

NC Technical Summary

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University of Wales Trinity Saint David

Ordnance, Munitions and Explosives



Advanced Chemistry of OME - ACDA6020

***Additives in Nitrocellulose-Based Gun
Propellants: Performance, Chemical Stability,
and the Environment***

Presentation Summary

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Date – 01/2026

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1. Introduction

A presentation on 'Additives in Nitrocellulose-Based Gun Propellants: Performance, Chemical Stability, and the Environment' was delivered to a cohort of Ordnance, Munitions and Explosives' students. Its purpose was to provide insight into how additives can be used to control propellant behaviour depending on the required performance and to discuss the harmful effect these additives have on the environment. This summary will provide a brief introduction to gun propellants before focusing on stabilisers and burn rate modifiers.

1.1. Gun propellants

Propellants are chemical substances which convert chemical energy into kinetic energy in order to launch a projectile from a barrel. They are found in small arms through to rocket motors, however, the focus of the presentation was medium calibre barrelled weapons - 20-155mm in diameter, found on aircraft, tanks, ships and self-propelled guns – an example is shown in Figure 1.

Gun propellants burn faster than rocket propellants but slower than small arms. Its geometry – such as multi-perforation grains allows for progressive burning, unlike the rapid burn in small arms. Propellant burn is a surface effect, therefore the surface area, and any chemical on the burning surface, have a significant effect on the burn rate.



Figure 1 Medium calibre barrelled weapon – personal photograph taken in Alvdalen, Sweden.

1.2. Nitrocellulose-based propellants

Nitrocellulose (NC) based propellants are generally classified into three types: single base, double base and triple base. Table 1 shows how each composition provides different performance characteristics and how they are predominantly utilised.

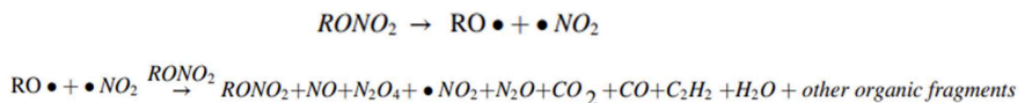
Table 1 General use and performance characteristics of NC based propellants [1][2]

NC based propellant	Composition	Use	Energy level comparison	Flame temperature comparison
Single base	Nitrocellulose	Small arms	Lowest	Lowest
		Some artillery systems		
Double base	Nitrocellulose and Nitroglycerin	Small arms	Highest	Highest
		Some cannons		
		Some artillery systems		
Triple base	Nitrocellulose, Nitroglycerin and Nitroguanidine	Artillery systems	Intermediate	Intermediate
		Navel systems		
		Rocket propellant		

Gun propellants, including nitrocellulose-based, contain a mixture of additives at varying quantities based on the required performance. As nitrocellulose naturally decomposes readily due to its weak nitrate ester bonds, there is a need to control its degradation as well as its performance. For this, additives must be used. Stabilisers improve the mechanical properties of the propellant, controlling the autocatalytic degradation reaction, and burn rate modifiers are used to produce the desired burn rate throughout the use of the propellant [3].

2. Stabilisers

Nitrocellulose decomposition is an exothermic reaction that produces reactive nitrogen oxides (NO and NO₂) and nitrous acid (^{HNO2}HNO₃), water, and free radicals which all accelerate its natural decomposition leading to autocatalytic degradation through thermolysis and hydrolysis reactions if not controlled [4]. The thermolysis reaction is shown in Equation 1 where R is CH₂.



Equation 1 Thermolysis reaction for the decomposition of nitrocellulose [5]

Additionally, research has shown that the activation energy of nitrocellulose decreases naturally as it ages, making it easier to initiate [6][7]. These factors highlight the importance of controlling the decomposition process through the use of stabilisers to enhance propellant thermal stability and prolong its shelf life.

Common stabilisers include:

- Diphenylamine (DPA) C₆H₅NHC₆H₅
- ACARDITE II C₁₄H₁₄N₂O
- Ethyl Centralite C₁₇H₂₀N₂O
- Methyl Centralite C₁₅H₁₆N₂O

Stabilisers, such as DPA – shown in Figure 2, slow down the degradation process by eliminating nitric and nitrous oxides or by removing moisture from the system [8], [9]. This prevents the formation of the autocatalytic reaction and while it is not possible to completely stop the reaction, the addition of stabilisers can increase shelf life from days to years [10], [11]. However, in doing so, hazardous compounds such as N-nitrosamines are produced. These are known to be highly carcinogenic, mutagenic and reprotoxic, as noted by Stucki [12] in 2004 and Rodrigues [13] in 2020.

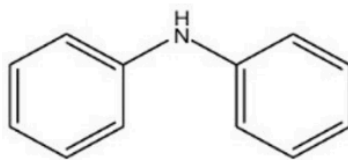


Figure 2 Chemical Structure of DPA [10]

2.1. Environmental Impact

As noted above, conventional stabilisers are harmful to people and the environment when they react. Research is ongoing into alternative green stabilisers that are less harmful and safer for both people and the environment. These include guaiacol, polymers, and natural source stabilisers [13] [14]. Green alternatives must provide the same performance as traditional propellants but have better biodegradability and lower toxicity levels.

3. Burn Rate Modifiers

Burn rate modifiers alter the natural combustion rate of the propellant grain. By regulating this reaction, the volume of gas produced is controlled and therefore the pressure within the chamber of the barrel is predictable. This allows the desired performance to be achieved whilst staying within safe pressure limits, helping to balance safety and performance [2].

Examples of burn rate modifiers include:

- Copper salicylate
- Lead 2,4-dihydroxybenzoate
- Lead salicylate
- Lead stearate
- RDX
- Oxamide
- Nanoparticles (e.g. iron oxide)

Figure 3 illustrates three possible burning effects generated by burn rate modifiers. Initially, at lower pressures, the reaction is catalysed considerably during super-rate burning. This transitions into plateau burning where the burn rate becomes less sensitive to pressure changes and levels off as the catalytic effect of the modifier diminishes, helping to stabilise chamber pressure. Then during mesa burning, the burn rate decreases as pressure increases, subsequently returning to a rate seen in a non-catalysed propellant [15] [16]. Keeping the burn rate in the desired effect provides improved combustion and pressure control.

Lead stearate is a common burn rate modifier that not only regulates the burn rate but can also reduce propellant sensitivity to pressure changes by introducing lead oxides into the propellant. These subsequently act as catalysts, reacting with nitrate esters in the nitrocellulose to reduce the activation energy of the propellant and accelerating decomposition at the burning surface [16].

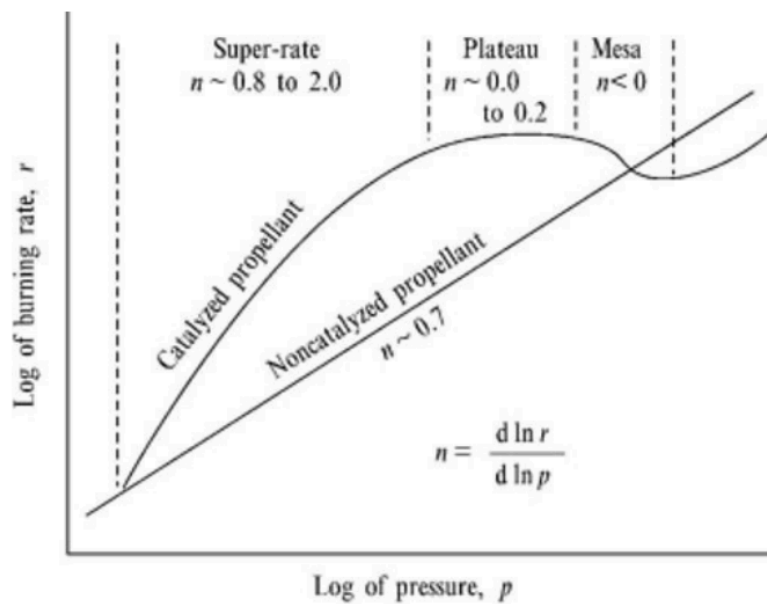


Figure 3 Propellant burn rate modification [15]

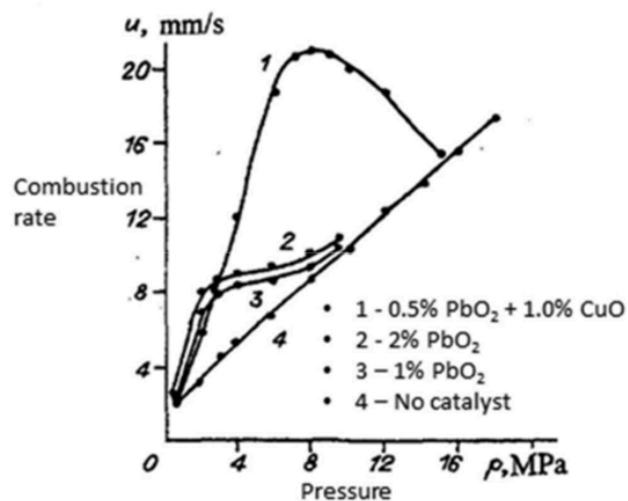


Figure 4 Catalysed and non-catalysed burning rate [15]

Figure 4 demonstrates the increase in initial combustion rate at lower pressures in the catalysed reactions, compared with the linear progression of the reaction in the non-catalysed reaction. The catalysed reaction slows to the rate of the non-catalysed reaction after the catalytic effect diminishes. The legend (1-4) indicates the catalyst used.

3.1. Environmental Impact

Lead is well known for being incredibly toxic to the human body and damaging to the ecosystem [17]. It bioaccumulates in the soil and water remaining there for many years, potentially entering the food chain. Due to its toxicity, its use is now restricted in favour of more environmentally friendly options under an European Union regulation - the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) [18] [19]. As with the stabilisers, green alternatives must provide the same or better performance as traditional burn rate modifiers and this can be difficult to achieve [20].

4. Conclusion

The presentation covered the intended topics of nitrocellulose-based stabilisers and burn rate modifiers providing an overview in both areas. The allocated time was limited and with an opportunity to present for longer, additional technical detail could be presented.

A single question was asked at the end of the presentation, this is covered in Appendix 1.

5. References

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6. Appendix 1

In the questions and answers session at the end of the presentation, a question was asked about the use of DPA stabilisers in all nitrocellulose-based propellants - is it compatible?

The following answer was given:

DPA can be used in all nitrocellulose-based propellants, but it is better suited to use in single base propellants. In double and triple base propellants DPA tends to react with nitroglycerine, which can lead to instability. It would be better to use other stabilisers such as Acardite in double or triple based propellants [10].

NC Technical Summary

GRADEMARK REPORT

FINAL GRADE

84/100

GENERAL COMMENTS

Engagement with Literature 13/15

You demonstrate excellent engagement with relevant, credible, and up-to-date literature. The technical summary draws on an extensive range of peer-reviewed journal articles, alongside well-chosen seminal works and regulatory/governmental sources. Claims are consistently supported by citations, and IEEE referencing is applied appropriately.

The presentation included visible references and links to sources, which supports the credibility of the material presented. In a small number of cases, images or statements on slides would have benefited from clearer attribution.

Strengths:

Wide use of current (2020–2025) peer-reviewed literature

Clear evidence of independent reading

Good integration of regulatory and environmental sources

To improve

Ensure all figures and slide content are explicitly referenced

Make links between individual claims and sources more explicit in slides

Knowledge and Understanding 17.5/20

You demonstrate a clear, accurate, and L6-appropriate understanding of NC-based propellants and the role of additives. Key concepts are explained correctly, including NC thermolysis, autocatalytic degradation, stabiliser depletion, ageing effects, and burn-rate modification.

The chemistry is consistently linked to real OME contexts, including manufacture, storage, ageing, safety, and environmental impact. The written work, in particular, goes well beyond textbook description and shows genuine understanding.

Strengths

.

Accurate explanation of degradation and stabilisation mechanisms

.

Correct use of chemical terminology, equations, and figures

.

Clear relevance to OME systems and lifecycle considerations

To improve: Develop thermodynamic and kinetic reasoning in greater detail where relevant

Cognitive and Intellectual Skills 19/25

There is clear evidence of analytical thinking, particularly in your discussion of why stabilisers are required, how ageing affects performance, and the trade-offs involved in replacing traditional additives with greener alternatives. You effectively link degradation chemistry, performance requirements, and regulatory pressures.

The analysis is strongest in the written summary. In the presentation, some points remain implicit rather than explicitly argued, and comparison between alternative stabilisers or burn-

rate modifiers could be more clearly developed.

Strengths

.

Clear “why, how, and so what” reasoning in the written work

.

Good synthesis of performance, safety, and environmental considerations

.

Awareness of limitations and trade-offs

To improve

.

Make comparisons between alternative materials or approaches more explicit

.

State conclusions more clearly during oral delivery

Practical Application Skills 20.5/25

Your work shows excellent application of chemistry to real OME systems. You demonstrate strong awareness of ageing, shelf-life management, stabiliser depletion risks, burn-rate control, and regulatory constraints such as REACH. The stabiliser depletion example is particularly effective in showing applied understanding.

While application is strong, most discussion remains qualitative rather than quantitative.

Strengths

.

Strong grounding in real OME problems

.

Good use of figures, diagrams, and realistic scenarios

.
Clear awareness of
industrial and regulatory constraints

To improve: Where possible, include diagnostic
thresholds or
quantitative indicators (e.g. stabiliser limits, DSC
trends)

Transferable and Professional Skills 14/15

Communication is clear, confident, and professional.
The
presentation shows good structure, time
management, and delivery under
pressure. The technical summary is well written,
logically organised, and
presented to a professional standard consistent with
technical reporting in
defence or engineering contexts.

A small number of presentational issues (e.g. slight
word-count exceedance) limited the maximum marks
achievable here.

Strengths:

.
Clear and fluent scientific
writing

.
Professional structure and
formatting

.
Strong sense of individual
responsibility and ownership

To improve: Keep within stated word limits

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