Increased impulse of solventless extruded double base rocket propellant by addition of high explosives RDX and FOX-7.

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1- BACKGROUND

At Björkborn in Karlskoga propellants have been manufactured for more than a century. Thanks to Alfred Nobel's work in nitroglycerine it all started with double base formulations. Over the years several compositions have been developed and we have now passed 1400 serial production recipes.

An area of propellant manufacturing is the extruded solventless double base rocket propellants. These are smokeless propellant grains mainly used in short range systems like shoulder-launched systems, unguided rockets and surface-to-air missiles and rockets. These are propellants with ballistic modifiers which alter the burning characteristics of the propellant, the goal is to have a low pressure exponent around the design pressure of a system. This paper describes work done in the area of broadening the performance and possibilities of using high explosives in rocket propellant formulations to increase the specific impulse.

2- OBJECTIVE

This project's objective was to investigate if increasing the specific impulse in double base propellants by adding high explosives affects other apparent parameters of the propellant. The high explosives evaluated in the project is precipitated FOX-7 with an average crystal size of around 12 microns and RDX with an average crystal size of around 6 microns.

The experimental plan consisted of six tests described in the table below.

	RDX (NSH873)	FOX-7 (about 10 µm)	Specific Impulse (Ns/kg) Expansion 70 to 1 bar
Test nr 1	0	0	2326
Test nr 2	5	0	2335
Test nr 3	10	0	2344
Test nr 4	15	0	2352
Test nr 5	0	5	2335
Test nr 6	0	15	2352

The specific impulse is calculated from internal thermochemical codes. Since each gram of FOX-7 and RDX contains the same molecules the theoretical specific impulse is the same.

3- PREPARATION OF HIGH EXPLOSIVES

This segment describes the manufacturing techniques which Eurenco Bofors has developed for producing small size RDX and FOX-7 products.

3.1- RDX

The RDX crystals of propellant grade are produced in the standard RDX plant at Eurenco Bofors. The process consists of first producing normal hexogen in the plant. This hexogen together with some NC and additives is dissolved and precipitated through an ejector based process to produce the small size particles. A representative particle size distribution is found in Figure 1. The additives facilitates the incorporation into the propellant formulation. The same method is used to produce the raw material for Eurenco Bofors LOVA-propellant production.

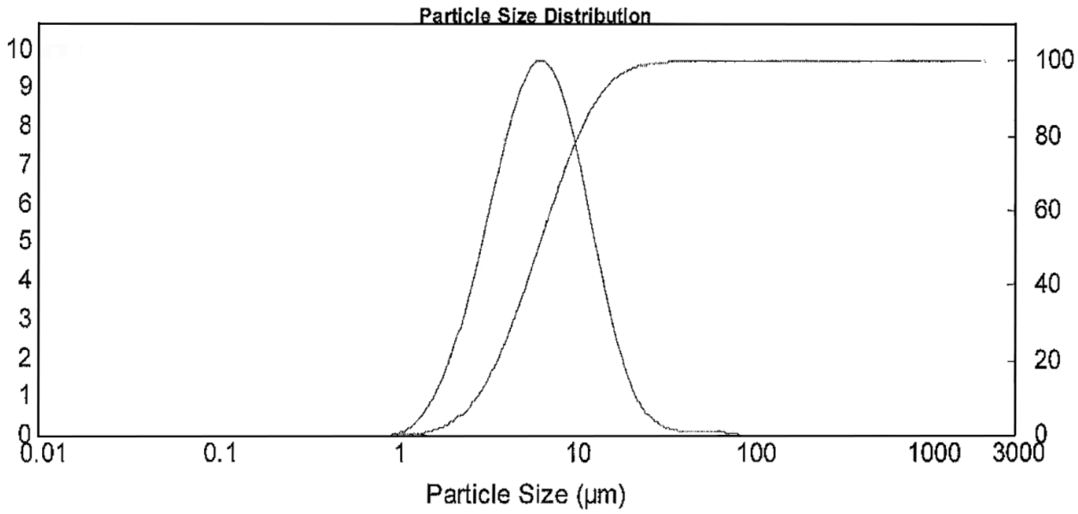

Figure 1 Particle size distribution of RDX, NSH873

3.2- FOX-7

Normal production process has been used to produce FOX7. It has been optimized to produce smaller crystals than normal. Smaller crystals are formed by adapting the process streams in the solvent/ non-solvent process. The main target is to achieve a faster feeding rate in the process. The particle distribution of the batch used is shown in Figure 2. There are several different qualities of FOX-7 in Eurenco's portfolio today, from 30 microns up to 300 microns, the quality now developed has an average particle size of 12 microns. SEM photos from the precipitated "raw" FOX-7 and the re-crystallized new quality is shown in Figure 3 and Figure 4 respectively.

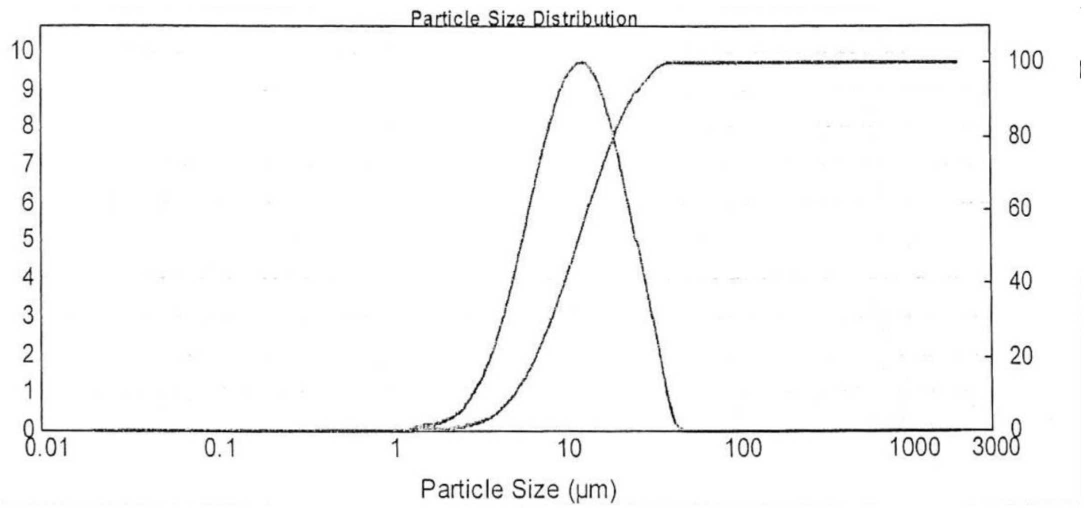

Figure 2 Particle size distribution of the FOX-7 batch used

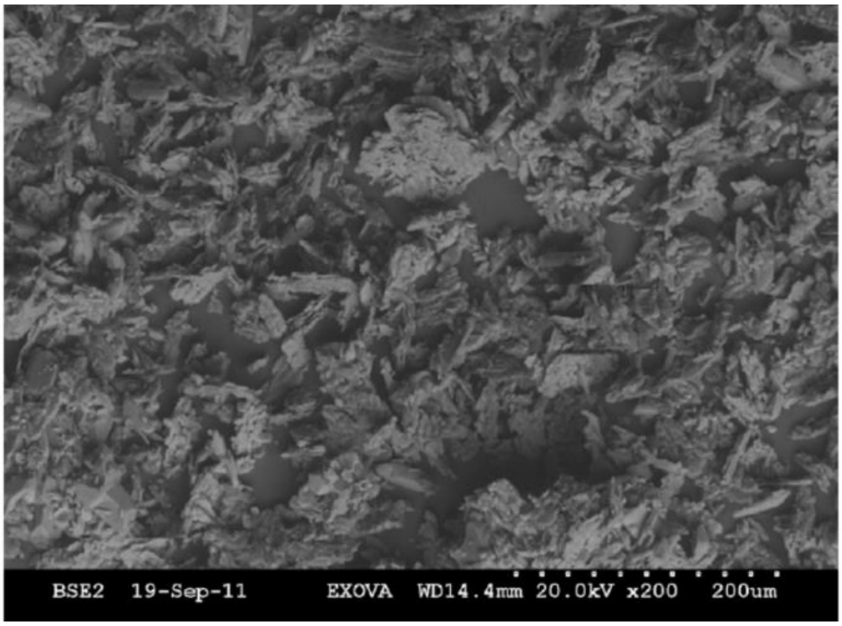

Figure 3 SEM photo of “raw” FOX-7 before re-crystallization.

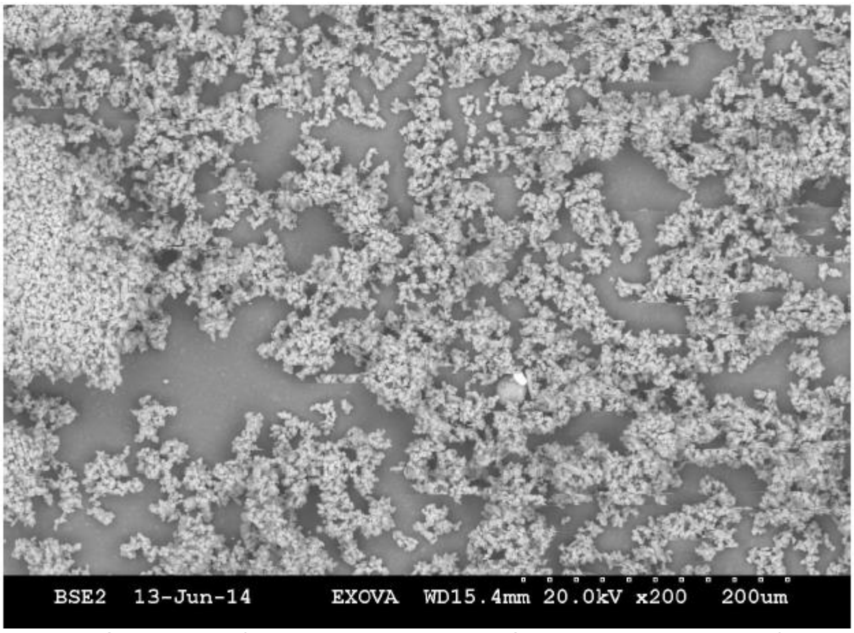

Figure 4 SEM photo of new small crystal size FOX-7 quality, 200x magnification

4- <u>METHODOLOGY</u>

This segment describes the ballistic analysis method and the way the propellant grains were prepared.

4.1- Production process

The production process used at Eurenco Bofors for producing extruded double base propellants is a solventless process described in the flow chart in Figure 5. In the current study the same operations were used but on a smaller scale. A homogenous mix of 100 kg without high explosives was prepared. This minimizes the variation in composition between the different tests. Up until this mixing step the process used is on full production scale.

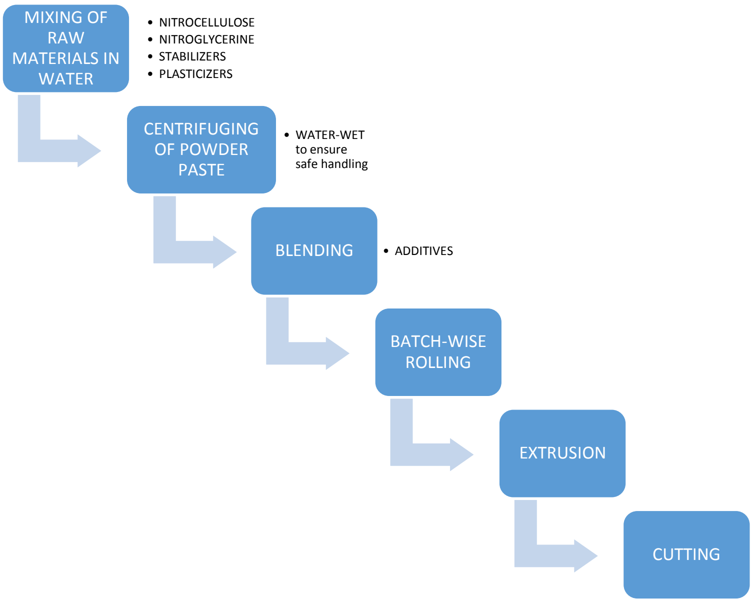

Figure 5 Flow chart of EDB production process

4.2- Composition

The composition which this study has been based upon is a 100% lead-free composition with a high specific impulse over 2300 Ns/kg. For an EDB rocket propellant this is in the upper regions of what can be achieved. This is obtained by having a relatively low additive and plasticizer content, 4.5% and 2% respectively.

The amount of additives in form of ballistic modifiers and processing aids were constant in all experiments. This has been achieved by using two different pre-mixes, with and without additives. 85% of the mix with additives has been used in all experiments.

Figure 6 Paste before and after final step of mixing. Pre-mix with additives (black), pre-mix without additives (white) and FOX-7 (yellow).

4.3- Propellant grains for experiment

A second blending step is required in order to thoroughly mix in the high explosives with the pre-mixed propellant paste. The second blending step is normally not performed in standard production. This final blending is performed in a 10-kg Z-blade mixer, see Figure 6.

The mixed paste is then rolled on differential rollers into a propellant carpet. The rolling is a process where the propellant paste is gelatinized into a plastic-rubber like material. This carpet is rolled into a carpet roll of a suitable diameter for the extrusion.

Figure 7 Photo from the rolling process at Eurenco Bofors.

The final processing step is to extrude the propellant. The carpet rolls are extruded in a ram press into their final shape as hollow cylinders with an outer diameter of 30 mm and inner diameter of 10 mm. They are cut into lengths of 100 mm, the weight of each grains is roughly 100 grams. Some of the grains used in this study is shown in Figure 8.

Figure 8 Photo of extruded propellant grains for ballistic testing

4.4- Ballistic analysis

The method used for the investigation is a standard rocket test which has been used in Eurenco Bofors for several years. In this method the burning rate of a composition is evaluated over a range of pressures. The results produced are the same as it would be generated with a Crawford Strand Burner. The design should resemble a rocket motor and has an exchangeable nozzle, the setup has been described more in detail in a previous conference (Tunestål, o.a., 2015).

The mock-up motors and propellant grains are conditioned for at least 12 hours in their respective temperature before firing.

The data output from this setup is a pressure time curve and the dimensions of the propellant grains are measured. The grains are measured manually with a calibrated caliper.

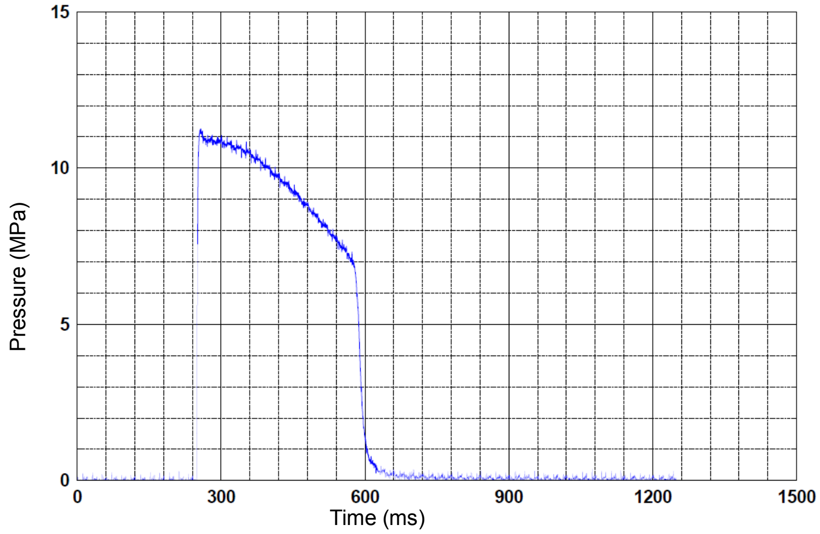

Figure 9 Representative result from a standard rocket firing

From the pressure-time curve and the dimension the burn rate at different pressures can be calculated. The results are normally presented as burn rate as a function of pressure or as a function of the ratio between propellant surface area and nozzle area.

5- RESULTS

This paragraph describes and discusses the results from the ballistic tests. The first part is regarding the base composition and the second and third subparagraphs discusses the RDX and FOX-7 enriched respectively. In this segment terminology from (Kubota, Ohlemiller, Caveny, & Summerfield, 1973) is used. The concept producing the catalytic effect in rocket propellant combustion is called super-rate burning. This occurs when the reaction rate in the fizz zone is increased.

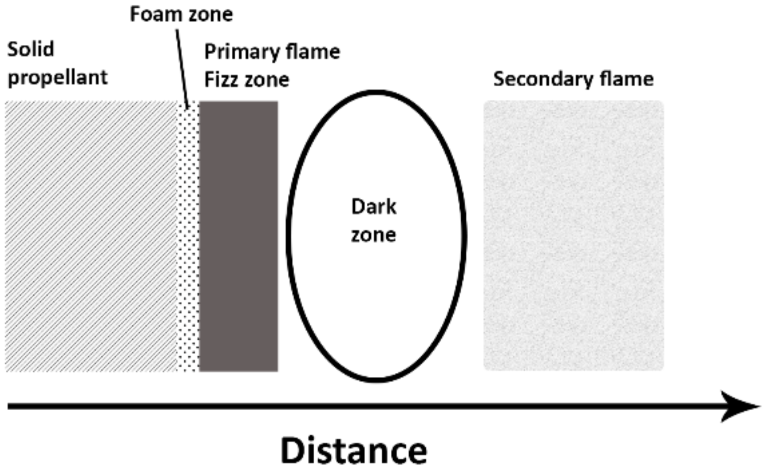

Figure 10 Description of the zones in propellant combustion

5.1- Base composition

The base composition has a relatively low amount of additives and a high energy content. This combination results in a composition which has smaller super-rate burning than what is characterizing an EDB rocket propellant. With an EDB composition you usually have a pressure region where the burn rate is constant (plateau burning) or even negative correlation (mesa burning) (Kubota, Ohlemiller, Caveny, & Summerfield, 1973). Comparing with other lead free compositions this composition shows less super-rate burning, see Figure 12. The same additive mixture used in the current formulation has also been used in another propellant with a lower specific impulse, see Figure 11. In that formulation the specific impulse is around 2170 Ns/kg compared to 2330 Ns/kg for the current and the energy content is 870 cal/g and 1100 cal/g respectively. The composition with a lower energy content generates a very nice super-rate burning and exhibits a plateau and mesa burning between 10 and 20 MPa.

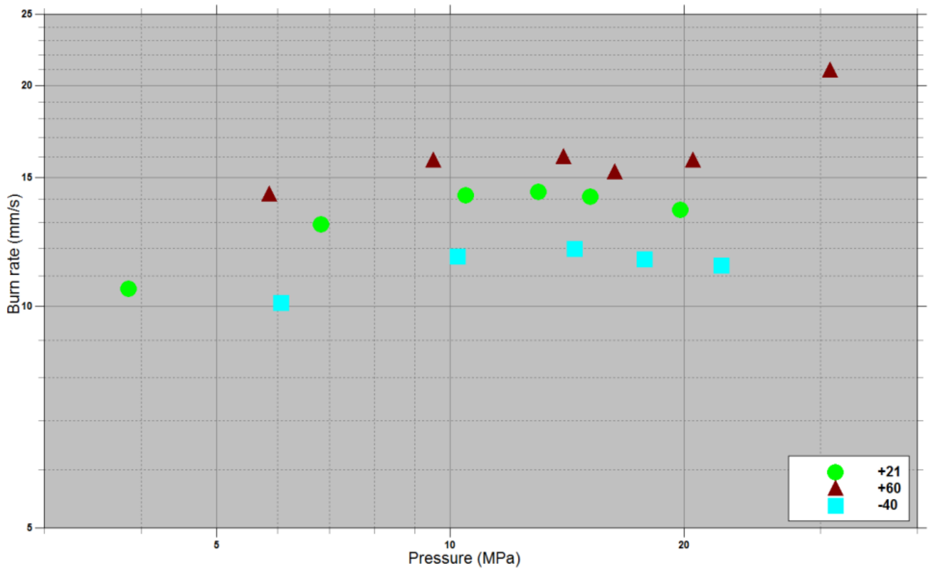

Figure 11 Burn rate results from lead-free propellant composition with 870 cal/g

For the current base composition there is not this pronounced behavior despite using the same mixture of additives. Though a plateau burning can be seen in the firings at -40°C from 12 to 16 MPa. At +21°C the pressure exponent is 0.297 using a curve fit to Vieille's law which is normally used to describe the pressure-burn rate relationship in propulsion technology (Kulkarni & Sharma, 1998).

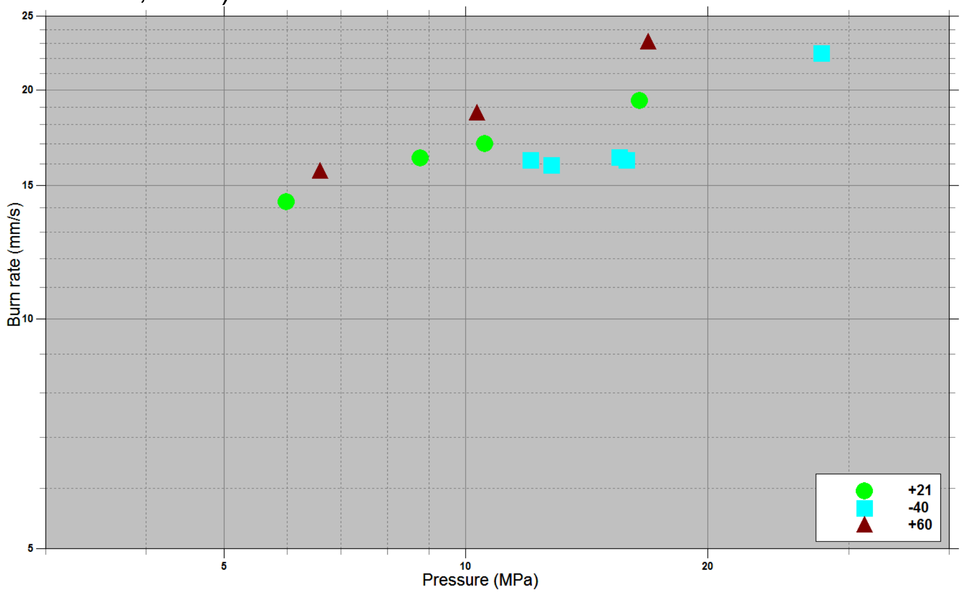

Figure 12 Burn rate results from lead-free propellant composition with 1100 cal/g

5.2- RDX enriched propellant

The addition of RDX into double base gun propellants is known to decrease the burn rate of the propellant. A theory to explain this is that the reaction rate in the fizz zone is decreased, due to becoming fuel rich when RDX is added to the composition (Yano & Gomi, 1986). The reactions in the fizz zone is also believed to be the cause of super-rate burning (Kubota, Ohlemiller, Caveny, & Summerfield, 1973) of catalyzed rocket propellants. In this study the lowered burn rate associated with RDX addition is confirmed also for catalyzed rocket propellants. The burn rate is lowered over the entire pressure region but the pressure exponent remains constant. However the changed reactions in the fizz zone does not affect the super-rate burning. The effect of adding RDX seems to diminish with content. From 0 to 10% RDX-content the burn rate is reduced by 2% per percent of RDX but only 1% per percent of RDX with higher content.

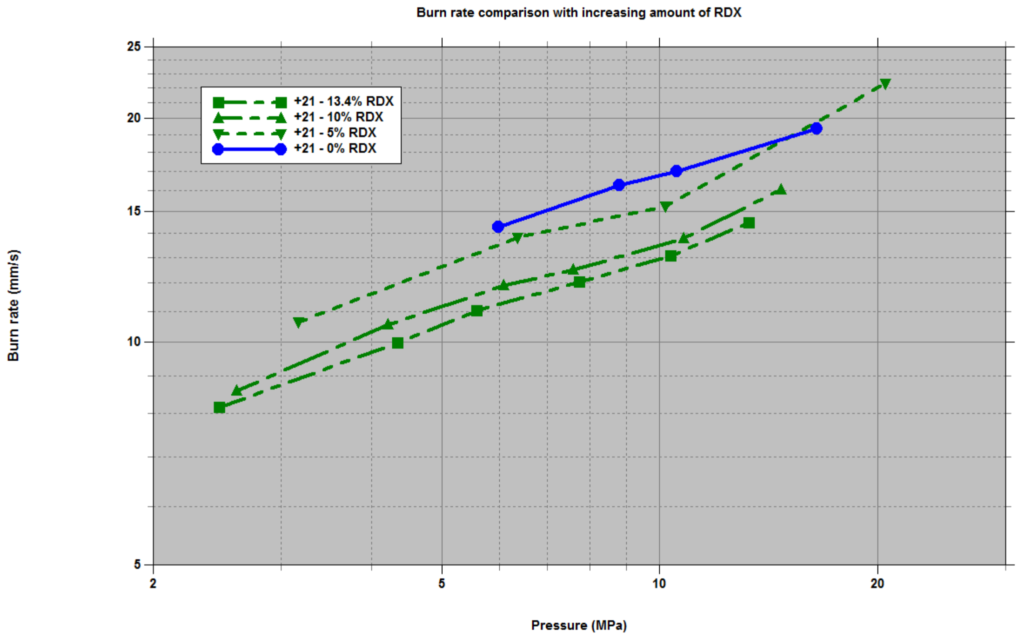

Figure 13 Burn rate with different amount of RDX content

When looking at the pressure exponent the test sample with 13.4% of RDX content has roughly the same slope as the nominal sample. When looking into details the average slope of all points at +21°C has an exponent of 0.330 and there is a pressure range from 5 to 10 MPa where it is a bit lower, 0.277. This should be compared to 0.297 for the entire test range for the nominal composition.

5.3- FOX-7 enriched propellant

No studies investigating burn rate when adding FOX-7 to propellant formulation has been found, but from the similar behavior of the molecules RDX and FOX-7 the hypothesis was that it would also decrease the burn rate. The results however show that the burn rate is not affected by the addition of FOX-7. A slight decrease can be noticed in the results for the 5%-sample but for the 15%-sample there is no difference. The results from the 5%-sample could be explained by experimental deviations.

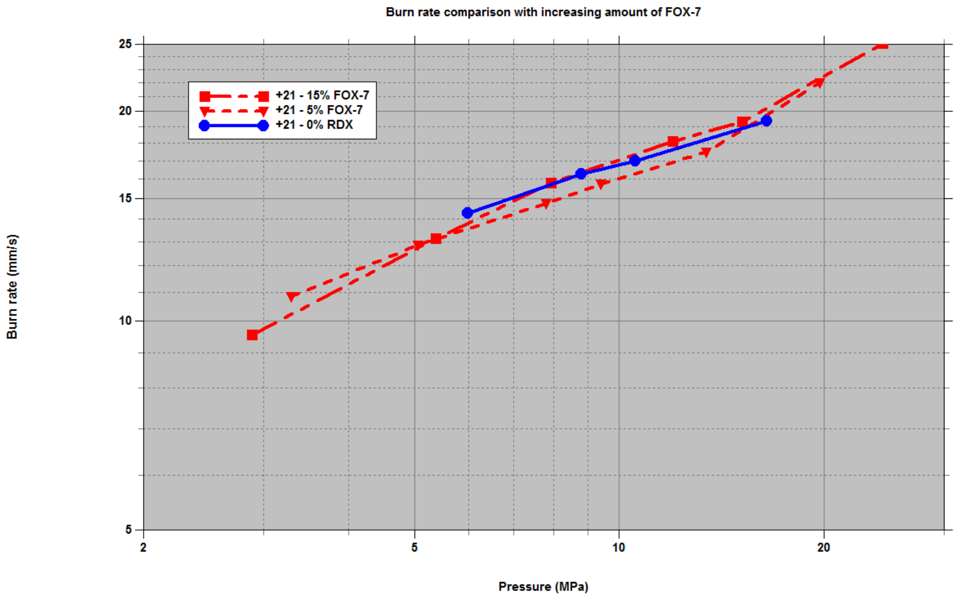

Figure 14 Burn rate with different amount of FOX-7 content

When looking at the pressure exponents for the test samples with FOX-7 there is overall a higher slope over the entire pressure range compared to the nominal, 0.431 compared to 0.297. But the evaluated pressure range is also much wider for the sample with FOX-7. The pressure exponent in the similar pressure region is 0.315 which is very close to the nominal.

6- DISCUSSION AND CONCLUSIONS

The significant difference between the FOX-7 and RDX behavior is not obvious to explain. The contents mentioned are weight-based which means that it is roughly the same amount of carbon, nitrogen, hydrogen and oxygen in the samples. This should result in the fizz zone chemistry remaining the same, the effect which is thought to cause the effect of decreased burn rate for RDX-propellant. The effects seen at +21°C also seems to be true for the samples evaluated at +60°C and -40°C since there is no significant difference in temperature coefficient for the tested samples.

The conclusion from these experiments are that you could indeed add high explosives to a propellant formulation in order to increase the specific impulse. The processing is not affected by the addition. When adding RDX the burn rate is decreased which could be used as a design parameter in order to reduce burn rate and still increase the specific impulse. In contrast FOX-7 does not seem to alter the burn rate which means it could be added to only increase the specific impulse.

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