TECHNICAL REPORT ARLCD-TR-78062

DETONATION OF GUANIDINE NITRATE
AND NITROGUANIDINE
MANUFACTURED VIA U/AN AND BAF PROCESSES

J. WENDELL LEACH

AUGUST 1979

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

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ERRATA

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* The attached page 34 (fig. 9) should be substituted for the original page appearing in the technical report identified above.

*Inserted by, pfcooper, DTIC/DDA-2, 23 Oct.'79

18 September 1979
The objective was to derive detonation data for hazards analysis and for the related safety design of facilities for manufacturing nitroguanidine by the urea/ammonium nitrate (U/AN) and the British aqueous fusion (BAF) processes. Critical diameter, propagation, sensitivity, and thermal characteristics of a number of mixtures and compounds, representative of selected streams in the processes, were determined.
Critical diameter tests indicate that streams from the Evaporator Outlet, Mixed Reactor Feed, and the Liquid Reactor Outlet of the H/AN process will propagate when initiated with a booster and that they are mass-detontable. Thermal analysis tests on the stream mixtures indicate that they do not react violently when being heated to elevated temperatures but they do thermally decompose under these conditions.

Propagation test results show that certain streams, peculiar to the H/AN process, propagate when detonated. However, propagation in 5.08 cm (2 in.) pipes was not complete on any mixture containing 25 percent or more water. The results also show that the process streams in the wet guanidine nitrate buildings, used in the BAF process, are not detonable; this is also true of cold melts (molten mixtures allowed to cool) in event of plant shutdown.

The sensitivity (hazard) data on guanidine nitrate shows it is a relatively low-order explosive when compared to TNT, but that it is mass detonable.
ACKNOWLEDGMENTS

The author wishes to express his appreciation to the following persons and organizations for their extensive contributions to the detonation study of guanidine nitrate and nitroguanidine.

1. Mr. Thomas Caggiano and Mr. George Karshina, Office of the USAMC Project Manager for Production Base Modernization and Expansion.

2. Mr. C. H. Nichols, Office of Process Design Technology Branch, Manufacturing Technology Division, ARRADCOM, Dover, NJ.

In addition to providing technical assistance to the Hercules Powder Company in the design and operation of the pilot plant, they also conducted many tests on selected process streams associated with the U/AN (urea/ammonium nitrate) process and the RAF (British Aqueous Fusion) process for guanidine nitrate manufacture and subsequent nitroguanidine production.
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INTRODUCTION

Improved procedures to produce nitroguanidine by the Urea/Ammonium Nitrate (U/AN) (fig. 1) and the British Aqueous Fusion (BAF) (fig. 2) processes were investigated under MM&T project 5714169 and were summarized in Technical Report 4566 (ref. 1). The current report presents detailed propagation, sensitivity, and dynamic explosive properties of various in-process streams related to the U/AN and BAF processes, in addition to guanidine nitrate and nitroguanidine. This data covers safety considerations related to the hazard analysis of the basic manufacturing processes and also of the BAF based production facility currently being erected at the Sunflower AAP under AMC project 5752632. The basic categories presented in the report cover the areas of critical diameter determination, differential thermal analysis (DTA) and thermal gravimetric analysis (TGA), and propagation and sensitivity determinations.

PICATINNY ARSENAL TEST STUDIES

A series of tests were performed under MM&T project 5714169 by Picatinny Arsenal in an effort to establish criteria necessary for the manufacture and production of nitroguanidine.

Critical Diameters

An important phase in the investigation of the U/AN process, figure 3, (ref. 6) was to determine the critical diameters for certain process streams which were suspected of being mass detonable. This data was required to develop design criteria for self-quenching detonation arrestors to reduce the potential loss of personnel and facilities, and to meet safety requirements. The design of an arrestor is normally based upon either an active method which uses a detonation trap, or a passive method based upon critical diameters. The passive method, which is the preferred method if realizable under MM&T project 5714169, is the approach used in this study. Critical diameter is defined as the largest diameter of pipe containing the explosive which shows no evidence of propagating an explosive reaction through the test specimen.
Critical diameter determinations were made for four mixtures simulating certain key streams in the U/AN process. The mixtures tested were as follows:

Composition coded #1 U/AN process, evaporator outlet, temperature 130°C:

- Guanidine nitrate 13% by wt
- Ammonium nitrate 74% by wt
- Urea 13% by wt

Composition coded #2 U/AN process, mixed reactor feed, temperature 120°C:

- Guanidine nitrate 9% by wt
- Ammonium nitrate 60% by wt
- Urea 31% by wt

Composition coded #3, U/AN process. liquid reactor outlet, temperature 180°C:

- Guanidine nitrate 33% by wt
- Ammonium nitrate 57% by wt
- Urea 10% by wt

Composition coded #4, nitroguanidine processes, nitroguanidine reactor outlet, temperature 40°C:

- Sulfuric acid 56% by wt
- Water 7% by wt
- Ammonium sulfate 14% by wt
- Nitroguanidine 21% by wt
- Guanidine nitrate 2% by wt

In testing for critical diameters, assemblies of two or more lengths of different diameter pipes (containing a test composition), joined end-to-end by reducing couplings were used. The length of each section of pipe was selected to assure that propagation would stop within the pipe. Each assembly was initiated with a combination of a C-4 booster in a 3/1:length/diameter ratio and a J-8 blasting cap. In assemblies up to 7.62 cm (3 in.) in diameter, a cylindrical booster 7.62 cm long and 2.54 cm in diameter was used. Assemblies of 10.16 cm (4 in.) in diameter were initiated with a 30.48 cm long by 10.16 cm in diameter conical booster. During some of the initial tests, a rack (fig. 4) was used which contained five pipe assemblies with C-4 boosters and one assembly without a booster.
The assembly without a booster was included to determine if sympathetic detonation would occur. After several initial tests with composition #1, the test rack was discarded because of the difficulty in maintaining and controlling the required test temperature. The rack was cumbersome and required too much time to set up and pour the material resulting in a heat loss. This necessitated reheating in some instances. The results of these tests are shown in Table 1. No sympathetic detonation was shown in the firings.

The compositions were conditioned and detonated within ± 5°C of the specified temperature.

The critical diameter was established in accordance with the procedure specified in the CPIA publication No. 194, procedure 2.18 (ref. 4). Assemblies with progressively increasing diameters were initiated until a detonation was sustained and ceased at some diameter within the assembly. Assemblies with diameters greater and less than this diameter were evaluated until a total of three cessations of propagation at the same diameter were obtained. This diameter was established as the critical diameter. The results of these tests are shown in tables 1 and 2.

Fourteen tests were performed on composition coded #1 at 130°C. The mixture proved to be mass detonable and established a critical diameter of 2.54 cm (1 in.).

Composition coded #2 was tested at 120°C in six different pipe assemblies and a critical diameter of 3.81 cm (1½ in.) was established. The third composition, #3, at a temperature of 180°C indicated a critical diameter of 2.54 cm (1 in.) after a total of eight assemblies were tested. Two assemblies consisting of a 50.8 cm (20 in.) long by 2.54 cm (1 in.) diameter pipe joined to a 30.48 cm (12 in.) long by 1.91 cm (3/4 in.) diameter pipe were tested but did not propagate. Subsequently, two tests were made using assemblies with 45.72 cm (18 in.) long by 3.81 cm (1.5 in.) diameter pipe joined to a 30.48 cm (12 in.) long by 2.54 cm (1 in.) diameter pipe. Propagation occurred through the 3.81 cm (1.5 in.) diameter pipe but not through the 2.54 cm (1 in.) diameter pipe.

The composition coded #4, at 40°C, required more extensive testing to determine if a critical diameter existed for this mixture. The testing started with a 30.48 cm (12 in.) long by 3.81 cm (1.5 in.) diameter pipe and proceeded to a 91.44 cm (36 in.) long by 10.16 cm (4 in.) diameter pipe. In each instance pipe damage was evident but it was assumed to be the result of the C-4 booster and not the composition. To verify this assumption, a test was performed with a 66.04 cm (26 in.) long by 10.16 cm (4 in.) diameter pipe filled with water. The resultant damage was the same as the damage to the pipes tested previously using the mixture; consequently, it was concluded that this mixture is not mass detonable.
Hazard Testing

A group of samples consisting of aqueous slurries of urea ammonium nitrate and guanidine nitrate were selected for friction and impact testing (ref. 7). Table 3 shows that five of the six samples did not initiate upon impact as per procedure outlined in Picatinny Arsenal Technical Report 3278, page 2. The sixth sample initiated on impact at a drop height of 38 inches which is probably due to the high ammonium nitrate content of the sample.

These samples were also Friction-Pendulum tested in accordance with instructions stated in Picatinny Arsenal Testing Manual #7-1. They showed no reaction with the steel shoe.

Thermal Analysis

The mixtures described in the critical diameter tests section of this report (table 2) were also subjected to differential thermal analysis (DTA) and thermogravimetric analysis (TGA). The objective of these tests was to determine if reactants and reactant product mixtures, present in the various stages in the production of nitro-guanidine, are capable of exploding during a heating cycle. Measurements were made with a DuPont 900 analyze. Figures 5 through 8 contain the thermal data obtained.

The DTA method involves heating the material being analyzed, simultaneously with a thermally inert reference material, to elevated temperatures at a constant rate. The temperature difference between the test sample and the reference is continuously plotted versus temperature. The resultant exothermic and endothermic curves reveal unique characteristics of the material and its physical, chemical, and thermal reactions. The DTA is a continuous record of the thermal effects accompanying melting, boiling, crystalline transition, dehydration, decomposition, oxidation, and reduction and provides a qualitative study of the material.

The TGA method involves continuous weighing of the material under investigation as it is being heated at a constant rate. The weight loss of the test sample is continuously plotted versus temperature. The TGA procedure presents an excellent visual quantitative study of the observed changes.
None of the four mixtures detonated or burned while being subject to either test, as evidenced by the curves. The DTA analysis of the four compositions in the U/AN process is shown in Table 4. In no instance during the determinations was there a violent reaction. The mixtures and components appeared to vaporize with some decomposition and reaction. However, the reactions appeared to be controlled.

Propagation

Tests were performed to determine the explosive propagation characteristics of various streams according to procedure No. 2.18 in reference 4 that may be encountered in both the U/AN and BAF processes. Emphasis was placed upon evaluating the behavior of guanidine nitrate, guanidine nitrate/water, and nitroguanidine/water to determine the minimum water concentration that would sustain detonation. All tests, unless otherwise stated, were conducted in nominal 5.08 cm (2 in.) diameter pipes using a cylindrical C-4 booster with a length/diameter ratio of 3 to 1 and a J-8 blasting cap. Witness plates of 1.55 cm (3/8 in.) thick mild steel were used to assess propagative behavior. The detonation rate tests were conducted using the test setup shown in figure 9.

U/AN Process Streams

The compositions and propagation results for the streams representing the guanidine nitrate (GN) crystallizer and the evaporator outlet are in Table 5. The crystallizer stream did not propagate in 5.08 cm (2 in.) diameter pipe. The evaporator outlet stream gave complete detonation of 5.08 cm diameter pipe but not in a 2.54 cm (1 in.) diameter pipe.

BAF Process Streams

The compositions of the process streams of the BAF process and their propagation results are listed in Tables 6 and 7, respectively. The tests were conducted over a range of diameters from 2.54 to 15.875 cm (1 to 6¼ in.). In no instance did any of the streams propagate.

Guanidine Nitrate - Guanidine Nitrate/Water

The detonation rates of technical grade guanidine nitrate are in Table 8. Sustained high order detonations occurred during all six tests. The average rate of detonation was 2,762 m/sec. The effect of its dilution with water on the propagation characteristics of guanidine nitrate (Table 9) indicates that propagation in 5.08 cm (2 in.) pipes did not occur when water constituted 25% or more of the mixture.
Nitroguanidine/Water

The propagation characteristics of nitroguanidine/water mixtures are in table 10. The results obtained by diluting nitroguanidine with water are approximately the same as those obtained above for guanidine nitrate. In 5.08 cm pipes, propagation did not occur for water concentrations greater than 30%.

The process streams after dewatering and continuing through drying, for manufacturing both guanidine nitrate and nitroguanidine, contain less water than the critical levels required to sustain propagation. Accordingly, these streams deserve maximum attention with respect to safety design. Additional comments on design parameters are presented in the transition test paragraph and in reference 5.

CONTRACTOR TEST STUDIES

Extensive sensitivity testing was conducted by the Hercules Powder Company under contract number DACA 45-71-C0121 for the Corps of Engineers (ref. 5) in accordance with CPRA publication No. 194 (ref. 4).

The testing (table 11) included impact, friction, electrostatic discharge, dust explosion, transition, and propagation tests on the reactor mixture charge, nitroguanidine, and guanidine nitrate, both pure and technical grade produced by the BAF process. The data indicates that these materials are relatively insensitive to the stimuli used on them.

Impact Tests

All impact values were greater than the limits of the impact apparatus, except for the technical grade guanidine nitrate which contained 6 to 7% of ammonium nitrate and which accounts for its increased sensitivity.

Transition Test (ref. 5)

A transition or critical height-to-explosion test is defined as the height of the material that will react explosively when initiated by flame. Experience has shown that as the diameter of the material increases, the corresponding critical height-to-explosion also increases. The transition test results show that, for all samples tested, the critical height-to-explosion for a 5.08 cm (2 in.) diameter is greater than 60.96 cm (24 in.). Since the reactors and precipitators have height/bed diameter ratio of less than 12, initiation of the materials in these areas of the process by impact, friction,
etc. would result in a fire and not an explosion. A ratio of more than 12 to 1 (height to diameter) would have to exist before an explosion could occur under these conditions.

Propagation Testing (ref. 5)

A propagation test determines the diameter of material that will propagate an explosive reaction when exposed to a shock stimulus. Table 11 shows that the critical diameter for the BAF reaction mixture, guanidine nitrate and nitroguanidine are >7.62 cm (3 in.) <2.54 cm (1 in.) and <1.27 cm (½ in.), respectively. This means that the interconnecting pipelines after the reactors will not propagate an explosive reaction if the diameter is 7.62 cm (3 in.) or less, and that the guanidine nitrate and nitroguanidine dryers will propagate an explosive reaction if subjected to a strong shock source. However, there is no evidence that a shock source exists in the proposed system. As stated in the discussion of the transition tests, any ignition by impact, friction, etc. would result in burning and not an explosion. Therefore, a shock source would have to originate from outside the process, such as from high velocity projectiles, sabotage, etc.

Tables 12 and 13 present a summary of initiation, transition, and propagation test results on simulated compositions found in the mix tanks, dryers, and other operations associated with the U/AN process. The results were similar to those obtained from the BAF materials. These compositions are also relatively insensitive to impact, friction, and electrostatic discharge stimuli. The transition test results also indicate that a maximum height/bed ratio of 12 would result in a fire when subjected to stimuli such as impact, friction, and electrostatic discharge, propagation to explosion would require a strong shock from an external source.

CONCLUSIONS

1. For the U/AN process, the critical diameters determined by using shock initiation were 2.54 cm (1 in.) for the evaporator outlet and the liquid reactor outlet streams, and 3.81 cm (1½ in.) for the mixed reactor feed stream.

2. The nitroguanidine conversion reactor outlet stream is not mass detonable.

3. Thermal analysis tests (DTA and TGA) on the process streams indicated in paragraph 1 above, showed no explosive behavior and produced controlled thermal decomposition only.
4. Propagation tests showed that the guanidine nitrate crystallizer stream in the U/AN process did not propagate; and, that the guanidine nitrate evaporator outlet U/AN process stream had a critical diameter of 2.54 cm.

5. Welland technical grade (fig. 10) guanidine nitrate yielded a detonation rate of 2,762 m/sec. Mixtures of guanidine nitrate and water did not propagate in 5.08 cm (2 in.) pipes when water was 25% greater in the mixture.

6. Mixtures of nitroguanidine and water did not propagate in 5.08 cm (2 in.) pipes when using a water concentration of 30% or greater.

7. Impact, friction, and electrostatic sensitivity show that the reactor mixture charge, nitroguanidine, and both pure and technical grade guanidine nitrate are relatively insensitive to these stimuli. Flame-initiated critical height tests indicate that these materials should not transcend to explosion within the process system. An external shock source, e.g., projectiles, sabotage, etc. would be required to stimulate an explosion.
RECOMMENDATION

If the U/AN process is selected for future facilitation, additional propagation studies should be conducted, on the various process streams associated with it, to gain additional data for more definitive statistical inferences to establish more accurate design characteristics.

REFERENCES


2. S. Levmore, Air Blast Parameters and Other Characteristics of Nitroguanidine and Nitrate Guanidine, Technical Report 4865, Picatinny Arsenal, Dover, NJ, November 1975

3. T. Caggiano, Research and Engineering Logbooks No. 151-2-72, 151-3-72, 151-8-72, and 151-10-72, Picatinny Arsenal, Dover, NJ


Table 1. Critical diameter tests and results.

<table>
<thead>
<tr>
<th>Comp. No.</th>
<th>Temp. °C</th>
<th>Pipe Assembly - Dia. &amp; Length</th>
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<th>Results</th>
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<tr>
<td>1</td>
<td>135</td>
<td>1&quot;Ø x 24&quot;, 3/4&quot;Ø x 12&quot;</td>
<td>12</td>
<td>DNP - No Sympathetic detonation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.54cm x 61cm, 1.91cm x 30.5cm)</td>
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<tr>
<td>1</td>
<td>135</td>
<td>2&quot;Ø x 10&quot;, 1½&quot;Ø x 10&quot;, 1&quot;Ø x 8&quot;</td>
<td>2</td>
<td>Propagation stops at 1&quot;Ø</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5.08cm x 25.4cm, 3.8cm x 25.4cm, 2.5cm x 20.3cm)</td>
<td>2.54cm</td>
<td></td>
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<tr>
<td></td>
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<td>CRITICAL DIAM OF COMP #1 is 1&quot;</td>
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<tr>
<td>2</td>
<td>130</td>
<td>2&quot;Ø x 10&quot;, 1½&quot;Ø x 10&quot;, 1&quot;Ø x 8&quot;</td>
<td>2</td>
<td>Propagation stops at 1½&quot;Ø junction</td>
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<td>2</td>
<td>130</td>
<td>1½&quot;Ø x 20&quot;, 1&quot;Ø x 12&quot;</td>
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<td>130</td>
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<td>3.81cm</td>
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<td>1</td>
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</tr>
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</tr>
<tr>
<td>3</td>
<td>190</td>
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<td>1</td>
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<td>1</td>
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<td>1.91cm</td>
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<td>1&quot;Ø x 10&quot;, 3/4&quot;Ø x 10&quot;, ½&quot;Ø x 8&quot;</td>
<td>1</td>
<td>Propagation stops at 3/4&quot;Ø junction</td>
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<td>2</td>
<td>DNP through 1&quot;Ø pipe</td>
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</tr>
<tr>
<td>3</td>
<td>190</td>
<td>1½&quot;Ø x 18&quot;, 1&quot;Ø x 12&quot;</td>
<td>2</td>
<td>Propagation stops at 1&quot;Ø junction</td>
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<td>(3.8cm x 45.7cm, 2.54cm x 30.5cm)</td>
<td>2.54cm</td>
<td></td>
</tr>
</tbody>
</table>
Table 1. (continued)

<table>
<thead>
<tr>
<th>Comp. No.</th>
<th>Temp. °C</th>
<th>Pipe Assembly - Diam x Length</th>
<th>No of Tests</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>40</td>
<td>1½&quot;Ø x 12&quot;</td>
<td>1</td>
<td>Pipe blown apart-Probably due to booster</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3.81cm x 30.5cm)</td>
<td>1</td>
<td>Pipe blown apart-Probably due to booster</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>2&quot;Ø x 12&quot;</td>
<td>2</td>
<td>DNP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5.08cm x 30.5cm)</td>
<td>1</td>
<td>DNP - Pipe blown apart</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>2¼&quot;Ø x 24&quot;</td>
<td>1</td>
<td>DNP - 8&quot; pipe remains</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>2½&quot;Ø x 24&quot;</td>
<td>1</td>
<td>DNP - 10&quot; pipe remains</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>3¼&quot;Ø x 36&quot;</td>
<td>1</td>
<td>DNP - 10&quot; pipe remains</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>(10.16cm x 91.4cm)</td>
<td>1</td>
<td>DNP - 14&quot; pipe remains</td>
</tr>
</tbody>
</table>

Ø DENOTES DIAMETER - DNP - DOES NOT PROPAGATE
Table 2. (U/AN) GN/NQ process detonation study.

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>STREAM</th>
<th>COMPOSITION</th>
<th>TEMP °C</th>
<th>MASS DETONABLE</th>
<th>CRITICAL DIAMETER IN.</th>
</tr>
</thead>
</table>
| U/AN    | EVAPORATOR OUTLET | 13% GN  
           |             | 150     | YES            | 1 (2.54 cm)          |
|         |              | 74% AN  
           |             |         |              |                      |
|         |              | 13% U     
           |             |         |              |                      |
| U/AN    | MIXED REACTOR FEED | 9% GN  
            |             | 120     | YES            | 1½ (3.81 cm)         |
|         |              | 60% AN  
            |             |         |              |                      |
|         |              | 31% U     
            |             |         |              |                      |
| U/AN    | LIQUID REACTOR OUTLET | 33% GN  
            |             | 180     | YES            | 1 (2.54 cm)          |
|         |              | 57% AN  
            |             |         |              |                      |
|         |              | 10% U     
            |             |         |              |                      |
| U/AN AND BAF | NQ REACTOR OUTLET | 56% H$_2$SO$_4$  
                          |             | 40       | NO             | NA                    |
|         |              | 7% WATER  
                          |             |         |              |                      |
|         |              | 21% NQ    
                          |             |         |              |                      |
|         |              | 2% GN     
                          |             |         |              |                      |
|         |              | 14% AS    
                          |             |         |              |                      |
### Table 3. Hazard testing results.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Location in Pilot Plant</th>
<th>Temp. °C</th>
<th>Wt. % GN</th>
<th>Wt. % AN</th>
<th>Wt. % U</th>
<th>Wt. % H₂O</th>
<th>PA App 2 Kg. wt., in.</th>
<th>Charge weight, gm</th>
<th>Friction Pendulum Steel Shoe</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Centrifuge drier</td>
<td>158°F 70°C</td>
<td>94.0</td>
<td>1.0</td>
<td>0.0</td>
<td>5.0</td>
<td>40+</td>
<td>0.015</td>
<td>No reaction</td>
</tr>
<tr>
<td>2</td>
<td>Centrifuge Ambient, 76°F</td>
<td>85.0</td>
<td>0.7</td>
<td>0.0</td>
<td>14.3</td>
<td>40+</td>
<td>0.017</td>
<td>No reaction</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Quench Product 100°C</td>
<td>35.0</td>
<td>30.0</td>
<td>5.0</td>
<td>30.0</td>
<td>40+</td>
<td>0.033</td>
<td>No reaction</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Evaporator Inlet 76°F</td>
<td>9.2</td>
<td>34.3</td>
<td>7.7</td>
<td>48.8</td>
<td>40+</td>
<td>0.026</td>
<td>No reaction</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Evaporator Outlet 135°F</td>
<td>17.8</td>
<td>66.7</td>
<td>14.9</td>
<td>0.6</td>
<td>38</td>
<td>0.052</td>
<td>No reaction</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Crystallizer Outlet 76°F</td>
<td>34.0</td>
<td>28.0</td>
<td>6.0</td>
<td>32.0</td>
<td></td>
<td></td>
<td>No reaction</td>
<td></td>
</tr>
</tbody>
</table>

Sample No. A Shaken 40+ 0.031 (75°F)
Sample No. B Decanted 40+ 0.029 (74°F)
Table 4. DTA tests on stream compositions.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Observed Endotherms (°C)</th>
<th>Observed Exotherms (°C)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>I. Evap</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed UREA (13%)</td>
<td>60°, 95°</td>
<td>120°, 135°</td>
<td>Sample vaporized away Smoothly beginning at 160°</td>
</tr>
<tr>
<td>Outlet Guanidine</td>
<td></td>
<td>160°, 270°</td>
<td></td>
</tr>
<tr>
<td>Nitratre (13%)</td>
<td>300°</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>II. Mixed</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reactor UREA (31%)</td>
<td>60°, 72°, 90°</td>
<td>95°, 130°</td>
<td>Extensive vaporization begins at 160° and is complete at 315°C.</td>
</tr>
<tr>
<td>Feed NH₄NO₃ (60%)</td>
<td></td>
<td>260°, 300°</td>
<td></td>
</tr>
<tr>
<td>Nitratre (3%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>III. Liquid</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reactor UREA (10%)</td>
<td>60°</td>
<td>330°</td>
<td>Frothing observed at 280°C. No violent reaction observed.</td>
</tr>
<tr>
<td>Outlet Guanidine</td>
<td></td>
<td>110°</td>
<td></td>
</tr>
<tr>
<td>Nitratre (33%)</td>
<td>260°</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>IV. NQ Dehyd</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reactor Sulfuric Acid (56%)</td>
<td>None</td>
<td>150°</td>
<td>Smoke and vaporization. No violent reaction after cooling residue was solid.</td>
</tr>
<tr>
<td>Hydration Water (7%)</td>
<td></td>
<td>175°</td>
<td></td>
</tr>
<tr>
<td>Outlet Ammonium Sulfate (14%)</td>
<td></td>
<td>320°</td>
<td></td>
</tr>
<tr>
<td>Nitroguanidine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Class II lot NOW 3-16 (21%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guanidine Nitratre (2%)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5. U/AN process stream composition.

<table>
<thead>
<tr>
<th>Operation</th>
<th>GN Crystallizer</th>
<th></th>
<th></th>
<th>GN Evaporator Outlet</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diameter</td>
<td>Diameter</td>
<td>Diameter</td>
<td></td>
<td>Diameter</td>
<td>Diameter</td>
</tr>
<tr>
<td></td>
<td>2 Inch</td>
<td>2 Inch</td>
<td>2 Inch</td>
<td>1 Inch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingredients</td>
<td>%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guanidine Nitrate (GN)</td>
<td>34.0</td>
<td>17.8</td>
<td>18.5</td>
<td>18.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium Nitrate</td>
<td>28.0</td>
<td>66.7</td>
<td>66.6</td>
<td>66.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urea</td>
<td>6.0</td>
<td>14.9</td>
<td>14.9</td>
<td>14.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>32.0</td>
<td>0.6</td>
<td>--</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>250°F</td>
<td>250°F</td>
</tr>
<tr>
<td>DNP*</td>
<td>Complete</td>
<td>Sustained</td>
<td>Detona-</td>
<td>DNP*</td>
<td>Detona-</td>
<td>DNP*</td>
</tr>
<tr>
<td></td>
<td>Propaga-</td>
<td>tion</td>
<td>tion</td>
<td></td>
<td>tion</td>
<td></td>
</tr>
</tbody>
</table>

*DNP - Did not propagate
Table 6. Composition of RAF process streams.

<table>
<thead>
<tr>
<th>Stream Identification</th>
<th>Operation</th>
<th>Stream Composition, Wt %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>4</td>
</tr>
<tr>
<td>Ingredients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium Nitrate</td>
<td></td>
<td>18.6</td>
</tr>
<tr>
<td>Guanidine Nitrate</td>
<td></td>
<td>16.7</td>
</tr>
<tr>
<td>Ammonium Nitrate</td>
<td></td>
<td>46.2</td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td>12.3</td>
</tr>
</tbody>
</table>

#4--R-202--Primary Reactor--Temp 250°F (121°C)
#14--R-205--Fourth Stage Reactor--Temp 250°F (121°C)
#94--L 236 A & B--Crystallizers--Temp 70°F (21°C)
#100--Stream--Temp 70°F (21°C)
#116--E-234--Evaporator--Temp 338°F (170°C)
Table 7. Propagation characteristics of BAF process streams.

<table>
<thead>
<tr>
<th>Stream Number</th>
<th>Nominal Diameter, Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>N</td>
</tr>
<tr>
<td>14</td>
<td>N</td>
</tr>
<tr>
<td>94</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
</tr>
<tr>
<td>116</td>
<td></td>
</tr>
<tr>
<td>BAF Reactor Cold Melt</td>
<td>N</td>
</tr>
</tbody>
</table>

N - Did not propagate or incomplete propagation.
Table 8. Detonation velocity of technical grade guanidine nitrate - witness plate data.

<table>
<thead>
<tr>
<th>No.</th>
<th>Alum (62 mls)</th>
<th>Pipe Size 1&quot; (2.54 cm)</th>
<th>Approx. Diam. of Depression inches</th>
<th>Guanidine Nitrate (GMS) of Depression inches</th>
<th>Approx. Depth of Depression Meters (1 x 10^-6)</th>
<th>Rate m/sec</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No</td>
<td>1.125</td>
<td>140</td>
<td>.195</td>
<td>111.2</td>
<td>2,741</td>
<td>Hi Order</td>
</tr>
<tr>
<td></td>
<td>2.86 cm</td>
<td></td>
<td>.50 cm</td>
<td></td>
<td></td>
<td></td>
<td>Lg Frag</td>
</tr>
<tr>
<td>2</td>
<td>No</td>
<td>1.125</td>
<td>146</td>
<td>.175</td>
<td>109.2</td>
<td>2,791</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>2.86 cm</td>
<td></td>
<td>.44 cm</td>
<td></td>
<td></td>
<td></td>
<td>&quot;</td>
</tr>
<tr>
<td>3</td>
<td>No</td>
<td>1.063</td>
<td>148</td>
<td>.165</td>
<td>108.6</td>
<td>2,807</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>2.70 cm</td>
<td></td>
<td>.42 cm</td>
<td></td>
<td></td>
<td></td>
<td>&quot;</td>
</tr>
<tr>
<td>4</td>
<td>Yes</td>
<td>1.000</td>
<td>145</td>
<td>.130</td>
<td>109.7</td>
<td>2,778</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>2.54 cm</td>
<td></td>
<td>.33 cm</td>
<td></td>
<td></td>
<td></td>
<td>&quot;</td>
</tr>
<tr>
<td>5</td>
<td>Yes</td>
<td>0.750</td>
<td>146</td>
<td>.100</td>
<td>111.6</td>
<td>2,731</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>1.91 cm</td>
<td></td>
<td>.25 cm</td>
<td></td>
<td></td>
<td></td>
<td>&quot;</td>
</tr>
<tr>
<td>6</td>
<td>Yes</td>
<td>1.000</td>
<td>142</td>
<td>.120</td>
<td>112.0</td>
<td>2,721</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>2.54 cm</td>
<td></td>
<td>.30 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2,762 m/s Avg.
Table 9. Propagation characteristics of guanidine nitrate/water mixtures.

<table>
<thead>
<tr>
<th>Mixture Composition, Wt %</th>
<th>Propagation Test Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pipe, Diameter, in.</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>GN</td>
<td>H₂O</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>95</td>
<td>5</td>
</tr>
<tr>
<td>85</td>
<td>15</td>
</tr>
<tr>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>70</td>
<td>30</td>
</tr>
<tr>
<td>60</td>
<td>40</td>
</tr>
</tbody>
</table>

*N - Did not propagate or incomplete propagation
Y - Detonated completely
Table 10. Propagation characteristics of NQ/H₂O mixtures.

<table>
<thead>
<tr>
<th>Mixture Composition, Wt %</th>
<th>Propagation Test Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>NQ</td>
<td>H₂O</td>
</tr>
<tr>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>70</td>
<td>30</td>
</tr>
<tr>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>40</td>
<td>60</td>
</tr>
</tbody>
</table>

*N - No Incomplete
Y - Yes
### Table 11. Test results for NG plant (BAF process).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Temperature</th>
<th>Impact</th>
<th>Friction</th>
<th>ESD</th>
<th>Dust Explosion</th>
<th>Transition</th>
<th>Propagation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca(NO₃)₂</td>
<td>125°C</td>
<td>211,500 ft-lb/sec</td>
<td>≥ 65,625 psi 8 ft/sec</td>
<td>5.0 Joules ambient (ambient)</td>
<td>&gt; 24&quot; @ 1&quot; ID (61cm @ 2.54cm)</td>
<td>1&quot; - NP</td>
<td></td>
</tr>
<tr>
<td>NH₄NO₃</td>
<td>40.2%</td>
<td>(287 kJ/s) (452 MPa @ 2.4 m/s)</td>
<td>≥ 104,761 psi 8 ft/sec (722 MPa @ 2.4 m/s)</td>
<td>0.5 Joules oz/ft² (4.1 kg/m³)</td>
<td>&gt; 24&quot; @ 2&quot; ID (61cm @ 5.1cm)</td>
<td>2&quot; - NP</td>
<td></td>
</tr>
<tr>
<td>H₂O</td>
<td>21.2%</td>
<td>Ambient</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaGN₂</td>
<td>Ambient</td>
<td>≥ 77.6 ft-lb/in² (175 kJ/m²)</td>
<td>≥ 122,400 psi 8 ft/sec (844 MPa @ 2.4 m/s)</td>
<td>1.26 Joules oz/ft² (4.1 kg/m³)</td>
<td>&gt; 24&quot; @ 2&quot; ID (61cm @ 5.1cm)</td>
<td>CF &lt; 1/2&quot; (SCH 40 Confinement)</td>
<td></td>
</tr>
<tr>
<td>NO</td>
<td>Ambient</td>
<td>≥ 59.7 ft-lb/in² (135 kJ/m²)</td>
<td>≥ 122,800 psi 8 ft/sec (847 MPa @ 2.4 m/s)</td>
<td>≥ 4.1 oz/ft² (4.1 kg/m³)</td>
<td>&gt; 24&quot; @ 1&quot; ID (61cm @ 2.54cm)</td>
<td>&lt; 1&quot; (1&quot;=2980 m/sec (2.54cm))</td>
<td></td>
</tr>
<tr>
<td>NO-Pure</td>
<td>Ambient</td>
<td>≥ 31.6 ft-lb/in² (71 kJ/m²)</td>
<td>≥ 205,800 psi 8 ft/sec (729 MPa @ 2.4 m/s)</td>
<td>0.075 oz/ft² (4.1 kg/m³)</td>
<td>&gt; 24&quot; @ 2&quot; ID (61cm @ 2.54cm)</td>
<td>(2&quot;)=3780 m/sec (6.4cm)</td>
<td></td>
</tr>
<tr>
<td>NO-Technical Grade</td>
<td>Ambient</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Drier Configuration Propagation Tests** 6" (15.2cm) Deep x 12" (30.5cm) Wide x 24" (61cm) Long

- **ON**
  - 1" booster - no propagation (2.54cm)
  - 2" booster - propagation 2900 m/sec (5.1cm)

- **NO**
  - 1" booster - 2560 m/sec (2.54cm)
  - 2" booster - 2785 m/sec (5.1cm)
Table 12. Summary of initiation test results.

<table>
<thead>
<tr>
<th>Sample Mixture</th>
<th>Simulated Mix</th>
<th>Temperature</th>
<th>Impact (ft-lbs/in²)</th>
<th>Friction (@ 8 fps)</th>
<th>ESD* (Joules)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AN 1 U GN</td>
<td>Mix Tank</td>
<td>Ambient</td>
<td>&gt; 69,000 psi (476 MPa)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 1 -</td>
<td>Mix Tank</td>
<td>Ambient</td>
<td>≥69,000 psi (476 MPa)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 1 -</td>
<td>Mix Tank</td>
<td>Ambient</td>
<td>≥59.7 (135 KJ/m²)</td>
<td>≥67,000 psi (462 MPa)</td>
<td>0.5</td>
</tr>
<tr>
<td>4 1 -</td>
<td>Mix Tank</td>
<td>135°C</td>
<td>84 x 10⁴³¹²</td>
<td>39,090 psi (269 MPa)</td>
<td></td>
</tr>
<tr>
<td>Pure Dryer</td>
<td>Ambient</td>
<td>≥59.7 (135 KJ/m²)</td>
<td>≥122,400 psi (844 MPa)</td>
<td>1.26</td>
<td></td>
</tr>
<tr>
<td>Technical Grade Dryer</td>
<td>Ambient</td>
<td>31.6 (71 KJ/m²)</td>
<td>&gt;105,800 psi (729 MPa)</td>
<td>0.075</td>
<td></td>
</tr>
<tr>
<td>4.5 1.5 4.0</td>
<td>Eutectic Tank</td>
<td>60°C</td>
<td>≥77.6 (175 KJ/m²)</td>
<td>45,614 psi (314.5 MPa)</td>
<td></td>
</tr>
</tbody>
</table>

(1) Rate term since sample under test was in a liquid phase. (ft-lbs/sec)

(2) At 10 fps.

* ESD - Electrostatic Discharge
## Table 13. Transition and propagation results.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Initiation Source</th>
<th>Simulated Mix</th>
<th>Test Sensing</th>
<th>Temperature</th>
<th>Critical Ht. or Critical Diam.</th>
<th>Velocity (m/sec)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Grade GN</td>
<td>12 gm bag igniter</td>
<td>Dryer</td>
<td>Visual</td>
<td>Ambient</td>
<td>1 x 24 (2.54cm x 61cm)</td>
<td>$\geq 24$</td>
<td>Smoke, muffle noise sample scattered</td>
</tr>
<tr>
<td>Technical Grade GN</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>2 x 24 (5.1cm x 61cm)</td>
<td>$\geq 24$</td>
<td>Smoke, muffle noise sample scattered</td>
</tr>
<tr>
<td>AN/U/Silica Gel 4/1/1</td>
<td>Pyrofuse (Al-Pd-alloy)</td>
<td>Reactor Tube after 2 hrs of heating</td>
<td>180°C</td>
<td>2 x 24 (5.1cm x 61cm)</td>
<td>$\geq 24$ (61cm)</td>
<td>No reaction, sample left in pipe</td>
<td></td>
</tr>
<tr>
<td>Technical Grade GN</td>
<td>Comp C-4 (1)</td>
<td>Dryer</td>
<td>Probe</td>
<td>Ambient</td>
<td>1 x 24 (2.54cm x 61cm)</td>
<td>$&lt; 1$ (2.5cm)</td>
<td>Sample consumed</td>
</tr>
<tr>
<td>AN/U/Silica Gel 4/1/1</td>
<td>&quot;</td>
<td>Reactor Tube after 2 hrs of heating</td>
<td>180°C</td>
<td>1 x 24 (2.54cm x 61cm)</td>
<td>$&lt; 1$ (2.5cm)</td>
<td>Propagation</td>
<td></td>
</tr>
<tr>
<td>GN/AN 5.4/4.6</td>
<td>&quot;</td>
<td>Reactor Tube</td>
<td>180°C</td>
<td>1 x 24 (2.54cm x 61cm)</td>
<td>$&lt; 1$ (2.5cm)</td>
<td>Propagation</td>
<td></td>
</tr>
<tr>
<td>AN/U 4/1</td>
<td>&quot;</td>
<td>Mix Tank</td>
<td>100°C</td>
<td>1 x 24 (2.54cm x 51cm)</td>
<td>1 (2.5cm) 1200-1300</td>
<td>Started, then stopped 13&quot; to 17&quot; pipe left (33cm) (43cm)</td>
<td></td>
</tr>
<tr>
<td>GN/AN/U 3.4/3.8/2.8</td>
<td>&quot;</td>
<td>Eutectic Tank</td>
<td>60°C</td>
<td>1 x 24 (2.54cm x 61cm)</td>
<td>$&gt; 1$ (2.5cm)</td>
<td>No propagation 17&quot; to 20&quot; pipe left (43cm) (51cm)</td>
<td></td>
</tr>
</tbody>
</table>

(1) Comp C-4 size - Diameter equal to pipe diameter and length 3 x diam.
(2) Pipe - Schedule 40, closed bottom for both tests, top capped for transition and top plate for propagation.
NITROGUANIDINE PROCESS REACTIONS
UREA/AMMONIUM NITRATE TECHNOLOGY

\[ 2 \text{NH}_2 - \text{C} - \text{NH}_2 + \text{NH}_4\text{NO}_3 \xrightarrow{\text{Catalyst}} \text{SiO}_{2} \rightarrow (\text{NH}_2)_2 - \text{C} = \text{NH} \cdot \text{HNO}_3 + \text{NH}_4\text{CO}_2 \text{NH}_2 \]

\[ \text{Urea} \quad \text{Ammonium Nitrate} \quad \text{Guanidine Nitrate} \quad \text{Ammonium Carbamate} \]

\[ \text{NH}_4\text{CO}_2 \text{NH}_2 \xrightarrow{\text{Decomposition}} 2\text{NH}_3 + \text{CO}_2 \]

\[ \text{Ammonium Carbamate} \quad \text{Ammonia} \quad \text{Carbon Dioxide} \]

\[ (\text{NH}_2)_2 - \text{C} = \text{NH} \cdot \text{HNO}_3 + \text{H}_2 \text{SO}_4 \xrightarrow{\text{Dehydration}} (\text{NH}_2)_2 \text{C} = \text{NH} \cdot \text{HNO}_3 \cdot \text{HSO}_4 + \text{H}_2 \text{O} \]

\[ \text{Guanidine Nitrate} \quad \text{Sulfuric Acid} \quad \text{Nitroguanidine Bisulfate} \quad \text{Water} \]

\[ (\text{NH}_2)_2 \text{C} = \text{NH} \cdot \text{HNO}_3 \cdot \text{HSO}_4 \xrightarrow{\text{Dissociation}} \text{NH}_2 \text{C} = \text{NH} \cdot \text{NH} \cdot \text{NO}_2 + \text{H}_2 \text{SO}_4 \]

\[ \text{Nitroguanidine Bisulfate} \quad \text{Water} \quad \text{Nitroguanidine} \quad \text{Sulfuric Acid} \]

\[ 2\text{NH}_3 + \text{H}_2 \text{SO}_4 \xrightarrow{\text{Neutralization}} (\text{NH}_4)_2 \text{SO}_4 \]

\[ \text{Ammonia} \quad \text{Sulfuric Acid} \quad \text{Ammonium Sulfate} \]

\[ \text{NH}_3 + \text{NH}_4 \cdot \text{HSO}_4 \xrightarrow{\text{Neutralization}} (\text{NH}_4)_2 \text{SO}_4 \]

\[ \text{Ammonia} \quad \text{Ammonium Bisulfate} \quad \text{Ammonium Sulfate} \]

Figure 1. U/AN process reaction sheet.
CHEMISTRY OF NITROGUANIDINE SYNTHESIS BAF PROCESS

CALCIAI M Cyanamide Manufacture
CaC₂ + N₂ → CaCN₂ + C

Guanidine Nitrate Manufacture
CaCN₂ + 3NH₄NO₃ → Ca(NO₃)₂ + NH₂-C-NH₂ + HNO₃ + 2NH₃

AMMONIA RECOVERY
2NH₃ + CO₂ + H₂O → (NH₄)₂CO₃

CALCIUM REMOVAL
Ca(NO₃)₂ + (NH₄)₂CO₃ → CaCO₃↓ + 2NH₄NO₃

CO₂ RECOVERY
CaCO₃ → CaO + CO₂

NO Manufacture
NH₁ + NH₂-C-NH₂ + HNO₃ → NH₂-C-NH₂-HNO₃ + H₂O (85-90% acid)

NO Recovery
NO dissolved + H₂O → NO precipitate + 25% H₂SO₄

Note: Numbers below compounds are molecular weights.

Figure 2. BAF process reaction sheet.
nitrate pilot plant process flow sheet.
Figure 6. DTA and TGA - Sample II.
Figure 7. DTA - Sample III.
NITROGUANIDINE

REACTIONS OF WELLAND PROCESS

CaCO₃ → CaO + CO₂
calcium carbonate calcium oxide

CaO + 3C → CaC₂ + CO
calcium oxide calcium carbide

CaC₂ + N₂ → CaCN₂ + C
calcium carbide calcium cyanamide

2 CaCN₂ + H₂O → Ca(HCN₂)₂ + Ca(OH)₂
calcium cyanamide calcium hydro cyanide
cyanamide

Ca(HCN₂)₂ + CO₂ + H₂O → 2H₂CN₂ + CaCO₃

calcium hydro cyanide

cyanamide

2 H₂CN₂ → (H₂CN₂)₂

dicyandimide

H₂N - C - N - CN + NH₄NO₃ → H₂N - C - N - C - NH₂ - HNO₃
Dicyandiamide biguanidine nitrate

H₂N - C - N - C - NH₂ HNO₃ + NH₄NO₃ → 2(H₂N - C - NH₂ - HNO₃)
biguanidine nitrate guanidine nitrate

NH₂
C = NH + H₂SO₄ → NH₂
NH₂ HNO₃

guanidine nitrate nitroguanidine

Figure 10. Welland process reaction sheet.
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