Detonation Characteristics of Ammonium Nitrate Products

Results of the 2005 EFMA study

TNO | Knowledge for business

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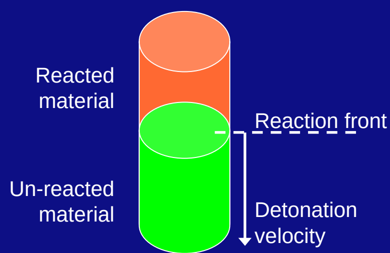
Detonation properties of ammonium nitrate

- Many materials have explosive properties, AN is one of these materials. However;
  - AN is able to detonate under extreme conditions,
  - Is produced and stored in large quantities, and,
  - Is easily obtainable in large amounts

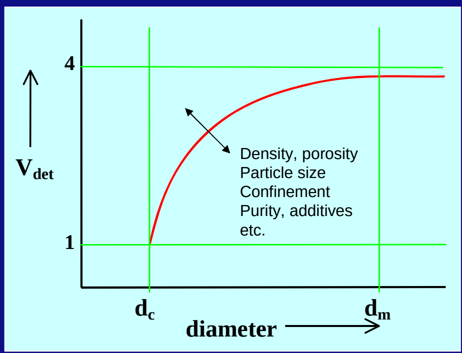
Definition of a detonation

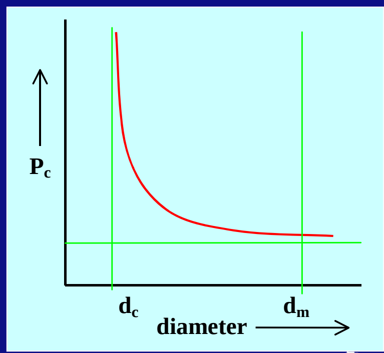
- Heterogeneous chemical reaction in which the reaction is sustained by adiabatic compression (shock) in the front
- Shock and reaction front proceed through the material with a velocity higher than sound (1 - 10 km/s)
- Very high pressures (10-400 kbars), damage at large distance
- Effects are mainly determined by the shock wave
- *Most "industrial" explosive materials have a wide "non-ideal" range in which the detonation properties depend on many parameters*



Non-ideal behaviour of ammonium nitrate

- AN behaves as a non-ideal explosive in a wide range of conditions
- The non-ideal behaviour is caused by
  - The “low” decomposition rate of AN (→wide reaction zone)
  - Lateral heat losses and rarefraction waves which extinguish the reaction

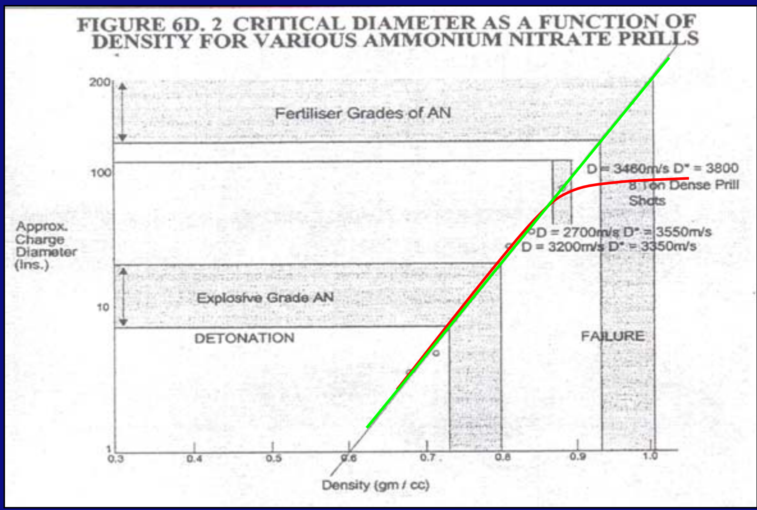




Detonative properties of AN

- Detonation properties depend on
  - Ammonium nitrate concentration
  - Combustible substances, coating
  - Water, sulphate content, pHwr
  - Void volume, bulk density
  - Oil retention, size fraction
  - Hardness
- For “pure” ammonium nitrate
  - Only the void volume and bulk density appear to show a clear and undisputed correlation with detonative properties
  - Hardness and resistance towards thermal cycling is important as well
  - Other parameters affect the result but do not show a consistent (sometimes even a contradiction) influence
- No systematic study on the effect of filler material on the detonative properties is described in literature

Bauer's work, critical diameter as a function of density



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What does the non-ideal behaviour mean in practice?

- A detonation can not be sustained below the critical diameter. In addition, the sensitivity reduces as the diameter approaches the critical value.
- Whether or not a detonation occurs under given test conditions depends on the characteristics of the AN, the imposed conditions and the initiation strength.
- *A "negative" test result does not necessarily mean that the material can not detonate! How to use this in practice?*
- *Safety of the given material is strongly determined by the "sensitivity" (critical diameter and initiation pressure). The detonation effect is bad anyhow…*

8 April 2006

The 2005 EFMA study
Main objectives

- To determine the order of magnitude of the critical diameter of some typical types of ammonium nitrate and ammonium nitrate based fertilisers
  - Validation of previous work on large scale detonation testing done at Queens University in Canada during the 1980's (Prof. Bauer & al)
  - Relates to both safety and security issues
  - Important parameter to assess detonation risk
- To determine the detonation properties and to assess the influence of product specifications on these properties
  - Initiation sensitivity and blast effect (TNT equivalence)
  - Validation of parameters used in advanced detonation simulation modelling
- To develop further guidelines for safe storage of AN-products
  - Critical storage volumes and separation distances
  - Separation distances for TGAN and FGAN/CAN

Test materials

- Four principle test materials (all granules)
  - Fertiliser grade ammonium nitrate, density of 0.92 g/cm³
  - Fertiliser grade ammonium nitrate, density of 0.97 g/cm³
  - CAN-27 (with dolomite without stabiliser)
  - AN and gypsum (AN + gypsum, 27% N)
- Product quality standard in accordance with EU requirements
- Technical grade ammonium nitrate (TGAN) as reference material

The experiments in this project were designed to determine the detonation properties of the various materials. For this reason, optimal test configurations and severe boosters were used.

Overview of the work in the project

1. Material selection and characterisation
2. Small scale testing (EC, denting, miniautoclave)
3. Medium scale detonation testing in tubes (up to 4 tons)
4. Sensitivity testing by full scale gap tests
5. Large scale detonation testing (28 tons)
6. Determination and evaluation of TNT equivalence
7. Modeling and simulation

11 April 2006

Material characterisation and small scale testing

- All test materials are fully characterised in terms of chemical and physical properties
  - Density (bulk, tapped, loose)
  - Particle size and distribution
  - Composition, including chloride and moisture
  - Effect of ageing on density
- Small scale detonation tests
  - EC detonation test (4” steel tube test)
    - With and without thermal cycling
    - Including an evaluation of records
  - Denting test
- Small scale thermal stability by miniautoclave testing to determine the stability, phase transitions, melting point and high temperature reactivity

12 April 2006

Findings from the small scale detonation tests

- All the fertiliser type of materials (thermal cycled and non-cycled) passed the test
- The thermal cycled materials showed more response to the imposed shock wave than the non-thermal cycled material, except for AN + gypsum.
  For AN + gypsum the results for the cycled and non-cycled material were about the same

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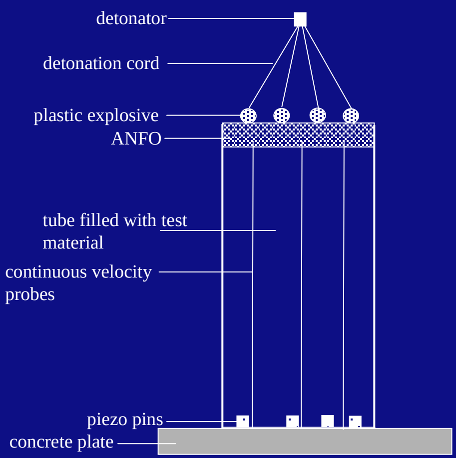
Medium scale testing



- *Purpose: to determine the critical diameter, detonation velocity and the explosion effect*
- Test material: 30 kg - 4 tons
- ANFO booster (initiated by HE)
  Booster configuration verified by computer simulations
- Velocity probes and ionisations pins to measure detonation
- Free field blast measured in two directions (angle of 90°)
- High speed video recording (6000 fps and 20000 fps)

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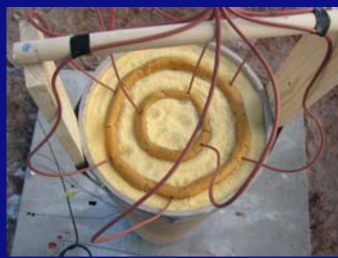
Test set-up





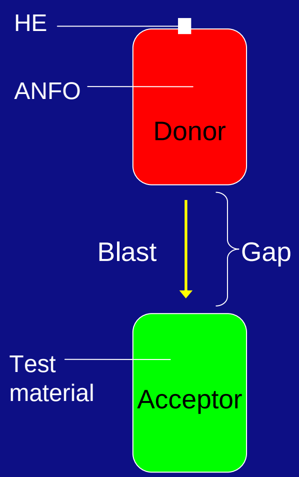

- Example of a test in which no detonation of the test material occurred.
- The explosion effect is due to the booster

Findings of the medium scale tests

- The test results with AN confirm Bauer's work; the critical diameter increases with density. However
  - Lower critical diameters were found than in Bauer's work
  - The variation of the critical diameter with density is less
- Non-ideal effect clearly observed with increasing density
- CAN and AN with gypsum showed similar behaviour. No detonation occurred in the materials.
  - The materials do contribute to the blast of the booster
- The tests in which a detonation occurred showed a TNT_{eq} of 40 - 50 %
  - Ideal configuration
  - Severe booster (overdriven detonation)

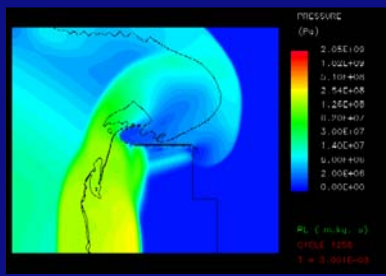
Gap tests (initiation sensitivity)

- Test to determine the initiation sensitivity
- Donor – acceptor principle
- Test design based on results of the medium scale tests
- ANFO donor (initiated at the far end of the acceptor
- The detonation velocity is measured with continuous velocity probes and ionisation pins
- High speed video recording
- The tests were performed with TGAN and FGAN(0.92)



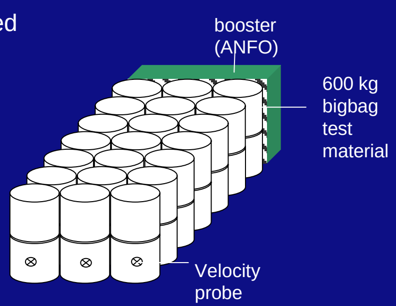
Findings

- Critical gap length (from the tests)
  - TGAN in between 3.5 and 4.5 m
  - FGAN in between 35 and 75 cm
- The results show that FGAN is very insensitive compared with TGAN
- The values determined in the tests can not be used directly for practical situations!
- From further simulations a critical separation distance between stacks of FGAN of 0.1-0.7 m was found



Full scale test

- Purpose: To validate the medium scale results and to assess large scale behaviour
- Tests performed with CAN and FGAN(0.92)
- Approximately 28 tons of test material. Severe and optimised booster (ANFO).
- The holes in between the bigbags are filled with material to simulate a bulk (simulation of bulk storage, worst case)
- Detonation velocity is measures at three places in the bottom row of bigbags over a length of 6 meters
- Blast is measured in 2 directions: Perpendicular and parallel to the row
- High speed video recordings



Findings full scale tests

- CAN
  - No propagation of detonation. Hence, the critical diameter is very large or the material has no detonative properties
  - Significant contribution to blast effect of the booster
- FGAN (0.92)
  - Propagation of detonation (as expected)
  - A TNT equivalence of 25 to 30 % was determined

Summarised results and discussion (1)
Detonation properties

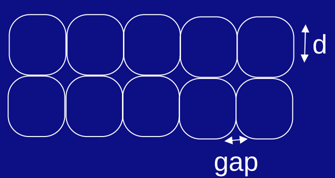
- To achieve a detonation in FGAN, large boosters and close to ideal conditions are required. The critical diameter increases with density
- FGAN is very insensitive towards initiation. Relatively small separation distances are sufficient to prevent sympathetic detonations.
- The results on CAN and AN+gypsum show that the critical diameter significantly increases with an decreasing nitrogen concentration
  - No detonation in tests
  - Contribution to blast of the booster

Summarised results and discussion (2)
TNT equivalence

- The medium scale tests in which a detonation occurred showed a TNT_{eq} of 40 - 50 %
- The full scale test with FGAN(0.92) showed a TNT_{eq} of 25 -30%
- The difference in findings on both scales can be attributed to:
  - Difference in configuration
  - Amount of booster compared to test material (overdriven det.)
  - Blast measurements (distance at which blast is measured)
- Major accidents indicate 10-20%
  - Non-ideal situation in accidents
- For FGAN, in line with the TNTeq observed in incidents, a value in the range of 10-20% seems appropriate for practical situations

Summarised results and discussion (3)
"Passive" safety

- The full scale test was arranged to simulate a bulk storage
- The propagation of a detonation can be more difficult when an air gap is present between the bigbags in a stack (low sensitivity, bag diameter<<critical diameter)
- Hence, passive safety (no propagation) can be obtained provided that the proper size of bigbags is chosen in relation to the detonation properties of the AN material.



Some final remarks…..

- The results relate to the materials as manufactured
- An assessment of safety and security issues has to include aspects such as
  - Contamination
  - Aging
  - Behaviour in fire
  - Misuse
  - Etc.
- *Safety of AN or AN based materials (with respect to the detonation hazard) is not an absolute property!*
- *Conclusions of the study are expected by beginning 2006 and will be communicated in industry storage guidelines (via EFMA)*