Guidance Document Regarding Acceptors under ATF Regulations at 27 CFR 555.220

October 2017
Guidance Document Regarding Acceptors under ATF Regulations at 27 CFR 555.220

To aid in the process of understanding what qualifies as an “ acceptor ” in 27 CFR 555.220 (Table of Separation Distances of Ammonium Nitrate and Blasting Agents from High Explosives and Blasting Agents), IME has developed the following framework in consultation with the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF).

<table>
<thead>
<tr>
<th>Included as AN acceptors in Table 27 CFR 555.220</th>
<th>DONORS in table 555.220</th>
<th>Excluded as an acceptor/ not included in Table 555.220</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Solid AN in prill, flake, and granule form</td>
<td>• BA/ANFO</td>
<td>• AN Solutions less than 93%</td>
</tr>
<tr>
<td>• AN Solutions greater than 93%</td>
<td>• HE</td>
<td></td>
</tr>
<tr>
<td>• Unsensitized ANEs – Watergels and Emulsions (UN3375)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• (Note – Blasting agents can be an acceptor for 555.220 as well, but are not addressed in this document.)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The information provided is not intended to cover all hazards, safe practices or technical challenges associated with the manufacturing of ammonium nitrate (AN); the manufacturing, storage or use of explosives or blasting agents containing AN; or the transportation of AN and AN-containing products. For additional information, please consult other sources including the appropriate references, standards, and regulations cited at the end of this document.
1. Ammonium Nitrate Solids and Solution

A. AN Solids:
The most common form of solid AN is that of prill. AN can, however, be manufactured as granules or as flake. The behavior of AN prill as an acceptor is well documented. AN is considered a 5.1 Oxidizer per DOT test procedures.

Chemical Properties of AN

AN has a molecular formula written as NH$_4$NO$_3$. It is described as a nitrate salt of ammonia and nitric acid. AN is a chemically bonded compound consisting of three (3) nonmetal elements: nitrogen (N), hydrogen (H) and oxygen (O) forming two molecules (ammonium and nitrate) that create a compound having an atomic weight of approximately 80. Table 1 shows the element breakdown of AN. AN prill products normally contain internal and external trace chemicals to increase the friability, hardness and mechanical stability of the prill. Typical formulas for AN prill are 99.8% AN or more with small quantities of additives. The maximum quantity of combustible material allowed in AN is 0.2%.

Table 1: Elemental Breakdown of Ammonium Nitrate

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic Wt.</th>
<th># Atoms</th>
<th>Atomic Wt. in AN</th>
<th>Percent AN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>14</td>
<td>2</td>
<td>28</td>
<td>35%</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>5%</td>
</tr>
<tr>
<td>Oxygen</td>
<td>16</td>
<td>3</td>
<td>48</td>
<td>60%</td>
</tr>
</tbody>
</table>

Prills are typically solid, white, spherical-like particles which can be porous or non-porous (used in agriculture). An image of the prills is shown in Figure 1. Porosity can be either high density typically 0.90 to 1.00 g/cc or low density typically 0.74 to 0.88 g/cc. Both densities are used in explosive products.
Figure 1. Photograph of AN prills
Figure 2. Image showing the AN Prill Tower
B. AN Prill Manufacturing Process

A typical flow diagram for the manufacture of AN prill is shown in the schematic below.

The process begins with nitric acid and ammonia as the raw materials. Typically 50-70% nitric acid is pumped into a batch neutralizer or continuous neutralizer along with the appropriate amount of vaporized ammonia wherein the acid is reacted with the ammonia to form ammonium nitrate in water (ANSOL). The resulting solution, generally in the 75-90% AN range, can be fed to storage or to an evaporator (heat exchanger) to reduce the water content to around 3% before the solution is sprayed into prill towers (See Figure 2). An upward movement of air in the tower causes the droplets to solidify into prills during their fall in the tower. From the tower the prills are dried, screened, cooled and coated. This finished prill product is transferred by conveyors into storage buildings in preparation for shipment to customers.
C. AN Granules and Flakes
The predominant form of solid AN used in the explosives industry is AN prill. For completeness, the two other forms – granules and flakes – are briefly described.

AN granules are formed by “graining” high strength ANSOL (~94-98% AN) in agitation tanks to form granules or grains of AN. These are typically pure AN, but additives can be introduced if particular properties are needed for a specific application(s).

Flaked AN is less common but can also be formed from high strength ANSOL forming a flake as opposed to granules or prills.

In composition, flakes and granules are almost identical to prill.

D. AN Solution (ANSOL)
AN solutions coming out of the manufacturing process (shown in the schematic above) are typically in the 75-90% strength range. These solutions are maintained at temperatures above their crystallization point so that they can be handled, pumped and used to make AN emulsions. Rail and truck transport of ANSOL are the typical methods of shipment. Rail shipments of ANSOL typically requires the ANSOL to be reheated at the destination to re-dissolve the AN due to temperature losses during transport that causes part of the AN to crystalize.

The principal use of solution is for the manufacture of AN emulsions (ANE).

There has been no recorded instance of a storage vessel of AN solution behaving as an acceptor. Research papers show that high concentrations can be detonated but only with aeration and not in a quiescent state.

Research papers can be provided.

2. Ammonium Nitrate Emulsions and Watergels (ANE)
ANEs are a relatively new type of substance and are denoted by UN3375. The substances are unsensitized emulsions and gels which are classified as Division 5.1 according to the UN Model Regulations.

The composition of ANEs must fit within the UN description as shown below.

Composition of UN3375:
UN3375 is defined in the UN Model Regulations through Special Provision 309:

This entry applies to non sensitized emulsions, suspensions and gels consisting primarily of a mixture of ammonium nitrate and fuel, intended to produce a Type E blasting explosive only after further processing prior to use.
The mixture for emulsions typically has the following composition: 60-85% ammonium nitrate; 5-30% water; 2-8% fuel; 0.5-4% emulsifier agent; 0-10% soluble flame suppressants and trace additives. Other inorganic salts may replace part of the ammonium nitrate.

The mixture for suspensions and gels typically has the following composition: 60-85% ammonium nitrate, 0-5% sodium or potassium perchlorate, 0-17% hexamine nitrate or monomethylamine nitrate, 5-30% water, 2-15% fuel, 0.5-4% thickening agent, 0-10% soluble flame suppressants, and trace additives. Other inorganic salts may replace part of the ammonium nitrate.

In the US, both emulsions and watergels\(^1\) are transported in bulk.

There is a well-defined testing regime for UN3375 – Test Series 8, although one of the tests has shown to be unsuitable for AN emulsions (the Koenen Test, 8(c)).

There has been no recorded instance of an ANE being initiated by shock alone. The only recorded instance of ANE acting as an acceptor is one in which an ANE storage tank (Porgera, PNG) was involved in a prolonged fire following a plant explosion. A bulk truck was on fire after the first explosion, and the fire impinged on the storage tanks, which were also breached. The explosion of the truck and ANE tanks occurred approximately 1h:15min after the plant explosion.

A. Manufacturing Process for Emulsion ANEs

\[\text{AN Solution (75-85\%)} \rightarrow \text{Oil Phase + Surfactant*} \rightarrow \text{Mixer} \rightarrow \text{Inline Mixer} \rightarrow \text{Progressive Cavity Pump} \rightarrow \text{Tank}\]

* - Oil can be diesel, mineral or vegetable
- Surfactant can be Sorbitan Monooleate, or Polyisobutenyl succinic anhydride (PIBSA) based

\(^1\) These substances may also be referred to as gels, suspensions, or slurries.
**Process Description:**

A schematic of the emulsion manufacturing process is shown above. The AN solution, typically (75-85%) is pumped into a mixing vessel together with the organic phase, which consists of the oil to be used as fuel, and the surfactant, which is used to stabilize the emulsion. The most common mixing vessel is a tank with a motor driven impeller. The shear action of the impeller disperses the AN solution phase in the organic (oil) phase. The surfactant prevents the AN droplets from coalescing. The emulsion is water-in-oil, i.e., the AN droplets are finely dispersed in the continuous phase which is the oil.

The resulting coarse emulsion is then pumped through in-line mixers, which further refines the emulsion to the desired viscosity, which is indicative of the droplet size. Smaller droplet sizes result in higher viscosities. The unsensitized product has the consistency of mayonnaise and is not free flowing. Emulsions with three different viscosities are shown in Figure 3.

![Figure 3. Emulsion samples with three different viscosities (lower to higher L to R)](image)

The emulsion as viewed under a microscope is shown in Figure 4 below:
Depending on the type of oil used, the emulsion can have different colors. In some instances, a dye may also be added. Examples of emulsion products are shown in Appendix A.

The emulsion is sensitized by voids, which can either be gaseous such as nitrogen gas, or enclosed voids such as glass or plastic microballoons. The generation of nitrogen gas into the emulsion typically takes place as the emulsion is being pumped into the bore-hole. The gassing agent commonly used is sodium nitrite, and this is metered and mixed with the emulsion as it goes into the bore-hole. If the emulsion is to be sensitized by microballoons, these are mixed in at the plant, in most instances. The microballoons can also be added while the emulsion is pumped into the bore-hole, but this is not common practice – the bulk density of the microballoons is very low and a large volume container is required to transport them.

Depending on the application, the emulsion may be ‘doped’ with AN prill. The AN bulk products cover the range of ANFO, straight emulsion, and blends of the two products.
B. Manufacture of Watergels

A watergel is a viscous gelatinous aqueous solution. It consists of oxidizing salts, nitrate salts of organic amines and fuels dissolved or dispersed in a continuous liquid phase. In contrast to an emulsion which has two liquid phases, watergels generally have a liquid and a solid phase. A relatively large amount of oxidizer surrounds a relatively small amount of fuel. The continuous liquid phase of the watergel is usually thickened by guar gum or other long chain organic polymers.

Manufacturing Process for gels:

![Schematic of watergel manufacturing process]

**Process Description:**

A schematic of the watergel manufacturing process is shown above.

The Ammonium nitrate solution and hexamine nitrate solution or monomethylamine nitrate solution are pumped into a mixer and blended together with dry AN, a thickener and liquid fuel. The most commonly used mixer is a ribbon blender.

The rheology of a typical pourable watergel is shown in the adjoining image.

Examples of watergels are shown in Appendix B.

Most common final watergel products are blends of the watergel matrix and AN or ANFO. These are manufactured at a fixed plant or in a mobile bulk truck. Fixed plants manufacture blends for packaged products, however, the most common method of making blends is in mobile bulk trucks on the blast site. This product is directly loaded into boreholes. The final product can be sensitized with solid microspheres, chemical gassing or by the introduction of porous AN prill.

For bulk products, the watergel matrix is transported in bulk tankers to a mine site or quarry where it is offloaded into a silo or a mobile bulk truck. On a mobile bulk truck, a calibrated amount of watergel matrix and AN or ANFO is blended together in a mixing auger. The blended mixture is discharged from the auger into a borehole. If the holes contain water, the ratio of the watergel matrix is increased and the product is pumped. The final product is then delivered through the hose to the bottom of the hole.
Usually, pumped product is chemically gassed for desired density and crosslinked to increase the water resistance of the product. A gassing additive and crosslinking agent can be added at the pump or at the end of the hose. In some cases, a straight watergel matrix is chemically gassed, crosslinked and pumped into a borehole.
Appendix A: Images of AN Emulsions

Figure A1. Emulsion as manufactured

Figure A2. Emulsion as manufactured
Figure A3. Emulsion with pink coloration

Figure A4. Emulsion made with recycled oil
Appendix B: Images of Watergels

Figure B1: Watergel matrix Type “a”

Figure B2: Watergel matrix Type “b”

Figure B3: Watergel final product cross-linked

Figure B4: Watergel final product 70/30 blend

Figure B5: Final watergel product 70/30 (gel:prill) blend
Appendix C: Images of Emulsion and Watergel Loading in the Field

Figure C1: Final Product (Left) and Truck loading a hole with a Watergel/ANFO blend

Final product is manufactured at the borehole on mobile bulk truck. Watergel Matrix and ANFO are blended in a truck auger, chemically gassed to reduce density and crosslinked as pumped into the borehole.

Figure C2: Final Product being loaded into a Borehole from a Truck
Appendix D: AN solution

Figure D1. Road Transport Vehicle for AN Solution (Shipped as UN2426)

Figure D2: Truck carrying 85% AN solution (UN2426)
References:

- ATF Regulations, 27 CFR Part 555
- UN Model Regulations on the Transport of Dangerous Goods (https://phmsa.dot.gov/portal/site/PHMSA/menuitem.6f23687cf7b00b0f22e4c6962d9c8789/?vgnextoid=7e0e77cccd658110VgnVCM1000009ed07898RCRD)

Institute of Makers of Explosives
1212 New York Ave., NW, Ste. 650
Washington, D.C.  20005
202.429.9280
www.ime.org