**Retrofit Control Technology Assessment for $NO_x$, $SO_2$ and PM Emissions
From Kraft Pulp and Paper Mill Unit Operations**
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## 1.0     Introduction

This document summarizes the general applicability of currently available emission control technologies for $NO_x$, $SO_2$ and particulate matter (PM) to various pulp and paper mill sources. The three main unit operations in a kraft pulp mill that emit $NO_x$, $SO_2$ and PM are kraft recovery furnaces, lime kilns and boilers.  Boilers can be of the type which burn wood residues alone, wood in combination with coal, gas or oil, or coal, oil or gas exclusively.  Particulate emissions can also result from lime slakers and smelt dissolving tanks.  Other pulp and paper mill sources for PM are generally quite insignificant.

The origin and nature of the three pollutants in each relevant pulp mill unit operation is first discussed.  Such discussion should be useful in understanding why some control technologies, while being suitable candidates for certain unit operations in other industries, may not be suitable in the pulp and paper industry.  It is hoped this document will be useful in the evaluation of a Best Available Retrofit Technology (BART) site-specific engineering analysis.  However, it must be clearly noted that for any retrofit technology, site-specific considerations for a given emission source may disqualify a particular control technology from consideration, even though it might theoretically be feasible or may even have been installed elsewhere on a new, modern unit or a greenfield operation.

Cost and emission reduction estimates are specifically not covered in this document.  However, it is instructive to consider that a wide range in costs and potential emission reductions are expected due to the fact that site-specific factors play a critical role in determining how cost-effective various technologies will be in practice.  Many facilities are space-limited, have controls already in place, or have older combustion equipment that cannot be retrofit to reach required conditions, making installation of certain technologies problematic or very expensive.

## 2.0     Kraft Recovery Furnaces

## 2.1     $NO_x$ Control

Compared to coal- or residual oil-fired boilers of similar capacity, $NO_x$ emissions from kraft recovery furnaces are generally quite low, typically in the 60 to 130 ppm range.  These low $NO_x$ emissions are due to several factors inherent to kraft recovery furnace operations which include (a) low nitrogen concentrations in most "as-fired" black liquor solids (generally <0.2% ), (b) recovery furnace $NO_x$ formation resulting predominantly from "fuel $NO_x$" mechanisms (insufficient temperatures for "thermal $NO_x$" formation), (c) the highly staged combustion design of recovery furnaces, and (d) the existence of sodium fumes that might participate in "in-furnace" $NO_x$ reduction or removal.

Researchers have concluded that nearly two-thirds to three-fourths of the liquor N is released during pyrolysis or devolatilization, partly as $NH_3$ and partly as $N_2$, the rest remaining with the smelt product most likely as a reduced N species.  The ammonia released from the black liquor during pyrolysis partly oxidizes to NO and partly reduces to $N_2$.  A review of the theoretical kinetics governing the reactions between $NH_3$, NO, and $O_2$ suggests that, in the presence of

excess $O_2$, a decrease in temperature decreases the degree of oxidation of $NH_3$ to NO, thus implying that fuel $NO_x$ generation during black liquor combustion is more temperature-dependent than previously thought. However, a reduction in furnace temperatures, particularly in the lower furnace, is generally expected to result in a sharp increase in $SO_2$ emissions from the furnace. Most of the NO is formed by oxidation of the $NH_3$ volatilized during pyrolysis of the liquor droplets. Very little NO is formed from the N in the char bed. In certain instances, where the liquor droplet dries completely before reaching the char bed, additional NO can be formed during "in-flight" char combustion of the liquor droplet. The use of liquor sprays resulting in larger droplet sizes avoids the problem of additional NO contribution from char burning.

Some have observed that $NO_x$ emissions increased when firing liquors with increasing liquor solids contents. However, this may have had less to do with thermal $NO_x$ or an "in-furnace" capability of alkali fume to capture $NO_x$ as suggested by some, but more to do with a possible effect on increased conversion of ammonia to NO within the furnace due to an increase in lower furnace temperatures resulting from firing higher solids liquors.

### 2.1.1 Low NO$_x$ Burners

The use of low-$NO_x$ burners (LNB) for black liquor combustion has not been demonstrated. Unlike fossil fuels, black liquor has a large quantity of water and the drying, pyrolysis, and char burning of liquor droplets occurs over a long flight trajectory from the liquor guns to the char bed, thus making unavailable the benefits of staged combustion inherent in LNB designs.

LNBs could however be applied to oil guns or gas burners in recovery furnaces that are used to supply supplemental heat or for start-up/shut down purposes. However, for most recovery units, the use of auxiliary fuel is very limited; in such cases the benefit from conversion to LNB would be marginal.

### 2.1.2 Staged Combustion

Recent research has concluded that to the extent "staged combustion" is allowed to take place in the upper furnace during oxidation of the volatilized $NH_3$ to NO, such oxidation can be minimized. Limited short-term experience after installing "quaternary" air ports in two U.S. furnaces showed that a 20 to 40% reduction in baseline $NO_x$ levels is feasible using such air staging. However, to make it feasible to install a quaternary air system a recovery furnace typically needs to be fairly large in size. Unfortunately, most of the BART-eligible units in the pulp and paper industry do not meet this requirement.

### 2.1.3 Flue Gas Recirculation (FGR)

Flue gas recirculation (FGR) is also not a viable option for kraft recovery furnaces. In FGR, a portion of the uncontrolled flue gases is routed back to the combustion zone, primarily with the intention of reducing thermal $NO_x$. Thermal $NO_x$ is, however, not a concern in recovery furnaces, as discussed earlier. FGR would add additional gas volume in the furnace, increasing velocities and potentially causing more liquor carryover, which would result in increased fouling of the recovery furnace tubes.

### 2.1.4 Oxygen Trim + Water Injection

Oxygen-trim + water injection, a $NO_x$ control technology generally utilized in natural gas-fired boilers, would not be relevant to kraft recovery furnaces since (1) any injection of water into the

furnace would lead to an unacceptable explosive condition and (2) the oxygen trim technique would have marginal effect due to the already existing highly staged combustion air configuration in recovery furnaces.

### 2.1.5 Selective Non-Catalytic Reduction (SNCR)

At the current time, there is no published information on the extended use of SNCR on an operating kraft recovery furnace. Short-term tests with the SNCR technology have been reported in the literature on two furnaces in Japan and one in Sweden. There are a number of critical, unresolved issues surrounding the use of urea or ammonia injection in a kraft recovery furnace for $NO_x$ control over a long-term basis. A kraft recovery furnace is the most expensive unit operation in a pulp mill since its primary purpose is to recover chemicals from spent pulping liquors in a safe and reliable manner. Although steam is generated from liquor combustion, certain chemical recovery steps have to be accomplished inside the furnace. It is not known whether the injection of $NO_x$-reducing chemicals into the furnace would have deleterious effects on the kraft liquor recovery cycle on a long-term basis. Long-term tests would need to be carried out to address this important issue. In addition, there are several other factors that make the use of SNCR in a kraft recovery furnace problematic such as (1) the impact of large variations in flue gas temperatures at the superheater entrance due to fluctuating load and liquor quality, (2) limited residence times for the $NO_x$-$NH_3$ reactions available in smaller furnaces, (3) impact on fireside deposit buildup due to reduced chloride purging from long-term $NH_3$/urea use and resulting impact on tube corrosion and fouling, and (4) potential for significant $NH_3$ slip and plume opacity problems due to $NH_4Cl$ emissions. Unless these concerns are satisfactorily resolved, the use of SNCR in a kraft recovery furnace should not be considered as a feasible technology.

### 2.1.6 Selective Catalytic Reduction (SCR)

The use of SCR on a kraft recovery furnace has never been demonstrated, even on a short-term basis. The impact of high particulate matter concentrations in the economizer region and fine dust particles on catalyst effectiveness is a major impediment to the application of this technology ahead of PM control, as is catalyst poisoning by soluble alkali metals in the gas stream. For SCR installation after an ESP, the gas stream would be too cold for effective reaction with the $NO_x$. A substantial energy penalty would have to be incurred to reheat the flue gas prior to the SCR section which would be a major drawback.

### 2.1.7 Summary

In summary, optimization of the staged combustion principle within large, existing kraft recovery furnaces to achieve lower $NO_x$ emissions might be the only technologically feasible option at the present time for $NO_x$ reduction. However, the effect of such air staging on emissions of other pollutants, chiefly $SO_2$, CO, and TRS, and other furnace operational characteristics needs to be examined with longer-term data on U.S. furnaces. Ultimately, the liquor nitrogen content, which is dependent on the types of wood pulped, is the dominant factor affecting the level of $NO_x$ emissions from black liquor combustion in a recovery furnace. Unfortunately, this factor is beyond the control of pulp mill operators.

### 2.2 $SO_2$ Control

Black liquor contains a significant amount of sulfur, nominally 3 to 5% by weight of the dissolved solids. While the vast majority of this sulfur leaves the furnace in the smelt product, a small fraction (generally under 1%) can escape in gaseous or particulate form. Average $SO_2$

concentrations in stack gases can range from nearly 0 to 500 ppm, although most furnaces currently operate with <100 ppm $SO_2$ in stack emissions. Factors which influence $SO_2$ levels are liquor sulfidity, liquor solids content, stack oxygen content, furnace load, auxiliary fuel use, and furnace design. However, none of these factors has exhibited a consistent relationship with $SO_2$ emissions. At the present time, it is generally understood that conditions involving liquor quality (such as high Btu, high solids liquors) and liquor firing patterns and conditions related to furnace operations (air distribution, auxiliary fuel, etc.) that lead to maximizing temperatures in the lower furnace result in minimizing $SO_2$ emissions from kraft recovery furnaces.

There is no experience in the pulp and paper industry with the use of add-on flue gas desulfurization technologies on kraft recovery furnaces. Scrubbing may be possible on some units to reduce $SO_2$. However, the use of such technologies on flue gases from a recovery furnace is expected to be highly cost ineffective, both due to high capital costs and due to site-specific retrofit costs. Large equipment and additional induced fan capacity to overcome the increased pressure drop across a scrubber would be needed, leading to excessive costs.

## 2.3    Particulate Matter Control

Recovery furnaces are designed and operated in a manner so as to ensure the presence of high levels of sodium fumes in order to capture the sulfur dioxide produced as a result of oxidation of reduced sulfur compounds. Consequently, uncontrolled recovery furnace flue gases contain high levels of particulate matter. The uncontrolled particulate matter load from recovery furnaces is highly variable and has been reported to range from 100 to 250 lb/ODTP (oven dry ton pulp) for direct contact evaporator (DCE) furnaces and 200 to 450 lb/ODTP for non-direct contact evaporator (NDCE) furnaces. The lower particulate loading from DCE furnaces is due to the capture of some particulate matter in the direct contact evaporator. ESPs built for NDCE furnaces are designed to compensate for the higher particulate loading.

Particulates generated in the recovery furnace are comprised mainly of sodium sulfate, with lesser amounts of sodium carbonate and sodium chloride. Similar potassium compounds are also generated, but in much lower amounts. Trace amounts of other metal compounds, e.g. magnesium, calcium, and zinc, can be present. A significant portion of the particulate material is sub-micron in size, which makes removal with additional add-on control devices more difficult.

Increasing liquor firing density (ton/day/ft$^2$) increases recovery furnace particulate loading. Other factors such as bed and furnace temperature, liquor solids, liquor composition, and air distribution also affect uncontrolled particulate emissions from recovery furnaces.

ESPs are the control device of choice for controlling PM emissions from kraft recovery furnaces. The use of larger ESPs is expected to result in better overall PM capture efficiencies. However, this option is expected to be quite cost ineffective based on the high, site-specific, retrofit costs incurred. Moreover, with the implementation of MACT II limitations in 2004, most recovery furnaces are operating at or below NSPS levels. Any additional benefit would thus be marginal.

## 3.0    Kraft Lime Kilns

## 3.1    $NO_x$ Control

$NO_x$ emissions from lime kilns result mainly from fossil fuel burning (natural gas and fuel oil). A recent NCASI study involving $NO_x$ testing at 15 lime kilns verified that "thermal" $NO_x$ was the sole mechanism operative in gas-fired kilns, while the "fuel" $NO_x$ mechanism was mostly

operative in oil-fired kilns. Gas-fired kiln $NO_x$ emissions appeared to be strongly dependent on the dry-end lime temperature. Oxygen availability in the combustion zone was determined to be the key factor in oil-fired kilns. $NO_x$ emissions for gas-fired kilns also exhibited high short-term variability, unlike for oil-fired kilns. Analysis of long-term daily average data from two lime kilns showed no difference in $NO_x$ emissions between days with and without LVHC NCG burning. An earlier NCASI study had shown that when stripper off-gases (SOGs) containing ammonia were burned in lime kilns, a small fraction of the ammonia, up to 23%, converts to $NO_x$.

A BACT analysis conducted on a new lime kiln in 1997 concluded that the use of low $NO_x$ burners in lime kilns was technically infeasible due to complexities resulting in poor efficiency, increased energy usage, and decreased calcining capacity of the lime kiln.

Post-combustion flue gas $NO_x$ control using SCNR or SCR is not feasible due to the configuration of the kraft lime kiln. The necessary temperature window of 1500°F to 2000°F for reagent injection in the SNCR process is unavailable in a kraft lime kiln. The very high PM load prior to control would make SCR infeasible in advance of the controls and the requisite temperature window of between 550°F and 750°F for applying SCR after a PM control device is unavailable for a lime kiln, even for one equipped with an ESP.

Thus, $NO_x$ control in newer lime kilns may be achieved mainly by minimizing the hot end temperatures in gas-fired kilns and by reducing the available oxygen in the combustion zone in oil-fired kilns, both combustion related modifications. However, these modifications may be difficult to achieve in certain existing kilns due to their inherent design. For example, in order to complete the calcining reactions in kilns with short residence times, it is more difficult to control hot end temperatures in shorter kilns than in longer ones.

## 3.2    SO$_2$ Control

Sulfur dioxide is formed in lime kilns when fuel oil or petroleum coke is burned as primary fuel. $SO_2$ will also be formed if non-condensible gases (NCGs) or stripper off-gases (SOGs) containing sulfur are burned in the kiln. Lime muds also contain a small amount of sulfur, which when oxidized, would form $SO_2$. Median sulfur content of concentrated NCGs and SOGs have been reported as 1.1 and 4.2 lb/ADTP (air dried ton pulp), respectively. Median sulfur contents of 7 lime muds have been reported at 0.2%, which translates to about 1.8 lb S/ADTP. Thus, fossil fuels such as fuel oil, kraft mill NCG/SOGs, and soluble sulfides in lime mud can contribute a significant amount of sulfur to the inputs of a lime kiln. Nevertheless, the regenerated quicklime in the kiln acts as an excellent in-situ scrubbing agent, and venturi scrubbers following the kiln can further augment this $SO_2$ removal process since the scrubbing solution becomes alkaline from the captured lime dust. Consequently, even though the potential for $SO_2$ formation in a kiln that burns sulfur-containing fuels with or without NCGs/SOGs is high, most lime kilns emit very low levels of $SO_2$ (~50 ppm). Some kilns do, however, occasionally emit higher levels of $SO_2$ (50 to 200 ppm). Not much is known about why this happens.

Emission test data show that $SO_2$ concentrations do not appear to be related to either the fuel type (oil, gas) or the presence or absence of concentrated NCG or SOG burning in the kiln. A preliminary sulfur input-output balance carried out on 25 kilns with wet scrubbers and 7 kilns with electrostatic precipitators (ESPs), with sulfur inputs from fuel oil, NCGs and SOGs, or just lime mud, showed over 95% of the $SO_2$ generated from the oil, NCG/SOGs, or lime mud was captured within the kiln. For kilns with wet scrubbers (majority) that have high $SO_2$ emissions, alkali addition to the scrubbing fluid could further reduce the $SO_2$ emissions.

### 3.3 Particulate Matter Control

While passing through the kiln, the combustion gases pick up a good deal of particulate matter both from lime mud dust formation and from alkali vaporization. This PM must be removed before the gases exit to the atmosphere. Mechanical devices such as dust chambers or cyclones are generally used to remove larger particles, which are mainly calcium-containing. A wet scrubber or electrostatic precipitator follows for removal of smaller particulates, which are mainly sodium sulfate and sodium carbonate and have aerodynamic diameters less than 10 μm.

Kraft lime kiln PM emissions are typically controlled by venturi-type wet scrubbers. Scrubbers with increasingly better PM removal efficiencies, such as the Ducon Dynamic Wet Scrubber, have been installed up until the late 1980s. However, most of the PM control installations on lime kilns since about 1990 have been ESPs. Replacing a wet scrubber with an ESP will most likely reduce PM emissions, but may increase emissions of $SO_2$. The wet scrubber acts as an additional alkaline $SO_2$ scrubber since it captures alkaline PM leaving the kiln. Just as for recovery furnaces, with the implementation of MACT II limitations in 2004, most lime kilns are operating at or below NSPS levels. Any additional benefit would thus be marginal.

### 4.0 Boilers

The majority of pulp and paper industry boilers are combination boilers, in that they are designed to burn more than one fuel. Thus, it should be noted that while a particular technology may be beneficial for a particular pollutant, the same technology may not address the control of another pollutant. For example, a wood-fired boiler with a wet scrubber for PM control may obtain better PM control with an ESP. However, if the boiler also fires some sulfur-containing fuel (as is often the case), the $SO_2$ removal capability of the wet scrubber will be sacrificed by the installation of an ESP.

### 4.1 Natural Gas-Fired Boilers

Gas-fired boilers are usually not equipped with particulate collectors. $SO_2$ emissions depend on the sulfur content of the gas, which is typically negligible. $NO_x$ emissions are dependent on the combustion temperature and the rate of cooling of the combustion products. There are several combustion modification techniques available to reduce the amount of $NO_x$ formed in natural gas-fired boilers and turbines. The two most prevalent ones are flue gas recirculation (FGR) and low-$NO_x$ burners. FGR reduces formation of thermal $NO_x$ by reducing peak temperatures and limiting availability of oxygen. Low-$NO_x$ burners reduce formation of thermal $NO_x$ by delayed combustion (staging) resulting in a cooler flame. In conjunction with FGR, the burners can achieve $NO_x$ emission reductions of 60 to 90%. Other techniques include staged combustion and gas reburning. In general, these techniques have been incorporated in newer boilers and thus their $NO_x$ emissions are lower than those of older units.

There are also add-on control technologies that can reduce $NO_x$ emissions from gas-fired boilers such as selective non-catalytic reduction (SNCR) and selective catalytic reduction (SCR). However, since most of the pulp and paper industry gas-fired boilers are of the package boiler type, cost considerations typically make the use of such technologies cost ineffective. Further, both the SNCR and SCR technologies have not been proven to apply to industrial boilers with frequent swing loads.

## 4.2 Fuel Oil-Fired Boilers

For fuel oil-fired boilers, criteria pollutants can be controlled by fuel substitution/alteration, combustion modification and post-combustion control.  Fuel substitution reduces $SO_2$ and $NO_x$ and involves burning an oil with lower S or N content, respectively.  Particulate emissions are lower when burning lower sulfur content oils, especially distillate oil.

### 4.2.1 $NO_x$ Control

For boilers burning residual oil, fuel $NO_x$ is the dominant mechanism for $NO_x$ formation and thus the most common combustion modification technique is to suppress combustion air levels below the theoretical amount required for complete combustion.  There are several combustion modification techniques available to reduce the amount of $NO_x$ formed in fuel oil-fired boilers, including low excess air, burners out of service, biased-burner firing, flue gas recirculation, overfire air, and low-$NO_x$ burners.  $NO_x$ reductions that could range between 5 and 60% from uncontrolled systems may be expected from using these techniques.

Post-combustion controls include SNCR and SCR.  $NO_x$ reductions from 25 to 0% and from 75 to 85% may be expected from use of SNCR and SCR systems on oil-fired boilers, respectively.  However, just as for gas-fired boilers, most of the pulp and paper industry oil-fired boilers are of the package boiler type, and cost considerations typically make the use of such technologies cost ineffective. Furthermore, both the SNCR and SCR technologies have not been proven to apply to industrial boilers with frequent swing loads.

### 4.2.2 $SO_2$ Control

$SO_2$ emissions are controlled by a number of commercialized post-combustion flue gas desulfurization (FGD) processes which use an alkaline reagent to absorb $SO_2$ in the flue gas and produce a sodium or calcium sulfate compound. The FGD technologies may be wet, semi-dry or dry depending on the state of the reagent as it leaves the absorber vessel.

### 4.2.3 Particulate Matter Control

Due to the extremely low level of PM emissions, most residual oil-fired boilers do not have particulate matter controls.  A few boilers are, however, equipped with mechanical collectors or ESPs.

## 4.3 Coal-Fired Boilers

### 4.3.1 $NO_x$ Control

$NO_x$ emissions from coal-fired boilers can be controlled by a) combustion controls and b) post-combustion controls.  Combustion controls involve a) reducing peak temperatures in the combustion zone, b) reducing gas residence time in the high-temperature zone, and c) air or fuel staging by operating at an off-stoichiometric ratio by using a rich fuel-air ratio in the primary flame zone and lower overall excess air conditions.  The use of combustion controls depends on the type of boiler and the method of coal firing.  Low-$NO_x$ burners and overfire air (OFA) have been successfully applied to tangential- and wall-fired units, whereas reburning is the only current option for cyclone boilers.  For large base-loaded coal-fired boilers, the most developed and widely applied post-combustion $NO_x$ control technology is SCR.  Catalyst deactivation and residual $NH_3$ slip are the two key operating considerations in an SCR system.  The use of SNCR

systems on coal-fired boilers is still in the development stage. $NO_x$ reductions from 30-70% and from 60-90% may be expected from use of SNCR and SCR systems on coal-fired boilers, respectively. SNCR has a narrow temperature window in which it is effective, in the 1500 – 1900° F range, and SCR has a similar, but lower temperature window of 550 to 750°F. Neither the SNCR nor the SCR technologies have been proven to apply to industrial boilers with frequent swing loads, due to the inability to maintain good control within the required temperature window. Most coal-fired boilers in the pulp and paper industry operate in the swing load mode, a function of supplying steam as required to the various components of the process.

### 4.3.2    $SO_2$ Control

Just as in fuel oil combustion, criteria pollutants can be controlled by fuel substitution/alteration, combustion modification and post-combustion control. $SO_2$ reductions can be achieved by burning a coal with lower S content. $SO_2$ emissions can be controlled by a number of commercialized post-combustion flue gas desulfurization (FGD) processes which use an alkaline reagent to absorb $SO_2$ in the flue gas and produce a sodium or calcium sulfate compound. The FGD technologies may be wet, semi-dry or dry depending on the state of the reagent as it leaves the absorber vessel. The pulp and paper industry has limited experience with operating FGD systems on coal- or oil-fired boilers. Retrofit considerations include space restraints in many facilities.

### 4.3.3    Particulate Matter Control

Particulate emissions from coal-fired boilers are controlled by using a) ESPs, b) fabric filters (FF) or c) venturi scrubbers. Multi-cyclones are generally used as precleaners upstream of more efficient ESPs or FFs. The key operating parameters that influence ESP performance include fly ash mass loading, particle size distribution, fly ash resistivity (which is related to coal sulfur content), and precipitator voltage and current. Data for ESPs applied to coal-fired boilers show fractional collection efficiencies greater than 99% for fine (<0.1μm) and coarse particles (>10 μm) and a reduction in collection efficiency for particles between 0.1 and 10 μm. Operational parameters that affect fabric filter collection efficiency include air-to-cloth ratio, operating pressure loss, cleaning sequence, interval between cleanings, cleaning method, and cleaning intensity. Collection efficiencies of fabric filters can be as high as 99.9%. Scrubber collection efficiency depends on particle size distribution, gas side pressure drop through the scrubber, and water (or scrubbing liquor) pressure, and can range from 90 to 95% for a 2 μm particle.

### 4.4    Wood-Fired Boiler Emissions

### 4.4.1    $NO_x$ Control

Most large wood-fired boilers used in the pulp and paper industry are of the spreader stoker design. $NO_x$ control technologies effective for use on gas and oil burners are not applicable to spreader-stoker design boilers. Furthermore, these boilers are often operated handling swing loads, which makes add-on $NO_x$ controls difficult to implement. Spreader stoker boilers inherently practice staged combustion, which lowers $NO_x$ emissions, but within limits.

Fuel $NO_x$ is the dominant $NO_x$ formation mechanism operative during wood combustion. Fuel $NO_x$ is most efficiently controlled by staged combustion. Overfire air ports inherent to most spreader-stoker boilers provide for staged combustion. The underfire and overfire air are balanced in most wood-fired spreader stokers to control $NO_x$.

As with other fuels, potential post-combustion controls include SNCR and SCR. SNCR has been applied to a few base-loaded wood-fired boilers, mainly in the electric generating industry. However, its long-term efficacy on wood-fired boilers with changing loads has not been demonstrated. Experience in the pulp and paper industry to date has shown it has been used on occasions for polishing, to get perhaps 10-20% $NO_x$ reduction during periods of air quality problems. The problem with control of the required temperature window is an inherent difficulty with use of SNCR for load-following boilers, whether wood or fossil fuel. Inadequate reagent dispersion in the region of reagent injection in wood-fired boilers is also a factor mitigating against the use of SNCR technology. At least one pulp mill wood-fired boiler met with significant problems and had to abandon their SNCR system. Significant ammonia slip, caused by inefficient dispersion of the reagent within the boiler, was to blame.

The use of SCR on wood-fired boilers operating in the forest products industry has also never been successfully demonstrated for spreader stoker boilers, and would face the same inherent problem of requiring it to be post PM-control to protect the catalyst, and achieving and maintaining the required temperature window for effective $NO_x$ control.

### 4.4.2    Particulate Matter Control

Particulate matter is the air pollutant of primary concern in wood-fired boilers. As for coal-fired boilers, the most common devices used to control particulate emissions from wood-fired boilers are wet scrubbers and electrostatic precipitators (ESPs). Fabric filters (FF) and the electrified gravel bed filter (EGF) have been used on a few units. Wet scrubbers are widely used, operating at gas pressure drops ranging from 6 to 25" $H_2O$. Liquid to gas ratios in the venturi system typically range from 8 to 10 gal $H_2O$/1000 acfm saturated. Solids buildup in the recirculation loop rarely is allowed to exceed 5% by weight. High carbon ash resulting from wood combustion is more difficult to remove with an ESP due to its high conductivity/low resistivity. Thus, specific collection areas (ratio of ESP plate area to gas flow volume through the ESP) for ESPs on wood-fired boilers are greater than for those for coal-fired boilers, ranging from about 300 to 500 ft$^2$/1000 acfm. Power requirements range from 150 to about 400 watts per acfm. To address fire concerns, ESPs on wood-fired boilers are sometimes operated in the wet mode, where the collection plates and internal parts are wetted continuously with water. A pre-quench is generally used to saturate the gas stream. Fabric filters are rarely used on wood-fired boilers due to concerns about bag flammability. Fabric filters have been successfully used where bark from logs stored in salt water is burned and the salt reduces the fire hazard. In this situation, the fabric filter is effective in removing the very small salt particulates exiting the boiler. Gravel-bed filters have a slowly moving bed of granular "rock" as the filtration medium through which the flue gas must travel. These systems are electrostatically augmented (10 to 20 watts/1000 acfm). A high voltage (about 50 kV) is applied to an electrical conductor positioned within the bed and this creates an electrical field between the conductor and the inlet and outlet louvers. Particulate collection efficiencies for wood-fired boilers range from 65 to 95% for two multiclones in series, over 90% for wet scrubbers, from 93 to 99.8% for ESPs and FFs and about 95% for EGFs. Once again, it should be noted that most wood-fired boilers are combination boilers that may burn other sulfur-containing fuels. Thus, a change in the control device might affect the ability to control other pollutants. For example, replacing a wet scrubber with an ESP for better PM control would result in higher $SO_2$ emissions from a boiler burning wood in combination with oil or coal.

## 5.0     Other Source Emissions

### 5.1     Slakers - PM emissions

Slakers are generally vented through a stack to discharge the large amounts of steam generated. The steam may contain particulate matter, which is largely calcium and sodium carbonates and sulfates.  Scrubbers are generally employed to capture this particulate matter.   Other PM control devices such as ESPs and fabric filters are both technologically infeasible (very high moisture source) and not cost effective.

### 5.2     Smelt Dissolving Tanks - PM Emissions

As with the recovery furnace, particulate emissions from smelt tanks are comprised of mainly sodium compounds with much lesser amounts of potassium compounds and some other trace metal compounds.  The dominant compound is sodium carbonate, followed by sodium sulfate. Roughly 90% (by weight) of the particles have equivalent aerodynamic diameters under 10 μm, and 50% have diameters under 1 μm.  Most smelt tank PM emissions are controlled by wet scrubbers, many of which are wetted fan scrubbers that are very effective in removing fine particulate.  A dry ESP is once again infeasible as an option due to the high moisture content of the gases.  The wet scrubber also serves to control total reduced sulfur compound emissions through pH control, thus replacing it with a wet ESP is not an option.  As noted for other kraft mill sources, MACT II Implementation in 2004 has also resulted in significantly reduced allowable PM emissions from smelt dissolving tanks.

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