

Reducing the Explosion Potential of Ammonium Nitrate Fertilizer by Coating with Coal Combustion By-Products

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ABSTRACT

Three coal combustion byproducts (CCBs--Fly-ash C, Fly-ash F, and FGD) were evaluated for their effectiveness as blast-mitigating agents when applied as a coating to ammonium nitrate (AN) fertilizer. Suitable coating conditions and binder-application rates were identified and used to prepare 5-kg samples of AN coated with 10% to 50 wt% CCB. Fuel oil was added and each charge detonated in a steel-containment canister. The detonation tests demonstrated that AN coated with any of the three CCBs at 15 wt% or greater prevented the AN explosion from propagating whereas application of a CCB coating at 10 wt% or less did not. However, when the coated AN samples were crushed prior to detonation, a 20 wt% coating was required to extinguish the explosion. In the first of two projects, the FGD byproduct was identified as the most promising of the CCBs due to its relative ease of coating, the integrity and uniformity of the coatings produced, and its historical use in agriculture. Additional evaluations of bulk density, particle size distribution, and resistance to attrition for the FGD-coated AN suggested that the coated particles would be suitable for use in farm-application equipment. In laboratory tests, the release rate for the nutrient nitrogen from the coated versus the uncoated AN was essentially the same. In a second project which is still in progress, one-ton AN samples have been successfully coated with each of the CCBs in a 500-lb/hr pilot plant; the blast-mitigating properties of the CCB coatings have been independently verified by the EMRTC at New Mexico Tech; little to no change in the sensitivity to detonate was found as a function of the amount of fuel oil added; preliminary agronomic studies showed an increase in corn yield per weight-of-nitrogen-applied; and half-ton quantities of the coated samples have been applied with commercial field-application equipment (fertilizer truck). Ongoing studies include evaluation of the migration and plant uptake of trace elements, yield studies for winter wheat and fescue, and an evaluation of the effectiveness of the CCB coatings in the presence of reductants that are more potent than fuel oil.

INTRODUCTION.

Despite its critical role in agriculture, ammonium nitrate (AN) is widely recognized as one of the more significant terrorist threats to society. The destructive power of AN has been demonstrated in a number of malicious attacks including the better known instances of the Alfred P. Murrah Federal building in Oklahoma City, the Marriott Hotel in Jakarta, and the Sari Club Discotheque in Bali. AN mixed with fuel oil creates a powerful explosive, ANFO, which is a weapon of choice for acts of terrorism due to its relatively low cost, ready availability, ease of assembly, and the magnitude of destructive force unleashed on detonation. The National Research Council stated in a report to Congress following the bombing of the Alfred P. Murrah Federal Building:¹

Ammonium nitrate (AN) is the common explosive chemical with the highest potential for use in a large terrorist bomb....

..Despite ongoing research in both the United States and abroad, no practical method for inerting ammonium nitrate has yet been found. No additive (such as claimed by the Porter patent) has been shown to be capable of rendering fertilizer-grade AN nondetonable under all circumstances when the additive is present in concentrations of about 20 percent or less...High concentrations of inertants may not be practicable, because of both their cost and their deleterious effect on the utility of the fertilizer.

Despite recommendations of the NRC, attempts to control the sale of agricultural-grade AN or to mandate the addition of desensitizing agents, have been met with resistance that stems from a perceived negative impact on price and accessibility coupled with an apparent ineffectiveness of the proposed desensitizing agents when added at concentrations that are compatible with agriculture. Thus, despite the deplorable manner in which AN fertilizer has been used as a terrorist tool, it remains widely and readily available. Unfortunately, this situation is unacceptable as it is merely a matter of time until this critical component of American agriculture is again used within our borders for malevolent purposes. Therefore, elimination of the threat posed by AN continues to be a national priority.

One possible solution to eliminating the threat posed by AN is to coat the AN with a diluent that is widely available, non-toxic, inexpensive, and beneficial to agriculture. Coal combustion byproducts are just such materials. In 2007, just over 120 million tons of CCBs were produced in the US compared to a domestic production of approximately one million tons of AN fertilizer. In addition to their advantages of cost and supply, CCBs often have agricultural value as many contain lime or other pH adjustment components, can serve as a soil ameliorant, and can supply valuable plant nutrients^{2,3,4,5} (e.g., calcium, potassium, trace elements). The addition of a low-cost blast suppressant that has potential agricultural benefits can address the obstacles that have historically prohibited the addition of an effective blast-mitigation agent to AN fertilizer.

COATING PROCEDURES AND EVALUATION

STUDY SAMPLES. Four types of coal combustion byproducts were selected for study as potential blast mitigants; fly ash C (FAC), fly ash F (FAF), FGD, and AFBC ash. Class C fly ash is generated during combustion of the lower rank coals generally found west of the Mississippi river and is relatively high in calcium (Ca) compared to its counterpart, Class F fly ash which is generated during combustion of the bituminous-rank coals generally found east of the Mississippi and is typically high in iron (Fe). The FAC samples were provided by Boral, Inc., San Antonio, TX. Samples of FAF were collected from electro-static-precipitator bins from both the Ghent and Mill Creek Power Plants operated by E.ON U.S. Flue gas desulfurization (FGD) byproduct is obtained when a slurry of calcined lime is injected into a flue gas stream to capture sulfur-oxide gases and is recovered primarily as calcium/magnesium sulfites and sulfates and co-collected fly ash. Since sulfites can be harmful to agriculture, the FGD samples used in these studies had been cleaned and oxidized prior to testing. Samples of oxidized FGD byproduct were also collected from the Mill Creek and Ghent Power plants as well as from the Miami Fort plant operated by Duke Energy. The AFBC sample was collected in ESP units downstream from an atmospheric fluidized bed combustor burning a bituminous coal. The samples of ammonium nitrate fertilizer used in the study were manufactured El Dorado Chemical, Inc. and either purchased from Werner Farm Supply in Somerset Kentucky or obtained directly from the Cherokee Nitrogen plant in Cherokee, Alabama.

COATING TECHNIQUES. Two methods of coating the AN prills were initially evaluated: disk pelletization and drum rolling. For the disk pelletizer, angle of incline, rotation speed, moisture content, and methods of adding the AN, CCB, and moisture were studied. While a few of the processing conditions provided reasonably good coatings, numerous problems were encountered including non-concentric coatings, multi-prill particles, low coating strengths, and the formation of CCB-only aggregates. An example of the FAC coatings obtained with the disk pelletizer is shown in **Figure 1** (note the exposed AN surfaces and multi-prill particles).

CCB coatings were next applied in batch mode a 3.8 L, 20-cm diameter (one-gallon, 8"-diameter) drum roller. In general, the coatings obtained with the drum roller exhibited a more uniform particle size distribution and better particle integrity than those obtained with the disk pelletizer. Accordingly, drum rollers were selected as the preferred method for coating the AN prills. An example of the coated particles obtained with the 8" drum roller is shown in **Figure 2**.

As the study progressed, progressively larger drums were used to coat the AN including a 19-L (5-gallon) plastic cylinder used in batch mode, a 208-L (55-gallon) steel drum used in both batch and continuous modes, and eventually, a 225-kg/hr (500-lb/hr) pilot plant in operated in continuous mode by Applied Chemical Technology, Inc. in Florence, Alabama.



Figure 1. AN prills coated with 25% FAC in a disk pelletizer.



Figure 2. AN prills coated with a 20% FGD byproduct in a drum roller.

EVALUATION OF PARTICLE COATINGS. The suitability of the coated particles was evaluated by measuring their particle size distribution and resistance to attrition as these are critical parameters for agricultural use. The equipment used for agricultural applications is designed to apply AN in the approximate -6 to +20 mesh size range. To retain compatibility, the coated particles need to remain reasonably close to this 6 x 20-mesh size and be strong enough to withstand the rigors of shipping, handling, and field application. Production of multi-prill particles larger than 6 mesh is not an insurmountable problem as these can be crushed or removed at the production site prior to shipment. However, -20 mesh particles that form during transport and handling are more problematic.

The particle size distribution of each sample was determined according to El Dorado Chemical test method EDCC-345. This measurement entailed placing a weighed amount of coated sample atop a series of stacked screens, shaking on a Ro-Tap™

mechanical screening unit for three minutes, and then weighing the amount of sample that partitioned to each screen and collection pan. EDCC-345 specifies the use of 6, 8, 10, 12, 14, and 20 mesh screens along with a bottom pan to collect the -20 mesh fines.

Resistance to attrition was determined by loading 200 g of sample to a 15-inch diameter, Plexiglas cylinder equipped with 2-inch lifters. The cylinder was rotated at 40 rpm for 5 minutes and the particle-size distribution of the resulting sample determined according to EDCC-345.

The particle compressive strengths were determined on 8 x 10 mesh particles using a Lloyd LRX Plus compressive-strength meter mounted to a Chatillon TCM 201 test stand.

BINDER SELECTION AND OPTIMIZATION OF COATING CONDITIONS. In addition to water, a number of common industrial binders were selected for evaluation.

Optimization of Water Addition. The optimum rate of water addition was determined by coating AN with CCB with variable amounts of water and then subjecting sample splits to sieve analysis both before and after attrition to measure coating efficiency and durability. Evaluation of the samples prior to attrition revealed that the FGD byproduct coated the most efficiently followed closely by the FAC sample and the FAF. The coating efficiency for the AFBC sample was poor. Coating efficiency tended to increase with increasing water addition for all four CCBs. However, while efficiency of the CCB uptake improved with higher rates of water addition, much of this increase was in the form of +6 mesh particles which, as discussed, is undesirable with respect to field application. Based on coating efficiencies, particle size distributions, and resistance to attrition, the optimum water addition rate was identified for each CCB.

Evaluation of Secondary Binding Agents. Four common binding agents (starch, guar gum, bentonite, and sodium silicate) were evaluated to determine if the addition of a secondary binder, along with water, would further improve the particle coatings. These studies revealed that of the binders evaluated, the use of water alone was the most effective for the FAF and FGD. Water alone also produced a coating that was as durable as that produced with a combination of water and bentonite for the FAC sample. However, the addition of a small quantity of bentonite improved the particle-size distribution for that sample (i.e., fewer +6 mesh particles). The results for the AFBC coating were poor for all four of the secondary binders evaluated. Based on the difficulty encountered in obtaining suitable particles coatings with the AFBC byproduct, this CCB was omitted from further study.

Optimization of roll time and roll speed. Two drum-roller speeds of 70 and 106 rpm (maximum speed) were evaluated. This study revealed that, in general, more durable coatings were formed at the higher drum-roller speed of 106 rpm. In a similar manner, the impact of roll time was evaluated by rolling mixtures for 5, 10, or 20 minutes. The most durable coatings were obtained at the shortest roll time (5 minutes).

DETONATION TESTING OF CCB-COATED AMMONIUM NITRATE

In the first project, detonation tests were divided into three phases. In the first, a series of approximate 5-kg (11-12 lbs) charges were detonated with an objective of determining how much CCB coating was needed to extinguish the AN explosion. The second phase focused on evaluation of samples that had been coated with a CCB then crushed prior to detonation with the objective of determining if the effectiveness of the coating could be thwarted by crushing. The third phase entailed detonation of a larger sample (~90 kg; 200 lbs) to determine if the coatings retained their effectiveness in a larger-sized detonation.

IDENTIFICATION OF THE MINIMUM EFFECTIVE CCB COATING. The preliminary-test charges were prepared by coating AN with each of the three CCBs at concentrations of 10, 15, 20, 30, 40, and 50% by weight. In addition, three samples of uncoated AN and three blanks, one of each CCB at 100% concentration, were tested for a total of 24 detonations.

Coatings were applied in the 19-cm-diameter (8") roller drum in batch mode. Water was used as the primary binder for all three CCBs with western bentonite added as a secondary binder for the FAC byproduct. The coated samples were sieved to -4 x +20 mesh prior to detonation. The total amount of material partitioning to these oversized and undersized fractions was typically 2% or less for the 10-30 wt% CCB coatings, but increased substantially at higher CCB concentrations, particularly for the FAC sample for which the combined +4 and -20 mesh fractions ranged up to about 10% of the product weight at a 50% FAC addition rate.

Detonation Procedures. Approximately 5 kg charges were prepared by blending each sample with fuel oil and then loading to a steel detonation canister on the day prior to detonation to give adequate time for the fuel oil to absorb into the particles. Canisters were constructed by welding a 10-cm diameter x 64-cm high (4" x 25") steel cylinder to a 40-cm-square (16") steel base plate (*witness plate-Figure 3*). Schedule 40 steel (~1 cm thickness) was used as the construction material to provide additional confinement during detonation.

Each detonation canister was filled to a height of ~60 cm (24"). The concentration of fuel oil was maintained within a narrow range to improve the consistency of the detonation-test results and at a rate that provided maximum energy release on detonation. Prior to detonation, each canister was placed atop a wood platform as shown in **Figure 3**. A plastic cup containing C4 booster and an electronic detonator were then inserted ~5 cm (2") into the top of the charge.



Figure 3. A detonation canister prior to detonation.

Preliminary-detonation test results. Canister remnants following the test detonations are shown in **Figure 4**. The rows of canisters are grouped according to CCB type with the remnant from detonation of a charge of uncoated (100%) ANFO shown at bottom left. Decreasing concentrations of CCB are shown from left to right. As can be seen, the energy release as a function of coating concentration was reasonably consistent, regardless of which CCB was applied. For all detonations of pure ANFO or AN coated with 10% CCB, the explosion propagated downward the length of the cylinder, destroying the cylinder and blasting a large opening in the witness plate. For samples coated with 15% or more CCB, the distance the explosion propagated was inversely related to the amount of CCB coated onto the AN. This is shown more clearly by the photo in **Figure 5**. The canister remnants in this photo simulate a bar graph, visually illustrating that the explosion propagated farther down the containment cylinder as the concentration of the FAF coating was decreased.

Further visual evidence that the CCB coatings were effective in stopping the propagation of the explosion is shown in **Figure 6**. This photograph shows the detonation canister in the position in which it came to rest following detonation of AN coated with 15% FAC. The damage to the upper portion of the cylinder provides evidence that the AN in the top of the cylinder detonated while the unexploded prills spilled to the ground provides evidence that the explosion was halted by the FAC coating. It was also apparent that a 10% coating was insufficient to stop the explosion as evidenced by the base plate remnants from detonation of the 10% FGD coating shown in **Figure 7**.



Figure 4. Detonated canisters. Rows are arranged according to CCB type and columns are arranged with decreasing CCB concentrations shown from left to right.



Figure 5. Detonated-canister remnants for the FAF-coated AN. l-r, 100, 50, 40, 30, 20, & 10%-coated charges.



Figure 6. Canister remnant following detonation of a 15% FAC-coated charge (note the large quantity of unexploded prills on ground).



Figure 7. Canister remnant following detonation of AN coated with 10% FGD byproduct.

Rate of expansion of the explosion cloud. Another means to compare energy release for the 5-kg charges was to measure the rate at which the explosion cloud expanded during detonation. Measurements were made from single-frame photos captured with a high-speed digital-video camera recording at 1,000 frames per second. The expansion of the explosion clouds for the three CCB byproducts as a function of coating concentration is plotted in **Figure 8**. Each CCB series exhibited a small but uniform increase in the rate of expansion as the coating concentration decreased from 50% to 20% and then each exhibited a significant jump in expansion rate for the 10% coatings.

Detonation of Crushed Charges. The use of CCB coatings to prevent AN from exploding is of lesser value if the effectiveness of the CCB can be countered by simply crushing the coated particles or by crushing the particles then screening to enrich the AN. To evaluate this possibility, two charges of AN coated with the FGD byproduct at 15% and 20%, respectively, were processed through a grinder mill. Gentle crushing, as opposed to harsh crushing, was selected in an effort to remove the smaller FGD particles from the surface of the AN prills while leaving the prills intact, thereby permitting the AN to be separated from the FGD byproduct by screening. However, the inner AN core, which was relatively hard prior to coating, was softened by the coating procedure resulting in most of the AN prills crushing to a small particle size during grinding. Subsequent efforts to enrich the AN by screening the crushed samples were unsuccessful for a number of reasons including the fact that following crushing the CCB and AN components were of similar particle size, the CCBs remained intimately associated with the AN powder, and attempts to screen the crushed samples resulted in *blinding* of the screens.

Approximately 5-kg of each of the crushed samples was loaded to a steel canister and detonated as before. The photograph in **Figure 9** shows the canister remnant following detonation of a crushed sample coated with 20% FGD. Again, note the spillage of

unexploded material onto the ground following detonation. In contrast, the canister remnant for the crushed 15% FGD-coated sample in **Figure 10** reveals that the explosion fully propagated in this charge, totally eliminating the upper portion of the containment cylinder and severely mangling the base plate.

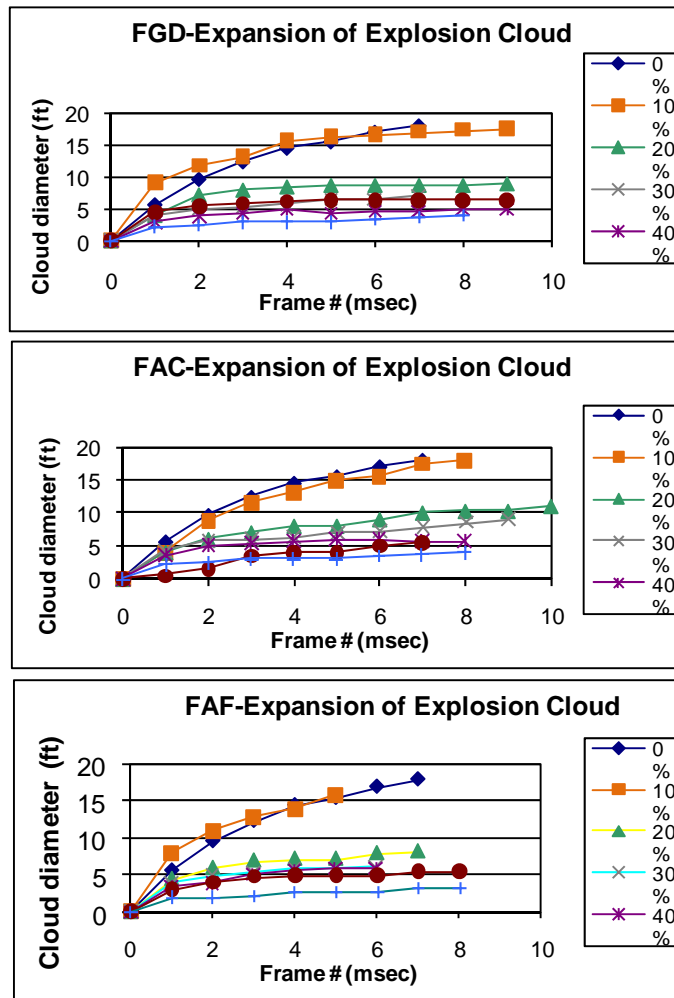


Figure 8. Expansion of the explosion clouds for various coating concentrations.

Summary of 5-kg test detonations. Based on the results from detonation tests of 5-kg charges of CCB-coated AN, it is concluded that CCB coatings of 15% by weight or greater were effective in stopping the propagation of an AN explosion. However, this level of coating is not effective in stopping the explosion when the coated prills were crushed prior to detonation. While the latter would require expending significantly more effort and an increased risk of detection, one must presume there are individuals willing to expend such an effort and assume such risks.



Figure 9. Photograph of the containment-canister remnant following detonation of a crushed sample of 20%-FGD-coated AN. Note the presence of unexploded material spilled onto the ground.



Figure 10. Base-plate remnant following detonation of a crushed sample coated with 15% FGD.

LARGER-SCALE DETONATION OF FGD-COATED AN. The next step was to determine if the coatings were effective for stopping the explosion of a larger test charge. Based on its performance in the 5-kg detonations tests, its relative ease of coating and historical use in agriculture, a 20% FGD-coated charge was selected for a larger-scale detonation.

Preparation. The large scale sample was prepared in essentially the same manner as were the 5-kg charges only using a 19-L, 28-cm-diameter drum (5-gallon, 11" diameter). About 125 kg (~275 lbs) of sample was produced and screened to -4 x 20 mesh. The amount of oversized +4 mesh particles removed during screening was 0.8% while 2.9 wt% of undersized -20 mesh particles were removed. Because the FGD/AN ratio is

higher in both the oversized and under-sized particles, the final FGD-coating concentration was reduced to approximately 17 wt%.

LS Detonation Results. On the day before detonation, ~90 kg (200 lbs) of the coated sample was mixed with fuel oil and loaded to an 18.5-inch diameter plastic drum to a height of ~60 cm (24") providing a length to diameter ratio of approximately 1.3. A 90-kg charge of 100% AN served as a control. The loaded drums were placed atop a 0.91 x 0.91 m square (3' x 3') schedule-40-steel witness plate atop a wooden platform. An electronic initiator was inserted into the C4 booster positioned in the top of each charge. Detonations were recorded with hi-resolution DVD and high-speed video cameras.

Post detonation inspection of the test site showed evidence of the effectiveness of the FGD coating in suppressing the explosion as demonstrated by a large quantity of unexploded prills on the ground and relatively minor disturbance to the surrounding area for the coated sample. In contrast, a large crater was apparent and no containment drum remnants or unexploded particles remained after detonation of the uncoated AN. **Figure 11** shows a witness plate with substantial deformation for the uncoated-charge detonation (front) and a flat, un-deformed plate for the coated charge detonation (back).



Figure 11. Witness plates following detonation of 90-kg charges of 100% AN (front) and 20% FGD-coated AN (back).

INDEPENDENT VERIFICATION OF THE BLAST-MITIGATING EFFECTIVENESS

In a continuation project, three one-ton samples of ammonium nitrate were coated with each of the CCBs in a continuous-mode, 225-kg/hr (500-lb/hr) pilot plant at Applied Chemical Technology, Inc. (ACT), Florence, Alabama. ACT is a leading provider of pilot plant, process-design, fabrication, and engineering services to the fertilizer industry.⁶ Water was used as the binder for the FAF and FGD coatings and a combination of water and bentonite for the FAC coating. The coatings formed were of about the same uniformity and durability as those made in the smaller batch units at the CAER. Each of the samples was screened through a Sweco continuous screener to recover the 4 X 20 mesh fractions for larger-scale evaluations. The CCB-coating concentration was

measured at approximately 21% by weight in each of the 4 x 20 mesh samples. The compressive strengths of the coated AN prills was essentially the same as for the uncoated AN prills from which they were produced.

Splits of each of the pilot plant samples were transported to the Energetic Materials Research and Testing Center (EMRTC) at New Mexico Tech for detonation testing. The EMRTC is recognized internationally as the premier facility for ballistic and explosives testing.⁷ In addition to the three CCB-coated samples, samples of uncoated AN and of calcium ammonium nitrate (80% AN/20% limestone, Yara International, Inc.) were also provided to the EMRTC for testing.

Detonation tests were conducted at the EMRTC staff under the supervision of staff scientist, Dr. Robert Abernathy. Each of the test samples were mixed with a targeted amount of fuel oil then approximately 140-kg (300-lb) was weighed to a 60-cm diameter (24") cylinders (Sonotube) positioned atop one-meter square x 1.5-cm (5/8-inch) steel witness plates (**Figure 12**). An electronic initiator was used to detonate a 2.25-kg (5-lb) PNT booster inserted into the top of each charge.



Figure 12. Witness plates prior to detonation of a Sonotube cylinder that was loaded with 140-kg charges as shown near the truck in back-center.

The witness plate remnants following the detonation tests at the EMRTC are shown in **Figure 13**. From left to right, these plates are from detonation of a) 100% ANFO, b) calcium ammonium nitrate (80% AN), c) 21.7% FAF-coated AN, d) 20.7% FGD-coated AN, and e) 21.0% FAC coated AN. As can be seen, the pure ANFO charge eliminated most of the witness plate while the witness plate was severely mangled by the calcium ammonium nitrate. However, the witness plates following detonation of the three CCB-coated samples showed relatively minor damage, much of which may have resulted from detonation of the large-sized booster used in the tests



Figure 13. Witness plate remnants following detonation of 140-kg charges of (left to right) 100% ANFO, calcium ammonium nitrate, and ammonium nitrate coated with 21.7% FAF, 20.7% FGD, and 21.0% FAC, respectively.



Figure 14. Witness plate following detonation of FGD-coated AN showing unexploded sample remaining after detonation.

Additional evidence that the AN explosion of the coated AN did not propagate can be seen in **Figure 14** where unexploded sample is seen atop the witness plate following detonation of the FGD-coated sample. Unexploded sample was also observed atop the witness plate for the FAF and FAC samples following detonation (not shown).

AGRICULTURAL EVALUATIONS.

In the initial project, a split of a 20% FGD-coated AN sample was subjected to a series of laboratory evaluations to obtain an indication of the impact that FGD coatings might have on agricultural use. Two of the evaluations, bulk density and particle size

distribution, provide an indication of how the coated AN prills might perform in field-application equipment. The third, measurement of nitrogen-release rate, provides an indication of how quickly the nitrogen is released to the soil following application.

Physical Properties. As expected, the average particle size of the coated particles was larger than for the uncoated AN. Nonetheless, the bulk of the coated particles fell within the size range targeted for field application (-6 x +20). Obtaining a closer fit to the conventional size distribution for the coated particles would require coating of smaller-sized AN prills. However, considering that a higher tons/acre setting would be needed to obtain the equivalent nitrogen application when applying coated particles, it is likely that a significant manufacturing adjustment of the pre-coated AN particle size would not be necessary but rather a simple increase in the hopper opening should suffice. Either of these approaches is achievable without a significant increase in production costs or disruption to normal farm operations.

Attrition testing of the coated particles resulted in only minor changes in the particle-size distributions. While one would anticipate that any FGD byproduct dislodged during tumbling would subsequently partition to the collection pan (-20 mesh) during screening, the amount of minus 20 mesh material exhibited only a minor increase from 0.3% before attrition to 0.7% after attrition suggesting that the particle coatings are relatively durable and thus capable of withstanding the rigors of handling and field application.

Bulk density can impact flow properties and, in turn, application rates. Measurement of the bulk density revealed a relatively minor difference between the coated (58.7 lbs/ft³) and uncoated (61 lbs/ft³) particles again suggesting that the coated particles would behave in an acceptable manner in the packaging and application equipment in common use.

The third evaluation was a comparison of the relative nitrogen-release rate for the coated versus uncoated AN prills. The time required for the nutrient nitrogen to be released into the soil following application could be a disadvantage if substantially prolonged. A split of the 20% FGD-coated sample was subjected to an irrigated-soil burial test in which the particles were exposed to moistened soil followed by a timed measurements of the amount of undissolved AN remaining. The results of this study, shown in **Table 2**, indicate that the release of nitrogen progressed at similar rates for the coated and uncoated samples. These results suggest that the release of nitrogen from the coated particles would not be significantly delayed and thus should be suitable for its intended use as a fertilizer.

Table 1. Irrigated-soil test showing undissolved nitrogen remaining at designated times.

	Initial Nitrogen	9 hrs	24 hrs	72 hrs
Uncoated AN	33.32%	1.01%	0.99%	0.79%
Coated AN (20%FGD)	27.77%	1.16%	1.06%	0.59%

In the second project, coated AN samples are being used to evaluate crop yields for corn, winter wheat, and fescue; nitrogen and trace-element uptake; soil migration and

leaching of trace elements; and suitability of the coated AN samples for application in existing farm equipment. Only the corn-yield data for the 2008 growing season are available in which the three CCB-coated samples along with uncoated AN were applied to triplicate corn plots (10' x 20'; ~2 x 6m) at nitrogen rates of 0, 50, 100, 150, and 200 lbs/acre. The average corn yield for plots treated with uncoated ammonium nitrate was 76.5 bu/acre while plots treated with CCB-coated AN averaged 91.3 bu/acre. There was no statistically significant correlation between yield and nitrogen source, or for that matter, application rate though there were indirect indications that nitrogen availability was better for the CCB-coated AN. The reason for the observed improvement in yield is not known but is speculated as possibly stemming from the provision of trace elements by the CCB coatings. However, it must also be noted that central Kentucky experienced a severe drought during the 2008 growing season resulting in average yields in this study of 85 bu/acre or about half of what is obtained in a typical growing season. These suppressed yields raise questions about the reliability of the 2008 yield results. It is hoped that additional crop studies in 2009 involving winter wheat and fescue along with a repeat study with corn will help to clarify these questions.

On a final note, it is worthy of mention that the highly-hygroscopic nature of AN results in the absorption of moisture during storage, often leading to severe problems during subsequent application. While not quantified, it has been noted that the CCB-coated particles tend to be less prone to moisture absorption as evidenced by a barrel of FGD-coated AN that has remained flowable for approximately four years after preparation. Thus, AN coated with a CCB barrier may provide long-term storage characteristics that are superior to those of uncoated AN.

SUMMARY

- Applying a CCB coating to ammonium nitrate fertilizer at a rate of 15 wt% or greater prevented the AN explosion from propagating. A 20% coating was needed to stop the explosion when the samples were crushed before detonation.
- Independent detonation testing at the EMRTC verified that a 20%-CCB coating was sufficient to extinguish an AN explosion in 140-kg charges.
- Of the binders evaluated, water provided the most suitable coatings.
- Durable CCB coatings can be produced in a drum roller in either batch or continuous modes of operation in a relatively short time.
- CCB coatings produced in a 225-kg/hr (500-lb/hr) drum roller demonstrated the commercial viability of the coating process.
- Efforts to enrich the AN by mechanical screening of crushed CCB-coated samples were unsuccessful.
- Differences in bulk density and nitrogen release rate between the coated and uncoated AN particles were relatively minor.
- A preliminary crop-growth study indicated an increase in corn yield for coated versus uncoated ammonium nitrate.
- The coated particles qualitatively appeared to be less prone to absorption of atmospheric moisture, a potentially significant benefit during storage.

In summary, coating ammonium nitrate with 20% CCB by weight was found to prevent a detonation from propagating. The findings in this study did not reveal significant obstacles to commercial production of CCB-coated AN nor have the limited agriculture studies to date identified potential obstacles to their intended use in agriculture.

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