PRESENTED AT THE ATI (ASSOCIAZIONE TERMOTECNICA ITALIANA) CONFERENCE,
MILAN, ITALY, JULY 2007

APPLICATION OF AIR POLLUTION CONTROL SYSTEMS TO BIOMASS AND WASTE-TO-ENERGY OPERATIONS

Robert A. Allan
TurboSonic Inc

1.0 SUMMARY

The increasing demand for energy worldwide has spurred the development of alternatives to traditional sources of energy. As a result, environmental concerns have dictated the establishment of increasingly stringent standards to minimize effects of atmospheric emissions on environmental quality.

A variety of technologies exist for the removal of particulate and gaseous contaminants from process exhaust gases. Focused research and development has produced particulate and acid gas emissions control technologies that are capable of meeting the most stringent control requirements. This paper will discuss several emission control technologies in use today, and present case studies relevant to these applications.

2.0 EMISSION SOURCES

A significant source of pollution in "waste-to-energy systems" is particulate matter, acid mist, sulphur dioxide and reduced sulphur compounds. The latter is commonly referred to as total reduced sulphur compounds (TRS), consisting mainly of hydrogen sulphide, combined with methyl mercaptan, dimethyl sulphide, and dimethyl disulphide.

This paper will deal with case applications in which particulate matter and acid mist are of issue.

2.1. WOOD-WASTE FIRED BOILERS

Combustion boilers burning organic waste, bark or other "hog" fuel were used originally as a disposal method because of space requirements or water pollution concerns. They are now used as a stable source of steam production especially when oil and/or natural gas are used for supplemental firing.

These boilers are a major source of particulate emissions and to a lesser extent $S0_2$ emissions during supplemental firing of sulphur-bearing oil or coal.

CO and fine carbon particulate can both be present, especially in older style boilers firing wet fuel. Large carbon particles (> 100 mm) can also be present in the off-gases. In the case of pulp mills, carbon ash emissions can be a major detraction of product quality (spec count) due to contamination of material stockpiles.

Large diameter cyclones, multiclones, electrostatic precipitators, venturi scrubbers and wet electrostatic precipitators (WESPs) have all been used in this application. Extremely fine (sublimate) sodium chloride can also be present in the ash when logs have been stored or transported in salt water, and abrasive grit present when they have been dragged through sandy soil.

The presence of abrasive grit can be a major wear problem with dry collectors. Carbon can avoid capture in mechanical collectors. It can also detract from dry precipitator performance, either due to its inability to hold a charge, thus passing through the precipitator, or causing re-entrainment of the dust layer when it releases into the gas stream due to the release of the charge holding the ash layer to the collector plates.

Carbon can also be a problem in all types of wet collectors due to wetting problems. In dry electrostatic precipitators, the presence of salt fume can increase the dust resistivity to levels beyond 1012 ohm-cm, causing major deterioration in performance. It will also degrade performance of cyclonic and wet scrubbers where prohibitively high energy would be required to achieve acceptable emission levels.

The use of more efficient combustion technology and/or hog fuel dryers can assist to alleviate these problems; however, when hog dryers are used the ash “stickiness” can be a problem depending on the nature of the wood fired.

Wet electrostatic precipitators have been successfully used in this application, as shown in the first case study presented herein.

Site-specific conditions must be studied carefully before a particular pollution control device is selected for this application.

2.2. MUNICIPAL SOLID WASTE (MSW) AND INDUSTRIAL WASTE-TO-ENERGY PLANTS

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.” 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 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 using conventional control devices in combination with a WESP.

3.0 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. 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.

4.0 GAS INLET CHARACTERISTICS

Before suitable pollution control equipment can be selected, it is necessary to define the gas flow, temperature and composition, the nature of the material to be removed and present and anticipated future regulatory emission levels.

It is necessary to clearly define the concentration of the contaminant gas and/or the size, shape, form, nature, etc. of the particulate. Typically, a bi-modal distribution is characteristic of emissions from a wood-waste fired boiler. If the wood has been contaminated by a salt during transport by sea, the distribution is tri-modal, with the salt adding a submicron (0.3 mm SMD) fraction to the emission.

In order to effectively remove the entire range of particulate, the emission source must be tested to determine the particulate size distribution. This information is mandatory to properly design the particulate abatement equipment.

Various factors which could influence equipment selection have been presented in Figure 1.

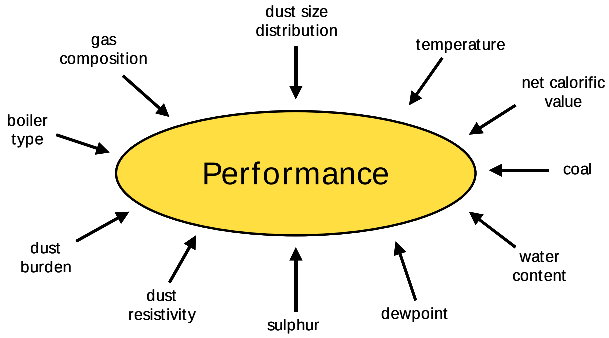


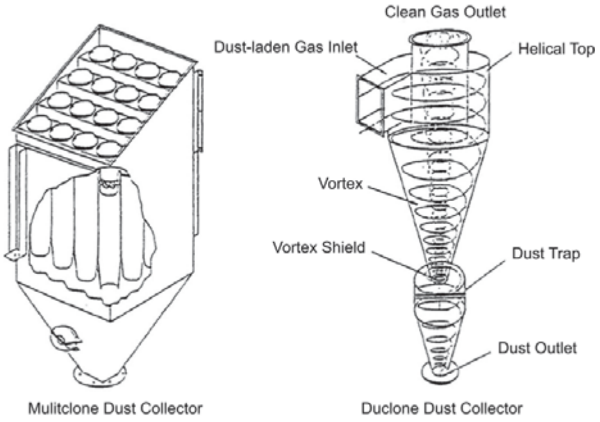
Figure 1. Factors influencing equipment selection.

5.0 EMISSION CONTROL TECHNOLOGIES

There are a considerable number of conventional and emerging pollution control technologies. As it is not possible to discuss all of the technologies, the following equipment has been selected as being most appropriate for description with respect to emission control in the waste-to-energy industry.

5.1. CYCLONIC SEPARATOR

The most common technology for particulate control is the dry cyclonic separator (see Figure 2). The principle of operation is based on particulate being removed from spinning gases by centrifugal forces. They are simple to construct and have no moving parts. They require much less space than other devices; however, they require considerable pressure drop.



Mulitclone Dust Collector

Duclone Dust Collector

Figure 2. Typical Commercial Cyclones.

They can also be constructed with smaller diameter, which enhances performance, and can conveniently be arranged in arrays in a “tube sheet”. This multiclone™ arrangement has been a standard in the industry and adequately described in the literature.

This equipment is effective in capturing large (> 100 mm) particulate with lower effectiveness in removing smaller (10-100 mm) particulate. Fine particles (10 mm) are not effectively removed. Outlet loadings of > 350 mg/m3 are typical for cyclonic separators on hog fuel boilers. This type of system is sensitive to fluctuations in gas volume and thus requires a constant flow in order to operate as designed.

5.2. VENTURI SCRUBBER

The venturi scrubber atomizes liquid by the velocity of the gases accelerating through the venturi throat. Although a small part of the energy is provided from that used in the liquid sprays, it is primarily the gas stream pressure drop that provides the energy for liquid atomization. Some venturi designs force the mixture through a set of fixed vanes, whereas others have a variable “throat” through which the gas/water mixture is forced (see Figure 3).

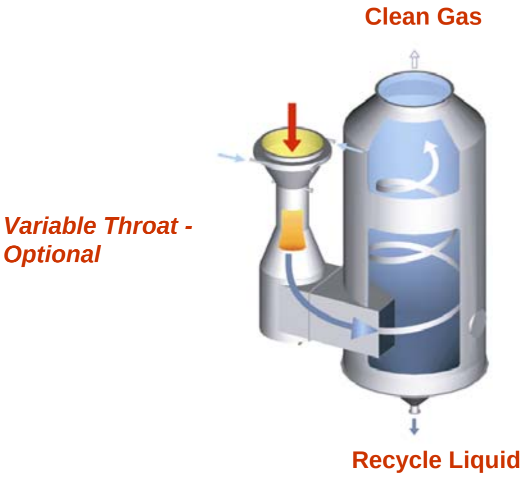


Figure 3. Variable throat venturi design.

Droplet collection can be provided by horizontal, angled or vertical mist eliminator blades or baffle plates, or by cyclonic collection.

Like the dry cyclone, the venturi systems are dependent on a constant gas velocity to operate effectively. In the case of a variable throat venturi, this can be accomplished by varying the throat area with changes in the gas volume. This can be done manually or with automatic controls maintaining constant pressure drop. A typical performance curve is presented in Figure 4.

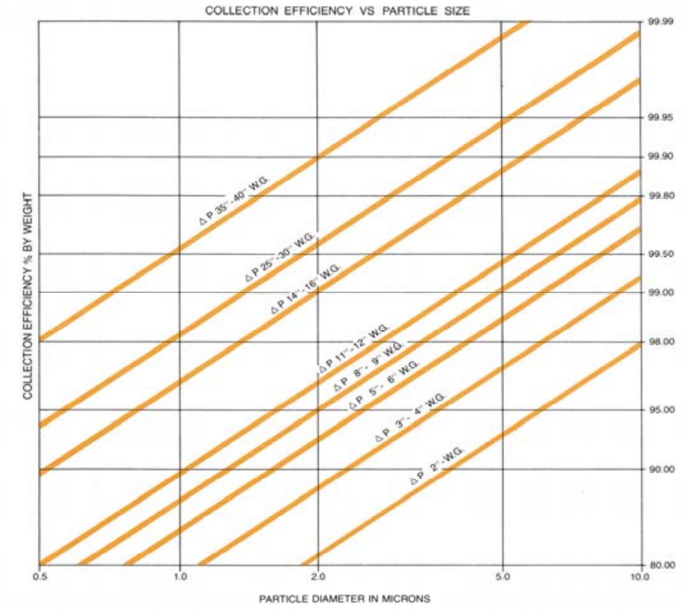


Figure 4

5.3. DRY ELECTROSTATIC PRECIPITATOR (ESP)

In a conventional single-stage dry electrostatic precipitator, particulate-laden flue gases enter the unit through a gas distribution or baffle screen to reduce pressure losses and ensure uniform gas flow (see Figure 5).

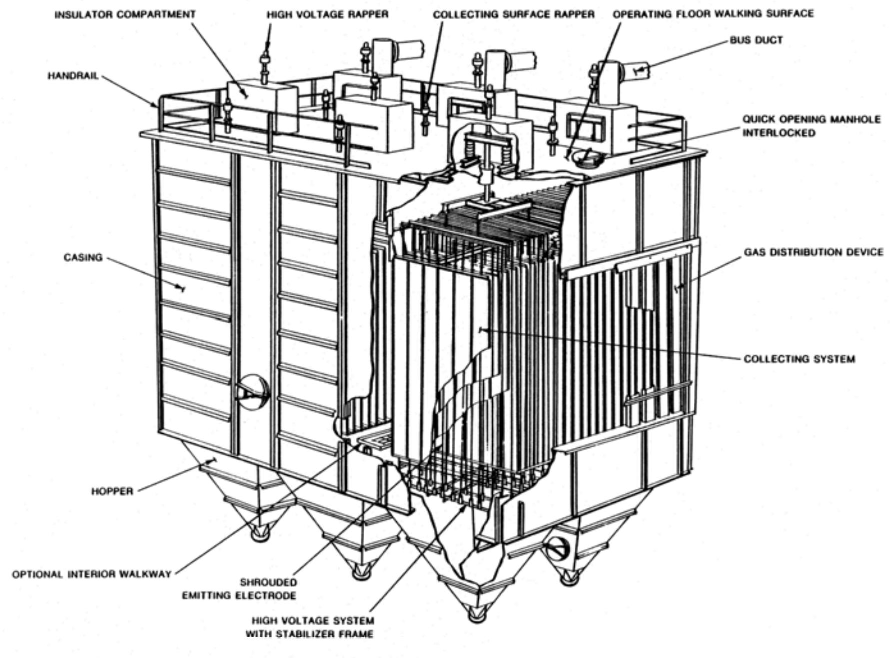


Figure 5. North American design.

The gases then pass between rows or ducts of grounded collecting electrodes (plates), between which are positioned a parallel array of emitting electrodes, to which a negative potential is applied.

If a sufficiently high voltage difference exists across the electrodes, the electrical break down of the gas surrounding the discharge electrodes results in a corona discharge that occurs in tufts at intervals along the wires. 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 dust particles by:

- collision with them;
- 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 toward, and deposit upon, the collecting electrodes.

The particulate matter is then rapped off the electrodes where it falls into the hoppers for removal. For effective rapping, dust must be removed from the plates in large clumps.

ESPs are capable of high removal efficiencies, including the submicron range. Large housings are used, which create low gas velocities resulting in low pressure drops for these systems. The ESP is sensitive to velocity changes and thus to gas volume changes. Relative to the other control technologies, the electrostatic precipitator has the lowest energy consumption rates. The size of the equipment involved dictates a high equipment cost.

In the past, electrostatic precipitators were traditionally divided into two main categories: European and North American design. The latter design in Figure 5 has been presented for illustrative purposes only. Today, electrostatic precipitators are usually of a hybrid design, combining the features of both styles of units.

5.4. WET ELECTROSTATIC PRECIPITATOR (WESP)

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.

Next, the gases pass between plates/rows or tubes, which are grounded collecting electrodes (Figure 6). A negative potential is applied to emitting electrodes, which are positioned in a parallel array between the collecting electrodes.

In the case of dry ESPs, the particulate matter is mechanically rapped off the electrodes where it falls into the hoppers for removal. This does not always happen efficiently, leading to re-entrainment of particulate.

WESPs utilize a liquid film to continuously remove the particles, thus avoiding re-entrainment, which occurs in a dry ESP.

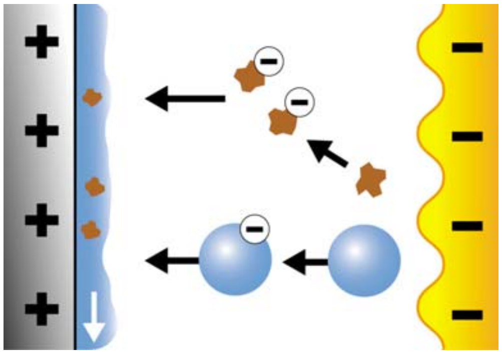


Figure 6. How a wet ESP works.

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 7).

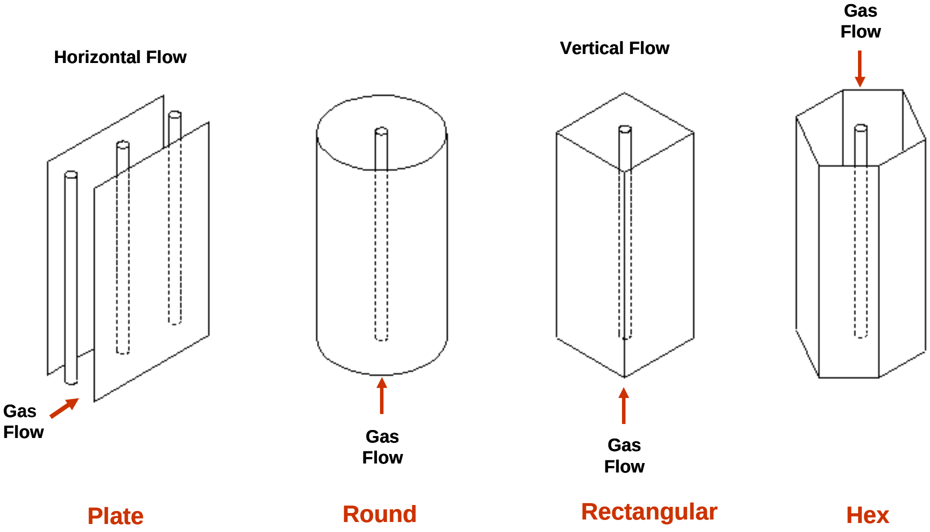


Figure 7. Configuration alternatives.

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. 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.

An example of a downflow hex tube WESP installation, cleaning off-gases from a hazardous waste incinerator, is shown in Figure 8.

Figure 8. Typical TurboSonic WESP on a hazardous waste incinerator.

6.0 TECHNICAL CONSIDERATIONS

The final selection of the appropriate pollution control system is the result of a number of factors and operating restraints, some of which are discussed below.

6.1. COLLECTION EFFICIENCY

The primary factor influencing equipment selection is the removal efficiency (and/or outlet loading) required. Allowance must also be made for future emission standards. Higher removal efficiencies can relate to higher energy consumption. Careful consideration should be given to the fact that the relationship between removal efficiency and energy consumption is different for all systems.

6.2. TURNDOWN RATIO

Some control systems require operation in a narrow range of gas volume treated. Fluctuations from this range can greatly reduce the effectiveness of these systems. If a boiler or MSW plant is operating over a wide range of flows, the control system must be able to handle this variability without affecting the removal efficiency.

6.3. ACID GAS/ODOUR REMOVAL

If supplementary fuels are used in boilers, such as oil and coal, it might be required to remove the resultant acid gases in addition to particulate removal. Wet scrubber systems can provide acid gas removal and WESPs can remove the haze causing $S0_3$.

6.4. LAYOUT FLEXIBILITY

While it is relatively easy to incorporate pollution control equipment into a new facility, most emission problems are associated with existing mills. These installations require a flexible system that can be fit into virtually any existing location with a minimum of structural modifications, without affecting performance.

6.5. FUTURE EMISSION STANDARDS

Current environmental considerations are leading to more stringent control standards, which will be periodically updated. Allowable emission rates are constantly being lowered and control equipment selected to meet current standards must have the capability to meet anticipated emission standards during its lifetime.

7.0 CASE STUDIES

7.1. WOOD WASTE FIRED BOILER – CANADA

7.1.1. INTRODUCTION

A 2400 t/d newsprint, market pulp and linerboard operation located on Vancouver Islands' eastern coast has a steam plant consisting of two waste-wood fired (hog fuel) boilers plus a natural gas/fuel oil auxiliary. The larger boiler operates typically at 50 kg/sec of steam at 4300 kPa. This boiler was originally equipped with a vertical flow venturi scrubber that was designed to meet the provincial standards of 230 mg/Sm^3D with an allowance for salt to 460 mg/Sm^3D. Normally the boiler had no problem meeting this limit despite having a frequent visible smoke plume.

Through the 1990s public objection to the larger boilers' visible emissions grew to the point where air quality became a very intense local issue. The pollution control equipment on the boiler had to be upgraded to meet modern standards.

7.1.2. ISSUES

The plant burns more waste than is generated in the immediate area, so hog fuel is imported to the mill site via barge from distant coastal lumbering operations. The BC coast forest industry is unique in the way it transports logs from the forest to mills. Logs are normally stored in salt water at remote logging sites prior to being barged to mills located on the lower coast. Logs are also stored at mill sites in either marine or fresh water depending on the location of the particular sawmill. Marine log storage causes two problems with the waste wood:excessive moisture retention and sea salt absorption.

Marine salts are a chronic problem for coastal wood fueled boilers. The salt content of hog fuel can often range over 2% by weight based on dry solids. This material will evaporate inside a boiler only to condense as a submicron-sized fume in the exhaust gases. On a boiler capable of burning 1000 tonnes of waste wood per day, 2% salt corresponds to 20 tonnes of material. The existing scrubber was very ineffective at removing submicron contaminants.

The salt combined with very high fuel moisture, resulted in a frequent haze that drifted for kilometers and could obscure the visibility of the surrounding mountains.

7.1.3. PILOT PLANT

The control equipment of choice on Canada's west coast has traditionally been a dry electrostatic precipitator. One problem faced by dry electrostatic precipitators has been that the high salt content in hog fuel causes compromised performance due to back corona and increased build-up problems, necessitating fossil fuel consumption to reduce particulate emissions. Elk Falls was interested in finding equipment to reduce the haze and salt problem that would not be compromised by problems with salt contamination in the fuel.

In October 1998, arrangements were made to run a series of pilot plant trials with a WESP. The main difference between WESPs and the more conventional dry precipitators is that the wet units are designed to operate at or below the flue gas saturation temperature. The WESP offers advantages over dry precipitators, including removal of collected deposits with a falling water film and intermittent flushing, rather than being rapped off the collection plates. In addition, the volume of the cooled saturated gas stream is much lower than the hotter dry volume, reducing the equipment footprint, and the existing wet scrubber can be retained, making for a simpler installation.

7.1.4. INSTALLATION

A slipstream of flue gas was extracted (see test location in Figure 9) after the ID fan and before the existing scrubber and routed to a downflow hexagonal tube pilot WESP, illustrated in Figure 10. Testing was conducted to evaluate the ability of the WESP to handle the salt-laden flue gas emissions over a range of gas flows and salt content in the hog fuel. Additional data was collected to assess how the pilot unit would handle dioxin emissions.

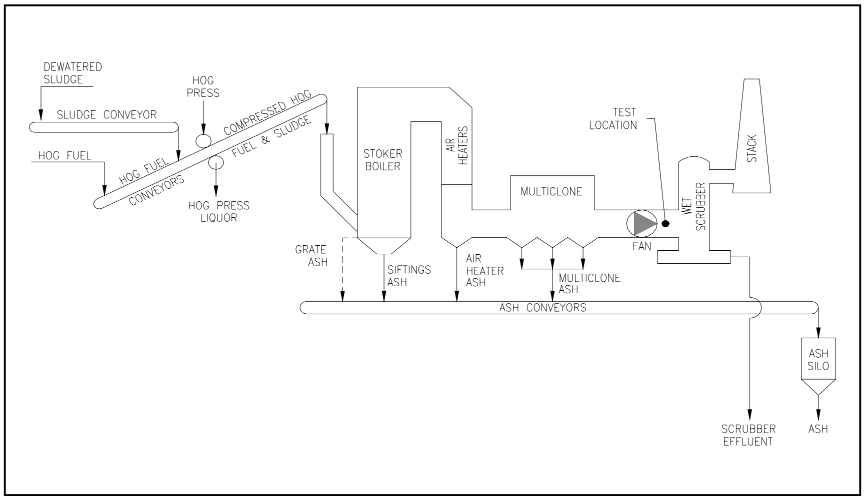


Figure 9. Siting of pilot test equipment.

Figure 10. Pilot WESP used for testing at Elk Falls.

Data was obtained over a range of gas flows, inlet loadings and salt content to define performance over the expected operating range. The value of WmPP was calculated from the Deutsch-Anderson equation for the pilot data and used to determine the full-scale performance parameter Wm,

$$h = 100 * (1 - e\text{-}Wm\ SCA/508)$$

Where SCA = A/Q = specific collecting area (ft^2/1000 ACFM)

Wm = migration velocity (cm/s)

h = efficiency (%)

The percent salt of the WESP inlet and outlet catch remained almost unchanged, which indicated that a WESP is equally effective in capturing both the salt and salt-free fractions. It is to be noted from Figure 11 that the salt and salt-free fractional migrational velocities are almost identical throughout the entire range of salt content measured. This clearly demonstrated that WESP performance is not affected by the salt content of the inlet loading, thus not placing any restriction on the salt content of the hog fuel.

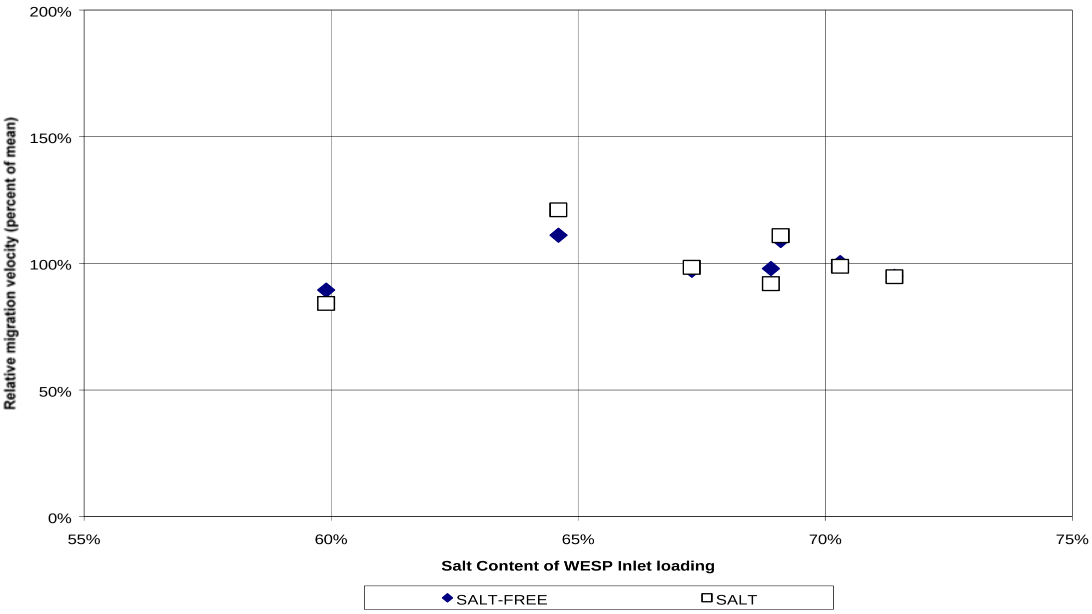


Figure 11. Relative migration velocity vs. salt content.

7.1.5. PERFORMANCE

Performance testing was conducted in July 2001. All particulate test results were within the design guarantee requirement, as illustrated in Figure 12. Dioxin emissions were substantially reduced; however, these data are not available for publication.

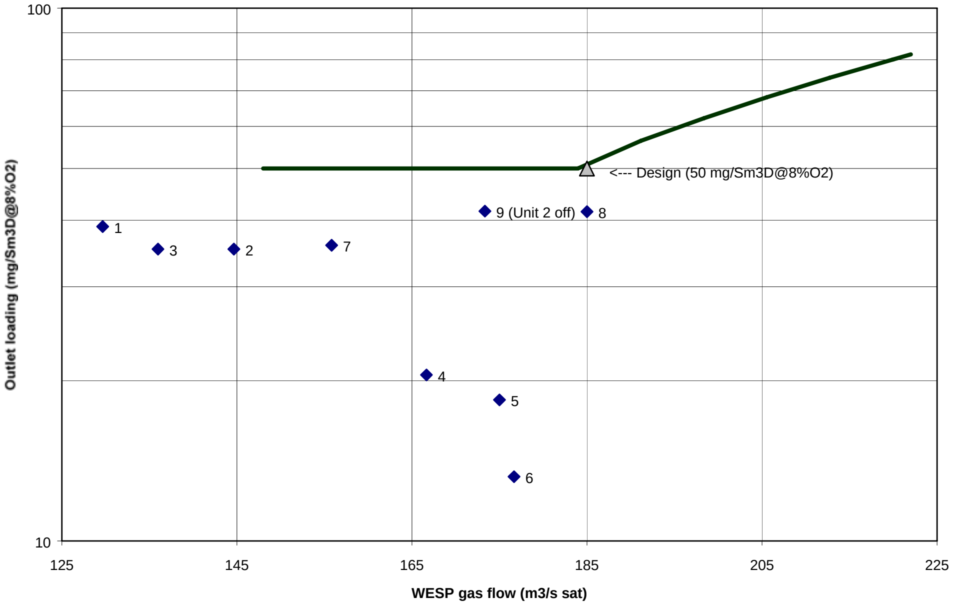


Figure 12. Performance test results.

7.1.6. CONCLUSIONS

This precipitator is a dramatic departure from the tried and true convention of using dry precipitators in this industry. This unit has shown that it is capable of operating below modern emission standards and coupled with the fact that it handles wet flue gas rather than dry gas, it is capable of removing additional water-soluble materials along with particulate.

The initial problem of haze resulting in an unacceptable number of public complaints has been rectified. The boiler is now operating at full loads without additional auxiliary fuel to control discharge opacity. Salt content of the waste wood fuel is not a concern.

7.2. MUNICIPAL WASTE INCINERATION PLANT – BEGLES, FRANCE

7.2.1. INTRODUCTION

Three TurboSonic Wet Electrostatic Precipitators were designed to operate at a municipal waste incineration facility in France.

The off-gas from the existing municipal waste incineration operation contains pollutants, including particulate matter, acidic gases, chlorides/fluorides and nitrogen oxides (N0x). This off-gas was treated by an existing dry electrostatic precipitator (ESP) followed by a wet scrubber.

A new primary gas treatment system was installed comprising of:

- a new gas to gas heat exchanger
- a new scrubber #2 (packed tower type)
- new TurboSonic Wet Electrostatic Precipitators

The WESP outlet off-gas stream then enters a final treatment system for DeN0x-Dediox. This new secondary gas treatment plant consists of a catalytic reactor, an economizer (gas-gas exchanger), and a fan before the gas is directed into the exit stack.

The three (3) TurboSonic SonicKleen™ WESP units are engineered as a gas cleaning polishing device to remove any remaining sub-micron particulate / pollutants, acidic mist droplets and condensibles (chlorides and fluorides). The WESPs have been designed to ensure compliance with the guaranteed outlet emissions as specified by the regulatory authority.

7.2.2. PROCESS OVERVIEW

The saturated gas stream exiting from the new scrubber is directed to the TurboSonic SonicKleen™ WESP unit via an inlet duct (one WESP unit for each of the three new gas treatment lines #1, #2, #3). The system consists of six (6) main sections.

- secondary treatment fogging system (conditioning nozzle)
- inlet plenum and gas distribution devices
- washdown (flushing) system
- wet electrostatic precipitator (WESP)
- high voltage insulator compartment
- outlet plenum

7.2.3. SECONDARY TREATMENT FOGGING SYSTEM

The saturated gas stream leaving the new scrubber #2 system enters a duct that contains a gas conditioning system using a Turbotak atomizing nozzle. This secondary treatment fogging system provides ultra-fine gas conditioning at the inlet to the WESP unit. This gas conditioning step promotes particle agglomeration, growth and ensures gas saturation as well as provides irrigation of the WESP collection surfaces.

7.2.4. INLET PLENUM AND GAS DISTRIBUTION DEVICES

The conditioned gas stream enters the inlet plenum that directs the gas to flow vertically downward into the WESP. Multiple perforated plates are utilized here as gas distribution devices that equally distribute the gas to all the collection tubes.

7.2.5. WASHDOWN SYSTEM

After the inlet plenum the gas enters the high voltage plenum that is equipped with a flushing header to provide an intermittent flushing spray to prevent any buildup of particulate on the high voltage frame or the collection tubes. The duration and the frequency of the spray depends on the severity of the application (particulate loading).

BIBLIOGRAPHY

[1] Allan, R.A. "The Use of Traditional Air Pollution Control Devices to Meet Existing and New Air Quality Standards", page 4, Canadian Pulp & Paper Association 1995 Environmental Conference, Halifax, Nova Scotia, October 23, 1995.

[2] EPA Factsheet, EPA's Revised Particulate Matter Standards, July 17, 1997.

[3] Allan, R.A., "The Wet Electrostatic Precipitator: A Proven Technology for Sub-Micron Particulate Control", EXFOR Environmental Conference, 87th Annual Meeting of PAPTAC, Montreal, Quebec, 2001.

[4] Allan, R.A., and Wood, R.W., "Particulate Control Strategies for Incineration", 25th Annual IT3 Conference, International Conference on Incineration and Thermal Treatment Technologies, Savannah, GA, May 15-19, 2006.

[5] Easton, C.A., et al., "Controlling Power Boiler Emissions with Wet Electrostatic Precipitators", Paper Presented at the TAPPI 2002 International Environmental Conference, Montreal, Quebec, February 2002.

[6] White, Harry, J., "Industrial Electrostatic Precipitation", Addison-Wesley Publishing Company Inc., London, 1963.