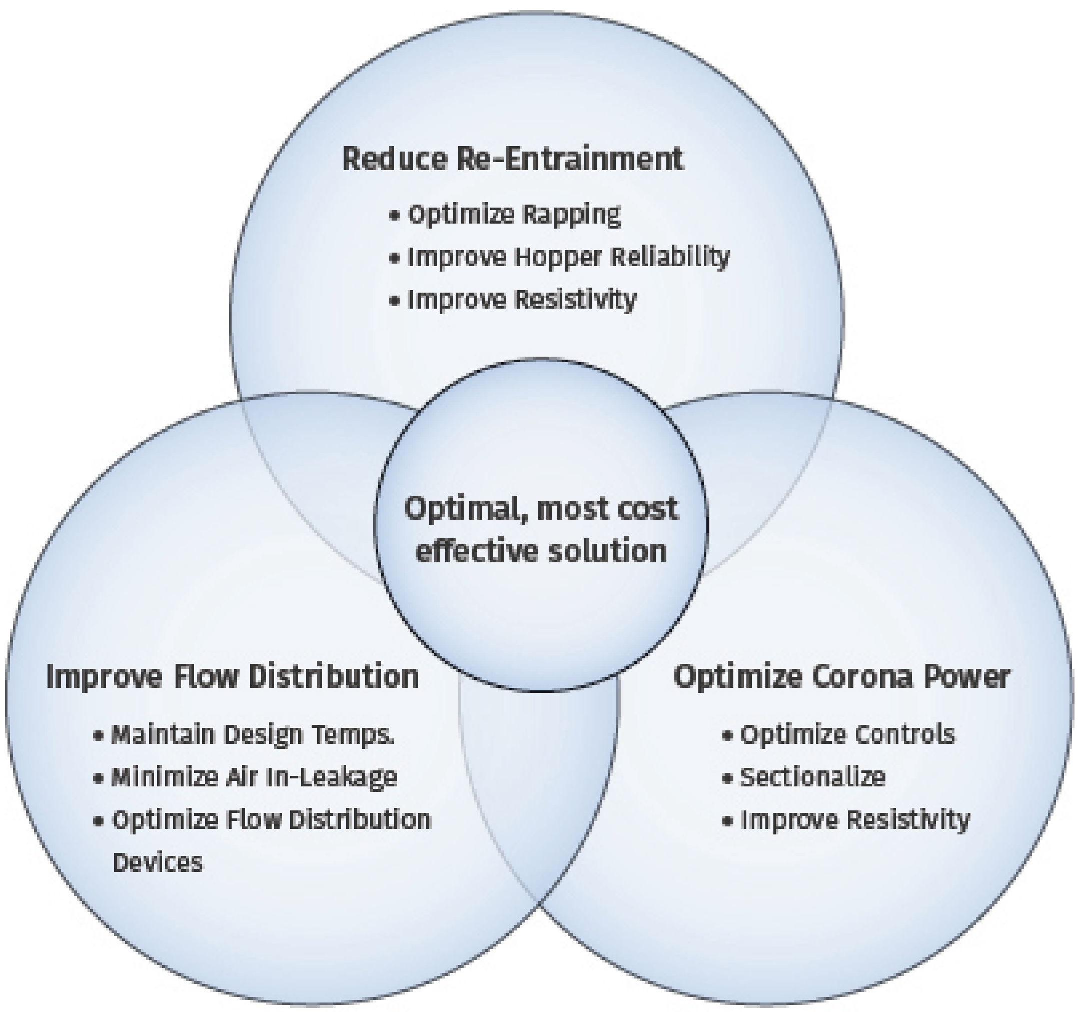
This is the final part of our 3-part series on achieving long-term peak performance for FCCU precipitators. The first two parts covered what influences FCCU precipitator performance and how we use data to help us troubleshoot and plan our shutdowns. This part will focus on what options we have to improve the performance of the FCCU precipitator.

The reasons we may need to improve performance are twofold. The first may be to correct for degraded performance. The second reason that we are increasing or changing our process conditions and want the existing precipitator to be able to keep us in emissions compliance.

This paper will focus on the three areas most commonly addressed when looking for performance improvement. These are;

- Reducing re-entrainment of dust
- Optimize corona power input
- Improve the gas flow distribution through the precipitator

The improvements described in this paper can produce improvement results independent of each other. However, when combined in the proper context they can result in exponential improvement. In some cases, the improvement may allow an existing ESP to capture an additional 30-50% more dust!



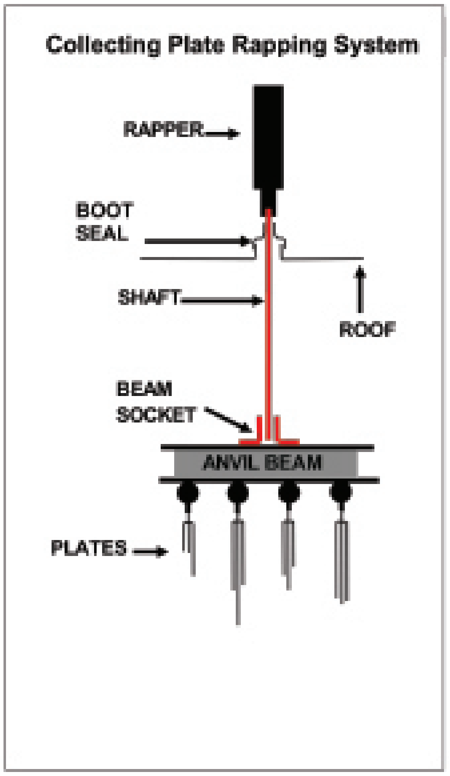
REDUCE RE-ENTRAINMENT

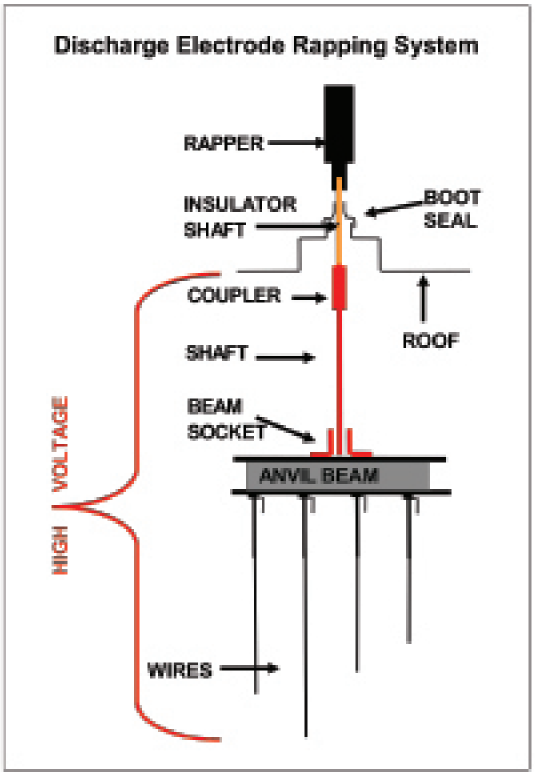
Re-Entrainment of dust that has been deposited on the collecting plates or in the hoppers can contribute 30% to 60% of the emissions from the precipitator (i.e. opacity). Controlling re-entrainment can yield big performance gains. The options we have at our disposal are; optimize the rapping sequencing, remove the dust collected in the hoppers frequently, and optimize our resistivity.

OPTIMIZE RAPPING

All ESP rapping systems allow for some adjustment of rapping frequency (time between raps). Although, variability between individual rappers or the actual frequencies that are available may be limited due to the types of rapping devices used and the controls used to operate them. For rapping systems that have pneumatic or electric actuators, variations of the rapping intensity can also be modified along with the rapping frequency.

For rapping systems that use motor-driven, internal hammers, intensity cannot be adjusted and frequency is limited. Today, state-of-the-art rapper controllers allow complete customization of the rapping sequences, including the selection of individual rappers, their intensity, and frequency, and also provide anti-coincidence schemes that allow only one rapper within a given lane to operate at the same time.





Typical Rapping Arrangements for Top Rapped Precipitators

An optimized rapping system starts with the discharge electrode (DE) rapping system operating on schedule and having typical repeat times in the range of 2 - 4 minutes. The same is true for the gas distribution screen rapping system in the inlet and outlet of the precipitator, however, they should be operated with repeat times of 2-3 minutes for the inlet and 2 - 3 hours for the outlet screens. Because the goal for DE and gas distribution rapping systems are to make sure that these components stay as clean as possible, these systems require the least amount of effort for optimization.

The only rapping system that gets the most attention for optimization is the collecting electrode (CE) rapping system. Precipitator field power input and stack opacity are excellent criteria to use for adjustment. Generally, normal collecting plate rapping starts with the highest frequency in the inlet fields (the least time between raps), progressing to the lowest frequency in the outlet fields.

Typically, the rapping frequency of the inlet field is increased or decreased until the electrical power input of the inlet field remains constant. Once the inlet field is satisfactory, the rapping frequency of the other fields should be adjusted in sequence until their electrical power inputs also remain fairly constant. If during this process the stack opacity trace shows spikes that correspond with rapping events, the rapping intensity should be reduced while simultaneously observing the electrical power input of the precipitator.

Adjustment of the rapping system for optimum precipitator performance is a methodical process and is often considered more of an art than a science. Doing it correctly is a slow process that requires a substantial amount of time for stabilization after each adjustment.

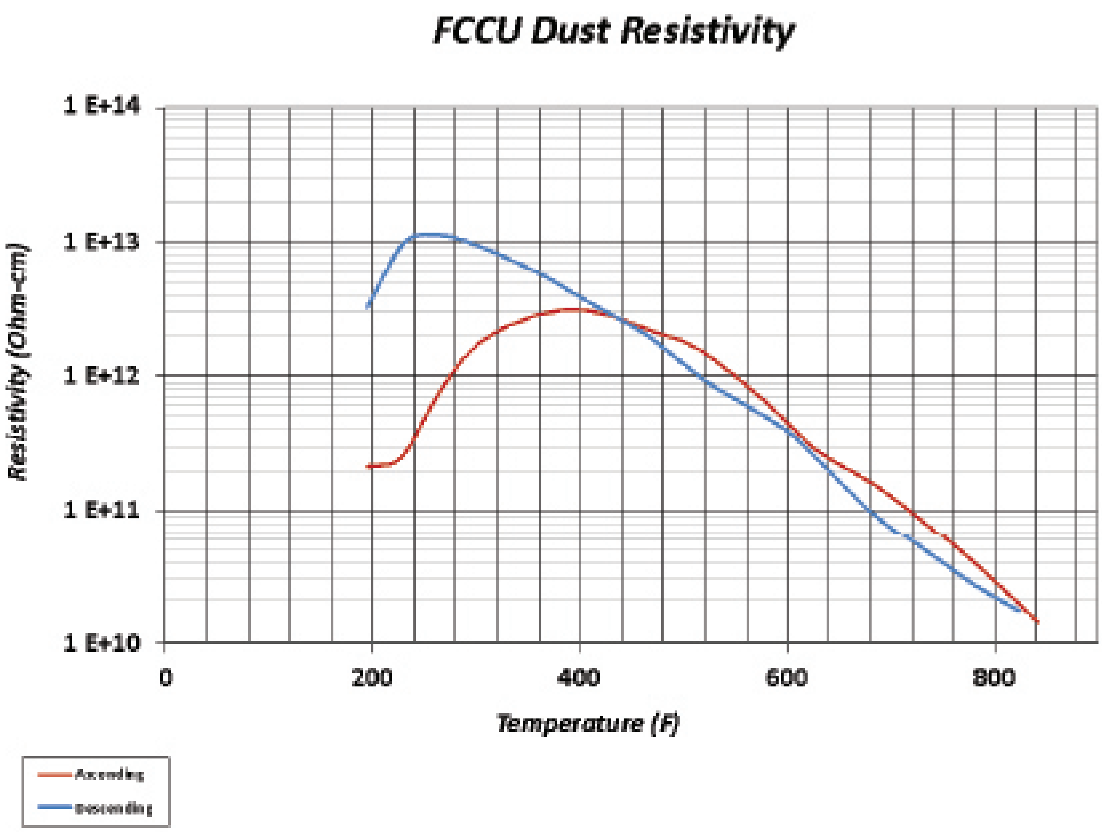
IMPROVE HOPPER RELIABILITY

Often the hoppers and hopper evacuation system are overlooked as crucial elements to overall system performance. However, when hopper systems are not emptied frequently or fail, it can be the source of several issues that can lead to excessive sparking or performance killing re-entrainment. As hopper levels get too high, the dust levels within the hopper get closer to the discharge electrodes and the flue gas path moving through the precipitator. This can cause sparking between the discharge electrodes and dust level in the hopper or allow the dust to be picked up by the faster-moving flue gas and carried out of the hopper. The latter type of re-entrainment is called sneakage because the dust sneaks below the collecting area and out of the precipitator.

IMPROVE RESISTIVITY

We discussed resistivity in Part 1 of this series. Resistivity is dependent on temperature, particle size, and chemistry of the dust. This is all determined by the operation of the reactor and the composition and age of the catalyst.

With an FCCU, we are concerned primarily with the temperature of the flue gas and chemistry of the dust as both of these change over the run-time period.



In the chart, you can see how temperature influences resistivity. Gas temperatures for FCCU precipitators are typically in the 450oF to 650oF. Most of the temperature comes from the catalytic process in the regenerator.

Metal content in the catalyst will also influence resistivity. As the catalyst ages, more metals are present in the catalyst, thus reducing the resistivity.

A common practice to improve baseline opacity is to reduce resistivity by injecting Ammonia (NH_3) ahead of the precipitator. Ammonia injected ahead of the precipitator will react with the SO_2 and SO_3 in the gas stream and create ammonia sulfates and ammonia bisulfates.

These compounds have three effects; reduce the resistivity of the dust particle, they agglomerate the small particles into larger ones which are easier to collect, and increase the ability of the inter-electrode space to increase kV. These increase collection efficiency and reduce the opacity. This can also help reduce opacity spiking occurrences.

OPTIMIZE CORONA POWER

OPTIMIZE CONTROLS

Precipitator corona power is the useful electrical power applied to the flue gas stream to precipitate particles. Either precipitator collecting efficiency or outlet residual can be expressed as a function of corona power in Watts/1000 acfm of flue gas, or in Watts/1000 ft2 of collection area. Corona power is the product of current and voltage. Current is needed to charge the particles, while voltage is needed to support an electrical field that in turn transports the particles to the collecting plates. In the lower range of the collecting efficiencies, relatively small increases in corona power result in substantial increases in collecting efficiency. On the other hand, in the upper ranges, even large increases in corona power will result in only small efficiency increases.

In order to maximize corona power in an ESP, the power controls must be optimized for the process conditions at that time. This includes correctly setting the secondary voltage and current limit, spark rate, spark rate setback and any other controllable variables that are available on the installed controls.

SECTIONALIZE

Electrostatic precipitators are divided into electrical sections that are cross-wise and parallel to the gas flow in order to accommodate spatial differences in gas and dust conditions. Optimization of corona power involves adjusting the corona power (secondary voltage and current) in each electrical section for optimum conditions. When voltage controllers sense a spark they momentarily cut power to the affected field in order to quench the spark. During the quench, collection efficiency of that field is also momentarily lost; however increasing sectionalization of the ESP can minimize this effect. This means splitting the fields and adding additional power supplies (T/R sets) so that a smaller section is affected when a spark is quenched by the voltage controllers.

Sectionalization has been demonstrated to show that it can allow a precipitator to accept a larger dust loading (throughput) and reduce emissions significantly. It has been noted and observed that sectionalization can improve performance more than adding an additional collection field making it a very cost effective option.

Below is an example of sectionalization. Figure one shows the original configuration of the precipitator. Figure 2 shows a possible sectionalization strategy. The new powering configuration is with smaller T/R sets, but there are more of them powering individual high voltage frames in the precipitator. This minimizes the influence of sparking on the collection area, thus increases average kV.

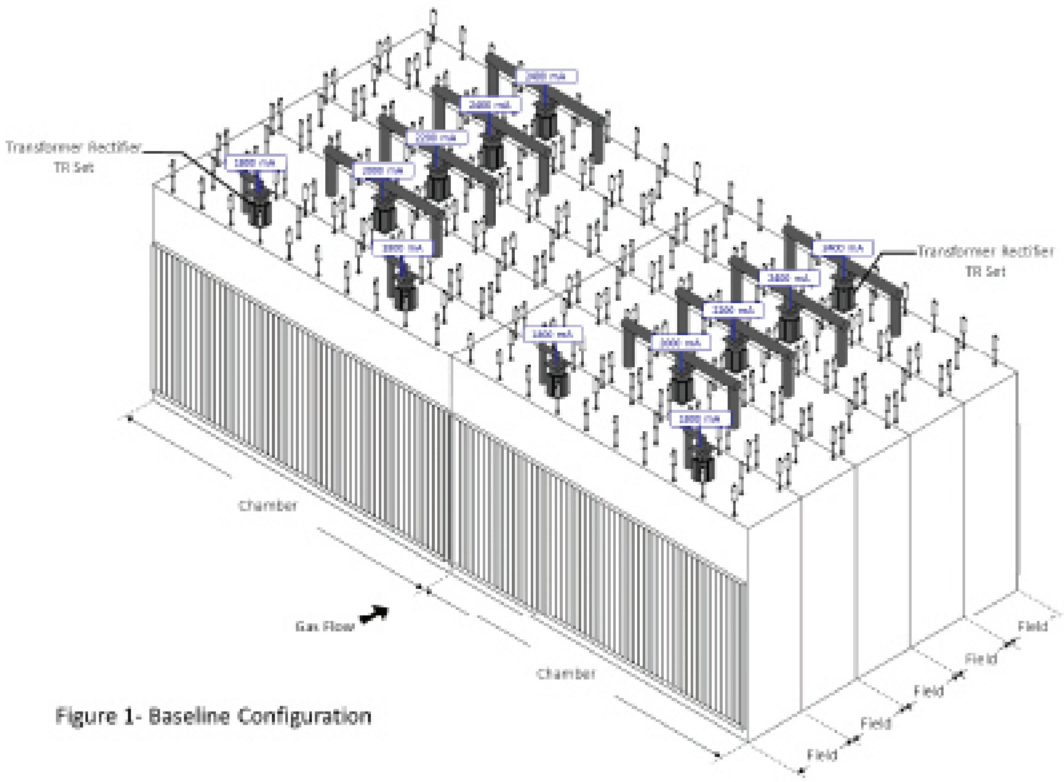


Figure 1- Baseline Configuration

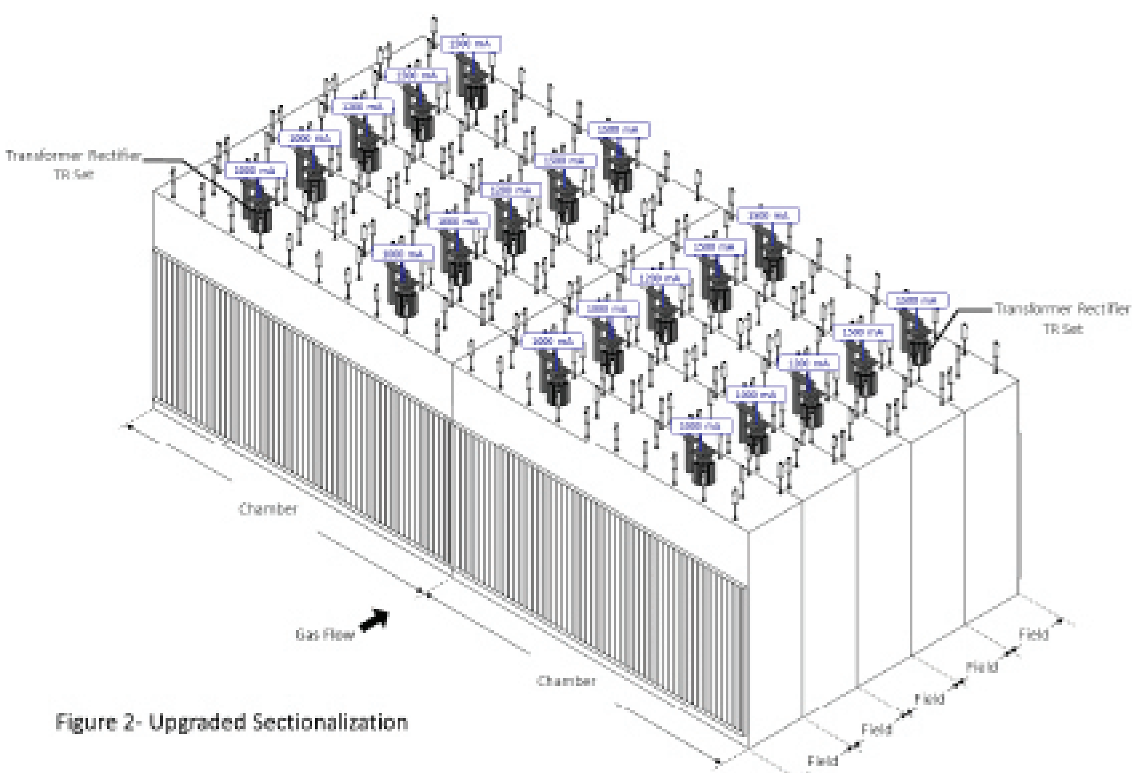


Figure 2- Upgraded Sectionalization

IMPROVE FLOW DISTRIBUTION

How the flow enters the precipitator and flows through the collection zones is extremely important in maintaining performance. It is also one of the areas that most precipitators are operating sub-optimally. Thus, it represents an opportunity for the greatest performance improvement. In some cases, the improvement just from optimal flow distribution can reduce emissions and allow greater throughput without adding additional precipitator collecting area.

MINIMIZE AIR IN-LEAKAGE

Anything that increases the volume of gas being treated by the precipitator is bad for collection efficiency. Finding air in-leakage can be complicated since it can get into the system at many locations. If tramp air is suspected, the hunt for a source usually starts by observing oxygen (O2) meter readings.

Some plants also have an O2 meter in the stack as part of a continuous emission monitoring system (CEMS). Changes in O2 readings can indicate air in-leakage may be a significant problem. We've observed cases where opacities have been cut 50% just by changing out a bad expansion joint.

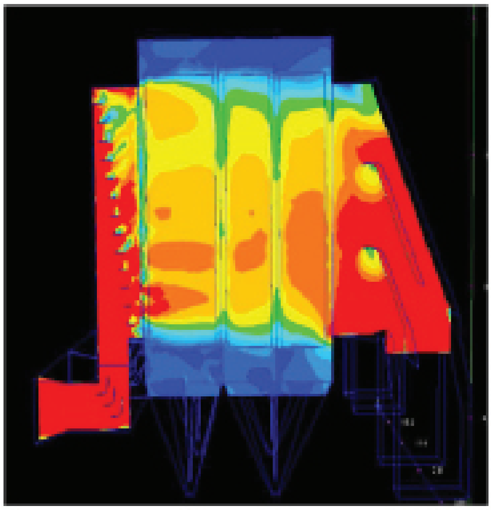
Regular testing for air in-leakage at multiple points should be part of every plant's operating policy. Test results help direct repairs to duct-work and equipment, ensuring that whatever maintenance is done will have maximum impact.

OPTIMIZE FLOW DISTRIBUTION DEVICES

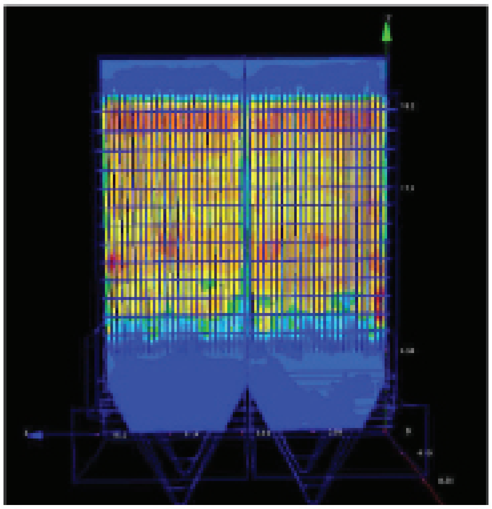
The goal of the flow distribution devices in an ESP is to distribute the flue gases across the ESP as evenly as possible. When process changes or air in-leakage occur the flow profile of the flue gases change and the flow distribution devices may no longer be able to carry out this job effectively.

Another possibility is that the flow distribution devices get dust buildup on them or deteriorate from corrosion/erosion. In any one of these situations, the flow distribution is skewed and leads to poor ESP performance. To optimize flow it is important to check your devices and make sure they are clean and in good condition. If buildup is present, one option may be to add some type of rapping that will periodically clean these systems. If permanent changes to the process have changed, it may be a good idea to have a flow study done to find out how the new conditions affect the precipitator and what can be done to correct this issue.

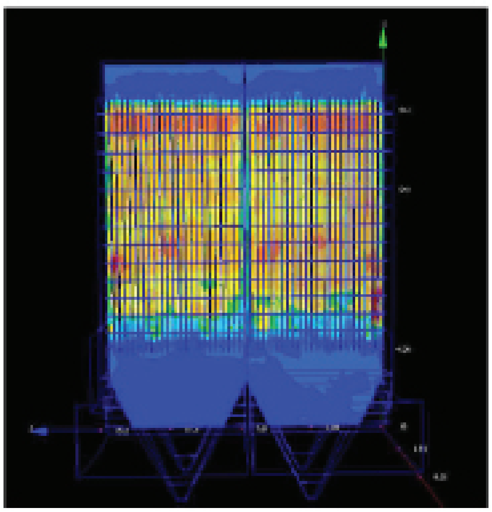
BEFORE



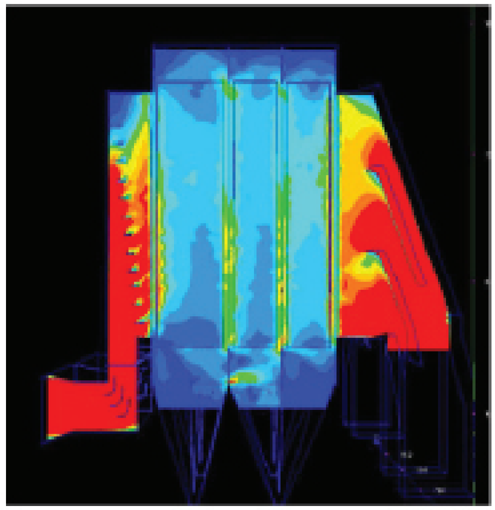
UNEVEN FLOW – INLET



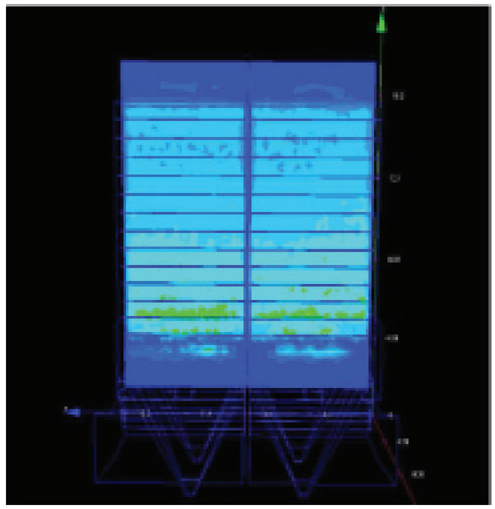
UNEVEN FLOW – OUTLET



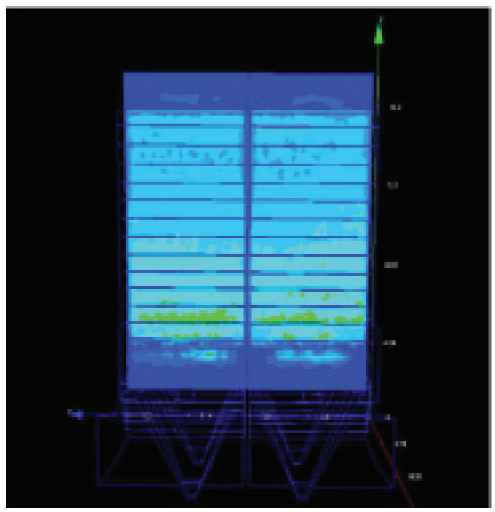
AFTER



CORRECTED FLOW – INLET



CORRECTED FLOW – OUTLET



The above graphics show the gas flow through a 3-field precipitator. Areas that are shown in yellows, oranges, and reds are where the gas flow velocity and dust concentration is the highest. In this case, only a portion of the total collection area is seeing the greatest concentration of dust, and performance suffers.

The "After" graphic shows areas in the shades of blue show where flows and dust concentrations are more balanced. This is helping assure that the collection area is not overloaded with dust and the velocities are lower, allowing for a greater chance of collecting the dust.

Optimization of the flow distribution devices can range from simple changes to gas distribution plate porosities or more holistic changes that involve turning vanes ahead of the precipitator and changes or addition of devices on the outlet of the precipitator. It is highly recommended that a comprehensive flow study be performed to determine the correct solution. Ad hoc changes can yield poorer results and even increase the pressure drop, resulting in process draft and ID fan issues

CONCLUSION

Improving precipitator performance whether a small incremental improvement or large step change is desired, does not necessarily mean you need an expensive complex solution.

Proper evaluation and identification of the areas that are the poorest performer will help you focus on the "sore thumb". Most often, these are related to re-entrainment issues, corona power, poor flow distribution, or a combination of all three. Performance modeling can help you determine what solutions will yield the lowest cost highest impact results and help you implement them with confidence.

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