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Ammonia Removal from Fly Ash: Process Review

Separation Technologies LLC (ST)–Ammonia Removal Process

1012697

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Technical Update, March 2007

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ABSTRACT

For several years EPRI has examined topics related to ammoniated fly ash. Recently, there has been a focus of interest on ammonia removal processes, several of which are commercially available. For a more detailed investigation of these processes, it was determined that site visits to commercial operating facilities would be beneficial in understanding important aspects of the ammonia removal processes. This report focuses on the site visit and technology aspects of the Separation Technologies LLC (ST) Ammonia Removal Process.

Ammonia contamination of fly ash is considered problematic primarily due to the potential for adverse impacts associated with ash end-use as well as ash disposal. Most problems are related to personnel exposure, with gas-phase ammonia releases presenting a potential for both nuisance odors and in certain severe cases health impacts. Under the conditions of concrete manufacture, ammonia-contaminated ash is known to evolve considerable amounts of ammonia, varying with the conditions of concrete preparation and use. Dry land-filling operations may be impacted due to ammonia releases creating nuisance odor problems with operational personnel, and land-fill run-off may contain high levels of aqueous ammonia, potentially impacting water treatment or receiving waters. Wet disposal of ammoniated ash (ponding, etc.) may contribute to algae blooms in the receiving waters, and outflows to adjacent streams may have unacceptably high nitrogen levels. These issues have created the need for ammonia mitigation technologies, several of which have been developed.

The ST process consists of treating ammonia-contaminated fly ash with alkali to induce ammonia volatilization, resulting in very low residual ammonia levels. The volatilized ammonia is typically returned to the boiler flue gas train. The fly ash is moistened as part of the treatment and is subsequently dried. Preferred alkali materials are calcium oxide (quick lime) and calcium hydroxide (hydrated lime). The quality of the fly ash for end-uses is not impacted. In particular, pozzolanic activity is not affected due to the very small quantities of water utilized and the subsequent drying step. The process consists of alkali addition, high-intensity mixing, low-intensity mixing, and drying. The process effectiveness is relatively independent of the initial fly ash ammonia concentration.

The ST process appears to be a highly robust process, and although no independent analysis of treatment effectiveness was conducted as part of this study, the process also appears to be highly effective. Significant capital equipment is necessary to implement the process, but the benefits of this equipment include low variable cost, flexibility in production rates, and insensitivity to initial ammonia level. Overall the general impression of the technology is highly favorable.

ACKNOWLEDGMENTS

The material presented in this report is largely the product of a site visit, and so we would like to offer our special thanks to the host utility. We would also like to thank Dr. Steve Gasiorowski, and Mr. Frank Hrach, both of Separation Technologies, LLC, for their assistance with the site visit, process review, and report preparation.

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INTRODUCTION

For several years EPRI has examined topics related to ammoniated fly ash. Recently, there has been a focus on ammonia removal processes, several of which are commercially available. For a more detailed investigation of these processes, it was determined that site visits to commercial operating facilities would be beneficial in understanding important aspects of the ammonia removal processes. This report focuses on the site visit and technology aspects of Separation Technology LLC's (ST) ammonia removal process.

Ammonia Adsorption on Fly Ash

Ammonia adsorption on fly ash is a phenomenon that has been well documented in recent years in association with various ammonia-based environmental control technologies as applied to coal-fired boilers. The use of ammonia in the flue gas train for various purposes including SCR, SNCR, and flue gas conditioning for particulate control all result in the contamination of fly ash with various levels of ammonia. In general, the higher the level of ammonia exiting the control process, the higher the level of ammonia that will be found on the ash. However, a number of parameters will strongly influence the level of ammonia that ultimately would be present on the fly ash for any particular operating unit. These parameters include the time/temperature history of the flue gas, the control devices present in the flue gas train, the type of fuel being burned, and a number of fly ash-specific characteristics such as particle size distribution, bulk chemical composition, and surface chemistry. In addition, flue gas components such as SO_3 will greatly affect ammonia adsorption. This is especially important since SO_3 is sometimes injected into the flue gas increase the effectiveness of particulate control devices, and because SCR catalysts promote the formation of SO_3. It is not uncommon for both ammonia and SO_3 to be injected into flue gas as conditioning agents to improve particulate capture in electrostatic precipitators, creating a favorable scenario for ammonia deposition on the fly ash. It is known that eastern bituminous coals produce acidic ashes having a high affinity for ammonia, especially since the presence of moderate to high levels of SO_3 associated with the combustion of these fuels promotes ammonia adsorption. The adsorption level of ammonia for eastern bituminous ashes is on the order of 80% (as a rule of thumb) for ammonia slip levels below 5 ppmv. This translates to approximately 100 ppmw of ammonia on the fly ash for each 2 ppm of ammonia slip leaving the control process (assuming a coal with 10% ash). The percentage of ammonia captured by the fly ash may be reduced at high levels of ammonia slip due to the saturation of the fly ash, although the fly ash is capable of supporting high levels of ammonia, ranging in the thousands of ppm for ash fines. Other fly ashes, such as those from Powder River Basin coals, where both the SO_3 level is low and the ash pH is high (basic), will exhibit much less ammonia adsorption, such that facilities burning these types of coals may rarely see problematic levels of ammonia on the associated fly ash.

Ammonia Chemistry

In most cases, ammonia is present on the fly ash surface as a mixture of ammonium sulfate (AS) and ammonium bisulfate (ABS). Other ammonia compounds may be present, or ammonia may be physically adsorbed on the fly ash surface, but ammonia-sulfur compounds are principally present unless the ammonia concentration in the flue gas far exceeds that of SO_3 on a molar basis. Consequently, it is believed that the presence of SO_3 in the flue gas represents a major driving force for ammonia adsorption/deposition. Both AS and ABS form at relatively high temperatures and typically will begin forming at some point in the unit's air preheater. The deposition of these compounds on fly ash surfaces, equipment, and ductwork occurs quite rapidly, and this deposition is often the primary source of air preheater fouling associated with ammonia-based controls. In general, the adsorption/deposition process is reversible to a large degree.

Ammonia behavior is affected by pH, as shown in Figure 1-1. In terms of gas/liquid equilibrium, the ammonium ion is typically present under acidic conditions (low pH). The highly soluble nature of the ammonium ion inhibits evolution and little ammonia release from the solution is noted. However, when pH is raised free ammonia is favored, which will evolve into the gas phase, especially under highly alkaline conditions (high pH). This phenomenon is the source of much of the behavior noted when ammoniated fly ash is wetted. For instance, acidic ashes, even when wetted, tend not to evolve appreciable amounts of ammonia as long as the localized pH remains low (acidic). However, when caustic materials are added in sufficient quantities to raise the pH above 7 (such as with the addition of lime in concrete manufacture) the ammonia may be rapidly released. Ammonia is often highly leachable from acidic ashes, such as in sluicing or land-filling operations, producing aqueous streams with high ammonia contamination. Subsequent pH change in these aqueous streams may result in the gas-phase evolution of ammonia.

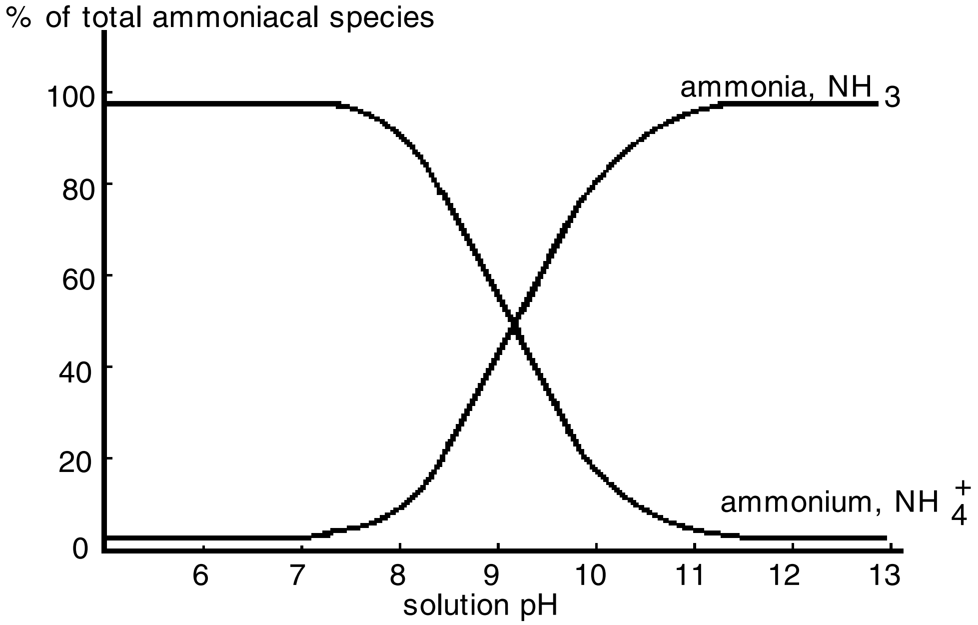

Figure 1-1
Free Ammonia and Ammonium Ion vs. pH

Adverse Impacts of Ammonia Contamination

The adverse impacts of ammonia contamination of fly ash are mainly related to environmental impacts and health and safety concerns. Most contaminated ashes having ammonia levels consistent with common environmental control process conditions have not been found to adversely affect the physical or chemical behavior of the ash during ash end-use, such as during the manufacture of concrete. However, because even relatively low levels of ammonia can produce nuisance (odor) and health problems and have adverse environmental impacts, ammonia contamination of fly ash is extremely important to the industry. It has the potential to disrupt both ash sales and ash disposal activities. Some of the potential adverse consequences of ammonia contamination are outlined below.

- Gas-phase evolution during handling and transport, causing odor problems for personnel.
- Long-term gas-phase evolution after land-filling causing chronic personnel exposure issues, mainly due to odor.
- Highly contaminated run-off water from sluicing, ponding, and land-filling causing environmental damage to receiving waters.
- Acute ammonia evolution during end-use activities such as concrete manufacture, causing odor problems for personnel, and potentially health problems in enclosed areas.
- Chronic ammonia evolution during end-use, creating nuisance odor problems with concrete pours, etc.

Ammonia Removal Processes

A number of ammonia removal processes are commercially offered. These processes can be divided into two general types, thermal and chemical, although the designations are not always clear-cut, since some removal processes will rely on both chemical and thermal principles. The Headwaters Ammonia Slip Mitigation technology, reviewed in EPRI report 1010381 is considered a chemical process.

Thermal Removal Processes

Thermal removal processes rely on heat to dissociate ammonia compounds or to force physically adsorbed ammonia from the fly ash surface. In either event the result is to volatilize the ammonia from the solid ash phase to the gas phase where it can be swept away, or thermally decomposed. In lower temperature applications, ammonia will be liberated from the fly ash surface creating an ammonia-laden gas stream. This evolved ammonia may then be treated to destroy the ammonia prior to environmental release. In some high-temperature applications, the thermal energy may be sufficient to thermally destroy the ammonia molecule, such that ammonia removal and subsequent destruction is integral to the process. However, a portion of the destroyed ammonia may contribute to nitrogen oxide (NOx) emissions in the thermal process off-gas. In essence, thermal removal processes reverse the ammonia deposition/adsorption process. The process is both time and temperature dependent, and chemical agents may be used to enhance the process performance. Thermal processes require considerable thermal energy and fly ash handling, but are very efficient in removing ammonia and generally have no detrimental effect on other fly ash characteristics. In some cases fly ash characteristics for end-use are improved in addition to the removal of ammonia by decreasing moisture or carbon content.

Chemical Removal Processes

Chemical removal processes rely on certain chemicals to either destroy ammonia by converting to other chemicals, combine with ammonia to limit its potential for volatilization, or force its release from the fly ash surface where the off-gas can be subsequently utilized or treated. Some treatments may also cause a reaction with the ammonia to form other, more benign, compounds. Chemical removal processes typically require less capital than thermal removal processes, but may have a higher variable operating cost due to the cost of the chemical itself. The added chemical may have the potential to affect ash properties, but most treatments are designed to avoid any adverse impact on the final use or disposal of the fly ash. Both chemical and thermal removal processes are well represented at full scale, with most thermal processes having the principal purpose of carbon removal (burn-out), while ammonia removal would be considered an ancillary benefit. Incentives for ammonia removal processing are strong and ammonia removal is becoming more widespread as a beneficiation technology in general.

2

PROCESS DESCRIPTION

Process Background[1]

The ST process is a patented process (US Patent #6,077,494) for the removal of ammonia from fly ash. The process recovers 100% of the fly ash treated, and may be used alone or in conjunction with the company's carbon separation technology, which employs electrostatic principals. Under the previously discussed process descriptions, the ST process would be considered a chemical removal process.

Fundamentally, the ST process relies on the gas/liquid equilibria phenomena to liberate the ammonia from the fly ash. Similar to the process that occurs when ammoniated fly ash is used in cement/concrete manufacture, the ST process utilizes the presence of alkali to shift the equilibrium of the adsorbed ammonia to favor free gas-phase ammonia (as described in Figure 1-1), which readily evolves from the fly ash. In cases of fly ash possessing naturally high alkalinity, no additional alkali may be required. For more acidic ashes, such as those common to eastern bituminous coals, additional alkali material is required to liberate the ammonia. Either quick lime (CaO) or hydrated lime ($Ca(OH_2)$) is typically used as the alkali source.

Process Chemistry

As discussed previously, ammonia is typically present as an ammonium salt. And, for most applications, the salt is some compound of ammonia and sulfur; ammonium sulfate ($(NH_4)_2SO_4$) or ammonium bisulfate (NH_4HSO_4). In typical applications of SCR technology, the principal compound present is thought to be ammonium bisulfate, although the process chemistry is similar irrespective of the actual ammonia compound present.

The following example reaction shows a generalization of the interaction between ammonium sulfate and lime:

$$\mathbf{(NH_4)_2SO_{4(s)} + CaO_{(s)} \bullet 2NH_{3(g)} + CaSO_{4(s)} + H_2O_{(g)}}$$

The above reaction does not occur, however, as a solid-phase or gas-phase reaction, and requires a localized aqueous solution to dissociate the ammonia salt to form an ammonium ion, which is then available for reaction/liberation. This process is shown in the following reaction.

$$\mathbf{(NH_4)_2SO_{4(aq)} \bullet 2NH_4{}^{+}{}_{(ag)} + SO_4{}^{2-}{}_{(aq)}}$$

For the lime reaction, water also plays a role, as calcium hydroxide (hydrated lime) is formed when combined with water, as follows.

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[1] The basic process description is summarized from the following citation; Bittner, J., Gasiorowski, S., Hrach, F., "Removing Ammonia from Fly Ash," Separation Technologies Incorporated, 10 Kearney Rd., Needham, MA, Presented at 14th International Symposium on Management and Use of Coal Combustion Products, January 2001.

$$\mathbf{CaO_{(s)} + H_2O \bullet Ca(OH)_{2(s)}}$$

The calcium hydroxide in slightly soluble in water, producing calcium and hydroxide ions as shown below.

$$\mathbf{Ca(OH)_{2(s)} \bullet Ca^{2+}_{(aq)} + 2OH^{-}_{(aq)}}$$

The aqueous calcium and sulfate ions now react to form calcium sulfate, which precipitates as follows.

$$\mathbf{Ca^{2+}_{(aq)} + SO_4{}^{2-}_{(aq)} \bullet\ CaSO_{4(s)}}$$

As a final step, equilibrium exists between ammonium ions and dissolved ammonia, with the degree to which free ammonia is formed being dictated by the pH. High ph (caustic) environments favor the formation of free ammonia (as discussed previously). This equilibrium can be described as follows.

$$\mathbf{NH_4{}^{+}_{(ag)} + OH^{-}_{(aq)} \bullet NH_{3(aq)} + H_2O}$$

Practical Process Application

The practical application of the above process chemistry dictates the use of a minimum quantity of water, which is a key feature of the ST process. The water utilized is on the order of 1 to 4% by weight, with 2% being typical. Thus, the ash is <u>not</u> wetted in the normal sense, only slightly humidified to create a localized environment on the ash surfaces to facilitate the chemical reactions. Large amounts of water are detrimental, both from an efficiency standpoint and a practical operational standpoint – ammonia release is slowed by excess amounts of water, and additional water requires more rigorous drying steps.

In addition to water, small amounts of alkali are normally added to the fly ash (as lime (CaO) or hydrated lime ($Ca(OH)_2$)), and typically in quantities less than 1% by weight (as $Ca(OH_2)$). A pH greater than 10.0 is targeted for the efficient removal of ammonia – a condition highly conducive for the evolution of free ammonia. The small quantities of alkali apply even to highly acidic ashes common to some eastern bituminous coals. Calcium-based alkalis result in a minimum alteration of fly ash chemistry. The addition of water and lime to the fly ash typically occurs sequentially with the dry lime added to the untreated fly ash first, then followed by the water. Both additions occur at ambient temperature. Because the process is controlled by ammonia equilibrium, the initial ammonia levels on the ash are not as important as the desired final treated ash ammonia level. In essence, the process design is controlled primarily by the final desired ammonia level, not the initial ammonia level.

The most efficient process scenario in terms of ammonia removal and alkali and water usage requires the careful balancing of the alkali and water addition. Figure 2-1 demonstrates the sensitivity of ammonia removal with respect to various levels of water and alkali addition. The figure depicts the remaining ammonia content of the ash as a function of mixing time. Also, two types of alkali are examined; lime (CaO/quick lime) and calcium hydroxide ($Ca(OH)_2$/ hydrated lime/slaked lime). The figure demonstrates some very interesting phenomena. For example, in the case of 1% CaO/1% H_2O addition, very little ammonia removal is noted over the 15 minute mixing time. However, when water is increased to 2%, the removal of ammonia is highly efficient. This demonstrates that excess alkali does not aid evolution (i.e., the moisture content is controlling in this particular scenario). Conversely at higher levels of moisture, such as in the case of 4% H_2O, an increase from 0.33% to 0.66% $Ca(OH)_2$ resulted in a dramatic improvement in ammonia removal.

Another interesting point is the performance difference between lime and calcium hydroxide. Since 0.5% lime and 0.66% calcium hydroxide are comparable in terms of alkali addition, the plots for .5% CaO/2% H_2O and 0.66% $Ca(OH)_2$/2% H_2O offer a convenient basis for comparison. The calcium hydroxide appears to be much more efficient under this comparison. This is due to the elimination of the relatively slow slaking reaction which results in the formation of calcium hydroxide from lime, which also consumes water.

Overall, the most efficient process scenario is obtained by creating a localized surface film of high pH, which favors the volatilization of ammonia. Using the optimal water addition ensures the most efficient evolution rate of ammonia from solution. The optimal dosages of both alkali and water will depend on the characteristics of the particular fly ash being treated.

Figure 2-2 provides additional data on the effect of water and alkali dosage. In this figure, a relatively acidic fly ash is being treated (pH 4.0). The plots demonstrate that high treatment levels of calcium and water do not necessarily significantly improve the rate of ammonia removal. In particular, in the case of high water dosage (19%), the ammonia release is slowed considerably compared to other scenarios that utilized both less water and less alkali.

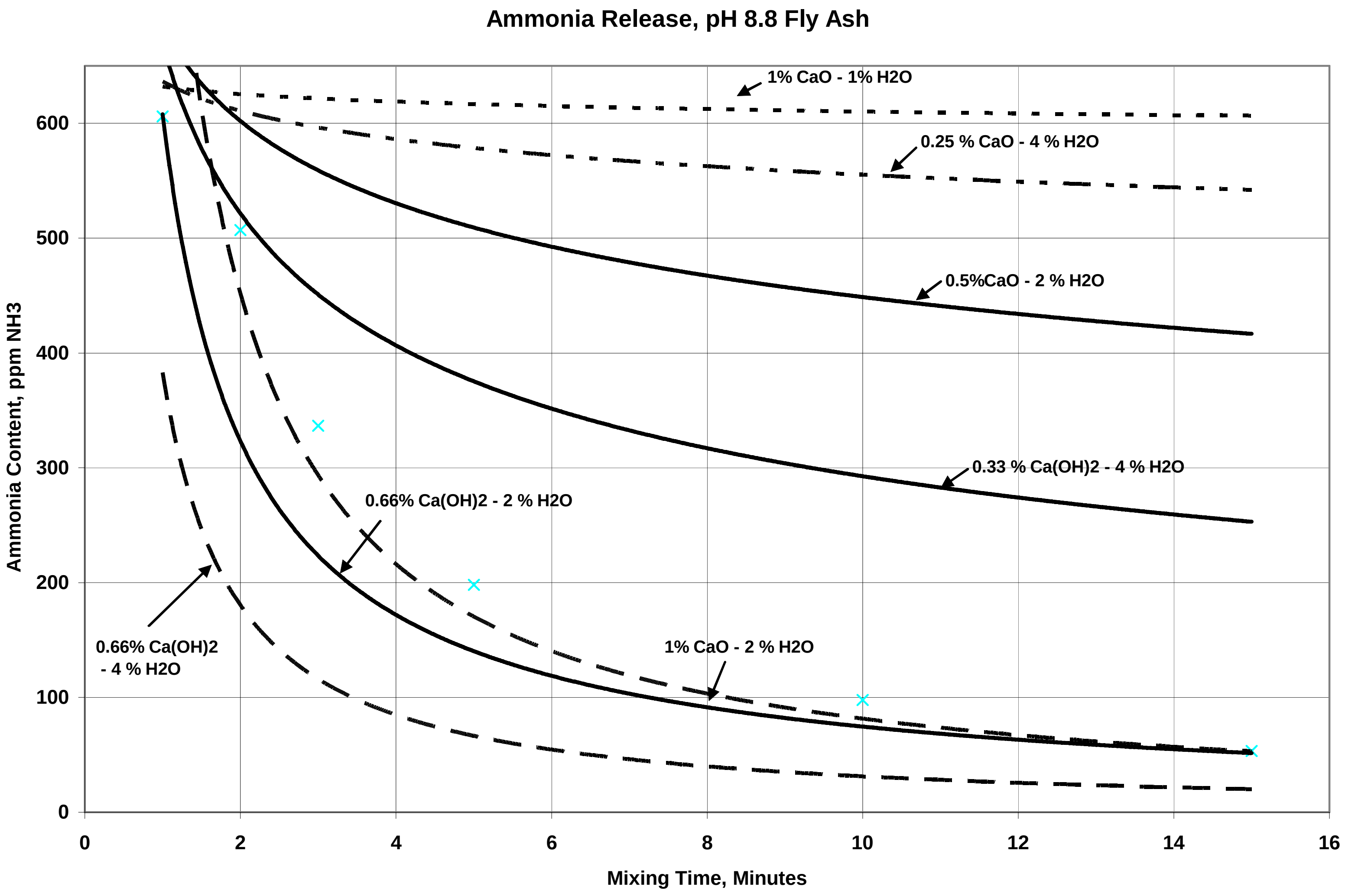

Figure 2-1
Ammonia Release from Fly Ash vs. Alkali and Water Dosage

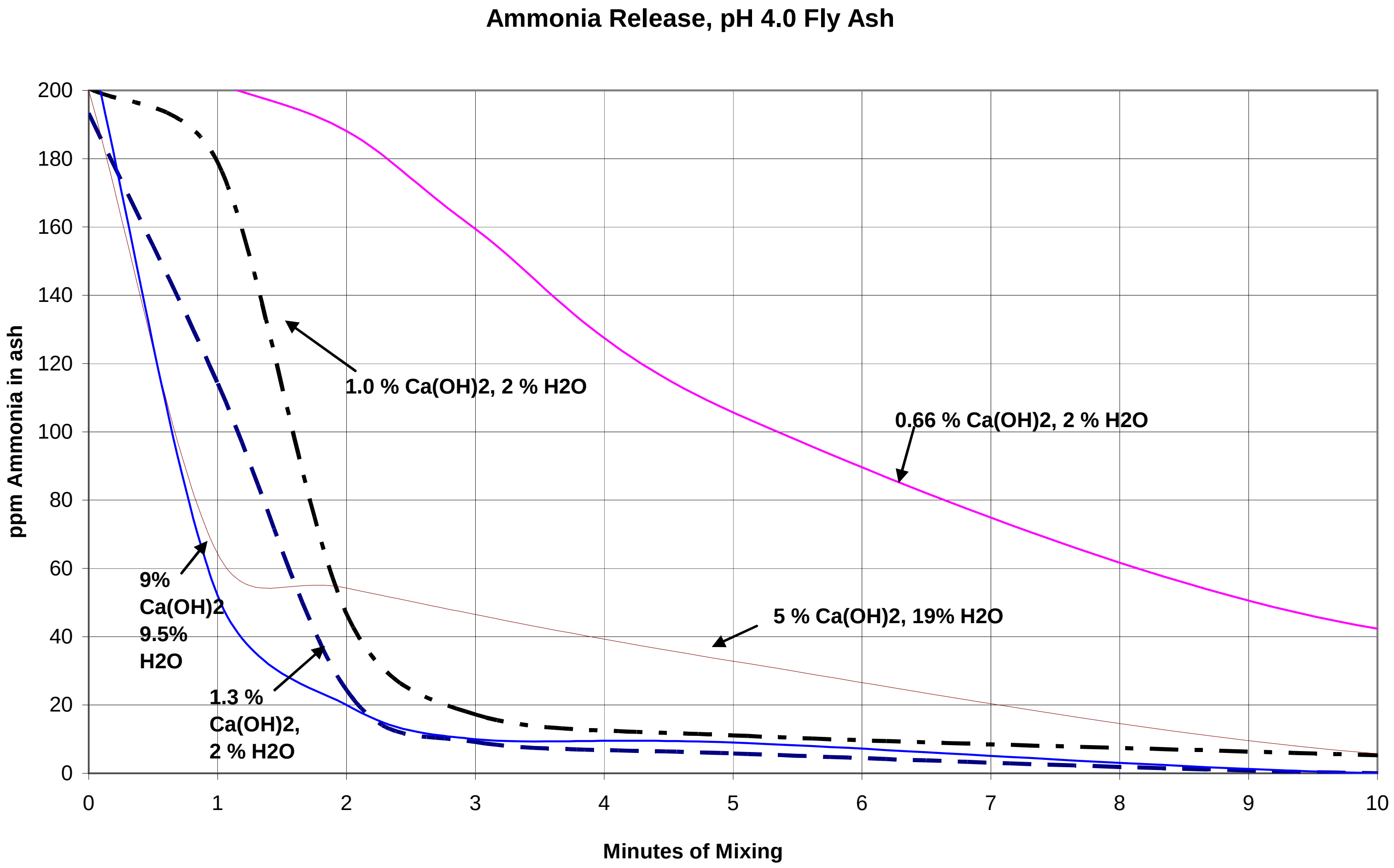

Figure 2-2
Ammonia Release vs. Alkali and Water Dosage – Low pH Ash/High Water Dosage

Process Design

The generalized process flow diagram is shown in Figure 2-3, with the principal unit operations consisting of a high intensity mixer, a low-intensity mixer, and a flash dryer.

The process begins by metering ammoniated ash utilizing a weight-differential solids flow meter. (In the case of the visited facility, the ammoniated ash is a product stream from the ProAsh® carbon separation process.) Dry alkali is then added just prior to a high intensity mixer. The mixer utilizes a rotating shaft with adjustable pitch paddles to integrally mix the alkali, ash, and water, which is added as a spray within the mixer itself. The residence time of this mixing process is very short, on the order of one second. Complete evolution of the ammonia requires a much longer residence time, on the order of several minutes. This is accomplished in a low-intensity mixer, similar to a pug mill. It is important to emphasize that the water addition is quite low and that the ash behaves as a highly agitated dry powder through the mixing processes. The long residence time and ash fluidization in the secondary (low-intensity) mixer insures that ammonia levels are lowered to the desired levels. The evolved ammonia from both mixers is swept using ambient air and typically returned to the boiler flue or boiler itself. The preferred return location is site-specific, but by returning ammonia upstream of the original injection point the ammonia can be recycled, maximizing ammonia utilization.

The final treatment step is flash drying to remove the excess water. Since water addition is minimized in the process optimization step, only a small amount of water needs to be removed by the drier, with a final end-stage ash temperature of only roughly 150°F (66°C) (being required to produce a complete free-flowing fly ash product. The resulting ash is well below the ASTM C 618 specification of 3 wt% for moisture content. The flash drier requires a source of hot gas, typically provided by a natural gas burner, although other site specific sources may be available. In the case of natural gas, a stand-alone burner similar to a duct burner is used to generate the hot gas, which then flows into the dryer where fly ash is added. The drier is usually a single-shaft air swept tubular system. The primary adjustment parameter for drier operation is the burner outlet temperature (typically 400°F [200°C]) which is adjusted to maintain a drier outlet gas temperature set point (typically 220°F [104°C]). These parameters can be adjusted depending on the product ash requirements and the specific nature of the ash being treated. The product ash is pneumatically conveyed from the drier into a fabric filter where the ash is separated and sent to storage, while the off-gas is released to the atmosphere via a small stack. Very little ammonia is released at this stack, since the primary ammonia removal steps take place during the mixing processes.

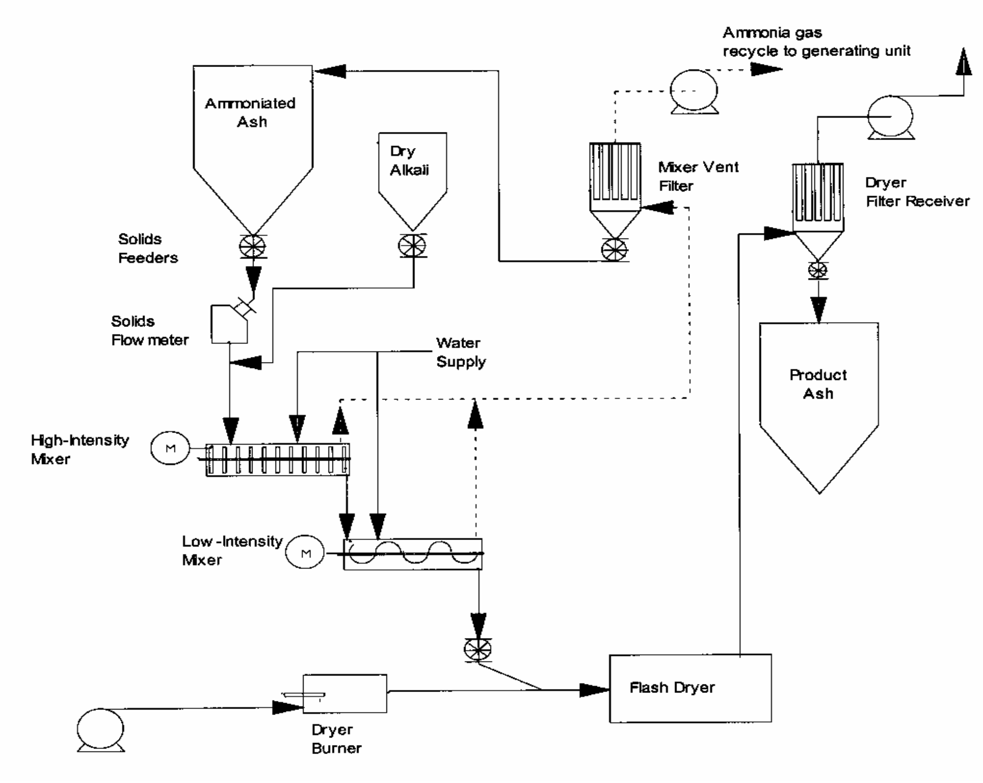

Figure 2-3
Ammonia Removal Process Flow Diagram

The treatment process can be summarized in the following basic steps:

- Fly ash metering
- Dry alkali metering and addition to fly ash
- High-intensity mixing with water addition (some ammonia removal)
- Low-intensity mixing (primary ammonia removal)
- Flash Drying

Treatment Effectiveness and Ash Characteristics

The ST ammonia removal process is capable of removing ammonia to virtually any product level desired, and is relatively non-sensitive to the original ammonia level, as previously discussed. Pilot trials have shown the process to be effective at treating ash containing ammonia levels as high as 1,000 ppmw with target ammonia levels of less than 20 ppmw. Important to any fly ash treatment process are the characteristics of the product ash, especially with respect to pozzolanic activity where the ash is intended for use in cement/concrete manufacture.

Table 2-1 shows treated fly ash properties as compared to ASTM specifications and typical ash properties, for an example plant. No significant changes in ash characteristics are noted with the ST process, although calcium levels will increase slightly – this is typically considered a beneficial effect.

Table 2-1
Fly Ash Characteristics[2]

	ASTM C 618 specification	Plant # 1 Ash Properties, Typical	Plant # 1 Ash After Ammonia Removal
Chemical Composition			
Silicon Dioxide	-	55 - 61 %	59.8 %
Aluminum Oxide	-	15 - 25 %	23.8 %
Iron Oxide	-	5 - 10.9%	7.35
Total (SiO_2 + Al_2O_3 + Fe_2O_3)	70.0 Min.	78 - 91 %	90.9 %
Sulfur Trioxide	5.0 Max	0.13 - 1.4%	0.87%
Calcium Oxide	-	1.4 - 12 %	1.79 %
Moisture Content	3.0 Max.	0.0 - 0.3 %	0.21%
Loss on Ignition	6.0 Max.	0.7 - 2.6 %	0.91%
Sodium Oxide	-	0.1 - 0.7	0.14%
Potassium Oxide	-	0.5 - 2.2%	0.56%
Available Alkalis (as Na_2O)	1.5 % Max	0.5 - 0.8%	0.51%
Physical Test Results			
Fineness, retained on #325 sieve	34% Max.	8 - 16%	14%
Strength Activity Index			
Ratio to Control @ 7 days	-	81 - 95 %	94.8%
Ratio to Control @ 28 days	75% Min.	94 - 102%	99.5%
Water Requirement, % of Control	105% Max.	93 - 97%	94.2%
Soundness, Autoclave Expansion	0.8% Max.	-0.035 - 0.010	-0.033
Dry Shrinkage, Increase @ 28 Day	0.03% Max.	-0.01 - 0.010	-0.009
Density	-	2.35 - 2.45	2.36

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[2] This data was provided by ST, no independent assessment was made by EPRI.

3
SITE VISIT

Site Background

The visited full scale operational site for the ST ammonia removal process was located at a utility plant in the Southeast U.S. The plant fires a fuel blend consisting of up to 30% petroleum coke (20% typical), with the balance consisting of coal from a number of sources off the spot market – both domestic and foreign. The plant consists of two large (500+ MW) units, with ash from both units being treated for carbon separation (ST ProAsh® process) and ammonia removal by ST. The total ash treated at the site is on the order of 500,000 tons per year. The current ash treatment configuration consists of two carbon removal trains (one per operating unit) with each having approximately 20-25% excess capacity, followed by a single ammonia removal train, capable of treating the ash generated by both operating units. The boiler design for both units is opposed wall-fired, utilizing low-NOx burners. The fly ash LOI produced by the furnaces is on the order of 20%. The ProAsh® carbon removal process has a target of roughly 4% carbon (4.5% specified max.) in the product ash. The ProAsh® process generates a carbon-rich stream, constituting a mass fraction of roughly 25% (~60% carbon), and a carbon depleted stream, constituting roughly a mass fraction of roughly 75% (~4% carbon). This carbon-depleted stream is subsequently treated for ammonia removal. The carbon-rich stream is typically utilized as a fuel/feedstock in cement kilns, while the ammonia-treated low-carbon stream is utilized in cement/concrete manufacture. The untreated ammoniated ash typically has ammonia concentrations on the order of 600 ppmw, but ranges from 200 to 800 ppmw. The target treated ash concentration of ammonia is 75 ppmw maximum, which is consistently achieved by the treatment process.

Equipment Layout

The actual ammonia removal process equipment is located somewhat distant from the generating units themselves, in an area dedicated to ash handling, storage, loading, etc. Figure 3-1 shows the primary equipment area, with the alkali storage bin shown in the upper right, the untreated fly ash feed bin in the upper center, and the drier ventilation stack along the left. Three levels house the metering, mixing, and drying equipment. Primary alkali and fly ash metering, along with high speed mixing are performed at the top elevation, while the low-speed mixing is performed at the intermediate level. The natural gas burner and drier are located at grade.

Figure 3-1
Ammonia Removal Processing Area

Metering and Mixing

The fly ash (previously treated for carbon removal) is fed via screw feeder to the initial high-intensity mixer. Flow of the fly ash is controlled gravimetrically. Figure 3-2 shows the gravimetric feeding device (red) and the screw feeder. Figure 3-3 shows the opposite end of the screw feeder where dry alkali is added gravimetrically from the silo above. Hydrated lime is utilized as the alkali source at the subject site. The ash/alkali mix is then fed directly into the high-intensity mixer, shown as the cylinder in the lower portion of Figure 3-3.

Figure 3-2
Ash Metering and Screw Transport

Figure 3-3
Alkali Metering and Addition to Fly Ash above High Intensity Mixer

Figure 3-4 shows a more detailed photograph of the high-intensity mixer. The alkali/ash is fed to the mixer on the right (the motor/drive is also located at the near end of the mixer), and water is injected utilizing four nozzles, as shown more clearly in Figure 3-5. The mixer is driven by a 100-hp motor and is equipped with paddles attached to a central shaft. The paddles have adjustable pitch to aid in the regulation of throughput and mixing characteristics. Water is introduced via four nozzles equipped with gate valves, with the overall flow controlled by a mass flow device as a function of fly ash flow rate. The residence time in the high-intensity mixer is only on the order of seconds, with the primary purpose of this mixer being to effectively integrate the ash, alkali, and water, not to provide the primary residence time for ammonia evolution.

Figure 3-4
High-Intensity Rotary Mixer

Figure 3-5
Detailed Mixer View Showing Water Injection Piping (4 lines)

After completion of the high-intensity mixing process the fly ash mixture flows down from the mixer exit to the low-speed mixer. This mixer is characterized by good aeration and mass transfer, and is similar to pug mills commonly used to control ash dusting prior to transport. The relatively long residence time in this mixer (on the order of 4-6 minutes) accomplishes the primary ammonia removal, utilizing sweeping air, which is returned to the boiler flue upstream of the precipitator. The ammonia in this return gas is relatively concentrated at roughly 0.5 % NH_3 by volume. At this point, the ash mixture is near ambient temperature, on the order of $120^{o}F$ ($49^{o}C$). The inlet side of the low-speed mixer is shown in Figure 3-6. The mixer is equipped with two paddle-equipped shafts with opposing rotation. Each shaft is driven by a 50-hp motor. Residence time is controlled by the ash flow rate and by the mixer size, with an overflow weir being used to insure total residence time. Figure 3-7 shows the opposite (exit) end of the mixer – the air inlet is clearly visible on the upper part of the mixer, along with air discharge line. At the completion of the mixing process the ash has complete dust suppression, but has low moisture, and has low ammonia levels of 75 ppmw or below.

Figure 3-6
Low Speed Mixer – Inlet Side

Figure 3-7
Low Speed Mixer – Outlet Side

Drying

The final process step is the flash drying of the ash. The ash actually contains relatively little moisture, so the heat input required for this step is minimal, reducing the ash from 1-2% moisture down to approximately 0.2-0.5% moisture. Drying is performed using a single-shaft air swept tubular dryer system. Heat input is provided by an external burner (similar to a duct burner) firing natural gas. Ash dryness is controlled by the drier outlet gas temperature, which is typically set at 220°F (104°C). For the current design, this requires an inlet gas temperature of roughly 400°F (204°C). The process control loop varies the dryer inlet temperature as a function of dryer outlet temperature. Once dried, the ash and gas are separated with a fabric filter, with the ash being ready for use (sale) at this point, while the gas is vented to atmosphere. Compliance testing of opacity is required annually for the vent stack. Product ash ammonia level is measured manually (Ion-Specific Electrode Method) roughly every two hours for ash quality assurance purposes. Figure 3-8 shows the natural gas burner, which is located separately from the dryer itself. The view shows the air intake. Hot combustion gases are then ducted to the dryer, which is shown in Figure 3-9.

Figure 3-8
Natural Gas Burner for Dryer

Figure 3-9
Air-Swept Tubular Dryer

Site Process Performance

The performance of the ammonia removal system at the visited site appears to be very good, easily meeting its performance requirements. Figure 3-10 shows actual performance data, as provided by ST, for a three-month operational period. The data show untreated ash ammonia levels ranging from less than 100 ppmw to over 600 ppmw, and treated ash ammonia levels typically around 20 ppmw or less, with some higher excursions. It is notable that the treated ash ammonia level appears to be independent of the original ash ammonia level. This is consistent with the process' underlying chemistry, as discussed previously.[3]

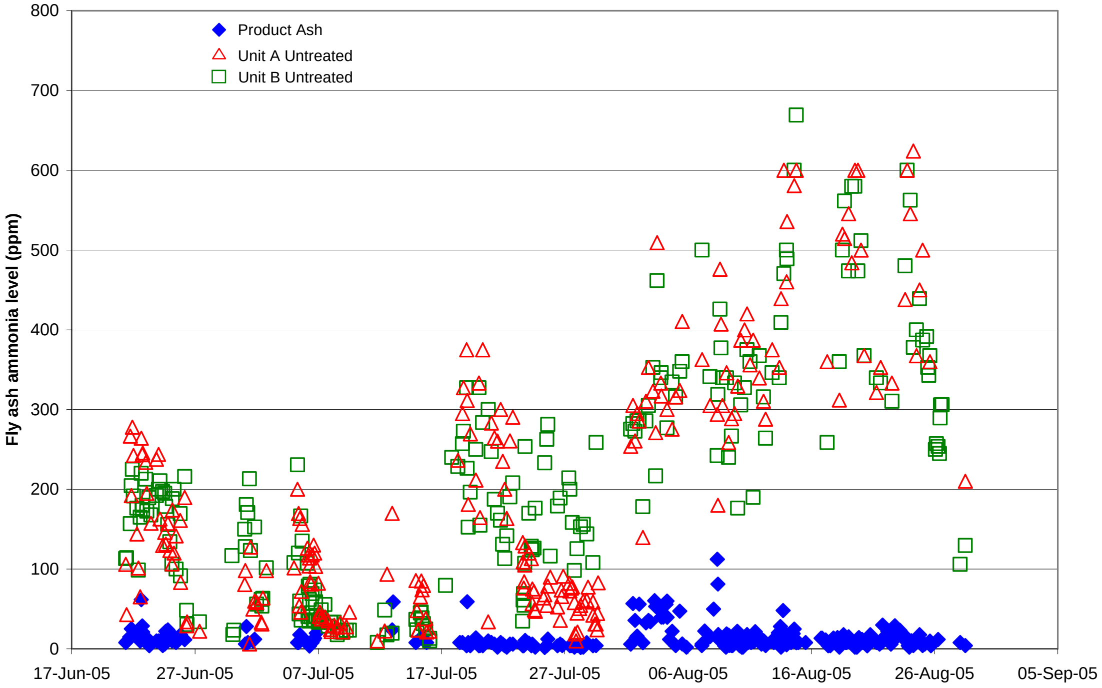

Figure 3-10
Actual Performance Data from Visited Site

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[3] The data presented and discussed were provided by ST. No independent assessment of treatment effectiveness was conducted by EPRI or its contractors as part of this report.

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ECONOMICS

The economics of the process are extremely site specific, and therefore any reference economics that could be cited would likely be misleading for a hypothetical installation. In any event, the process is relatively capital intensive and as such would demonstrate economies of scale. The desired maximum through-put for the process will control the sizing of the mixing and drying equipment, which will in turn govern the primary fixed capital costs. The primary variable costs consist of alkali cost and the cost to dry the ash product. Minimization of both alkali and water addition via process optimization will consequently help to minimize the variable operating costs.

It is clear that the process installation becomes more economically attractive with increasing plant size and increasing capacity factor. Thus, on a dollar per ton of ash treated basis, large base-loaded units will in general have lower treatment costs than smaller units used intermittently, all other factors being equal. Costs are not strongly a function of ammonia level, and thus the process may be particularly attractive for installations with very high untreated ammonia levels. Similarly, process costs may not be severely affected with increasingly stringent treated ash ammonia levels. However, a threshold will likely be present, below which costs may increase sharply as the required treated ash ammonia level approaches zero. This threshold would typically be far below the ammonia levels normally acceptable in the industry, however.

Some factors affecting economics are noted below;

- Maximum through-put requirement
- Proximity of treatment equipment to plant
- Tie-in location of returned ammonia-laden off-gas
- Source of dryer thermal energy
- Specific ash characteristics affecting ammonia removal and handling
- Untreated ash ammonia level and variability
- Treated ash ammonia and moisture requirements, including acceptable variability
- Requirements of redundancy/process availability
- Presence of other ash treatment equipment such as carbon removal

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CONCLUSIONS

The ST Ammonia Removal Process for the treatment of ammoniated fly ash appears to be a robust and highly effective technology. Although no independent analysis of treatment effectiveness was conducted as part of this study, the process appears to work very well in its application, treating highly ammoniated ash to achieve the required low levels of ammonia content. ST data shows that the process is effective for a number of ashes with widely varying characteristics, and that the technology is capable of treating ash of virtually any initial ammonia content to achieve very low levels of residual ammonia. The process effectiveness appears to be relatively independent of the untreated fly ash ammonia level, making the technology quite attractive for sites that have highly variable ammonia contamination levels. Furthermore, the technology can be optimized for a given installation by trading off the alkali utilization and water addition, thereby minimizing variable operating costs. The process does not appear to adversely affect the quality of the fly ash, making it compatible with typical ash end-uses such as cement/concrete manufacture. Once the initial process design is complete, routine variability in ash characteristics or ammonia level should not impact process efficacy. Overall the general impression of the technology is highly favorable.

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