

Technology development for ADN-based green monopropellant thrusters – an overview of the Rheform project

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Abstract

Goal of the project Rheform is to develop new technologies for propulsion systems that use monopropellants based on ammonium dinitramide (ADN). The aim is to enable the replacement of hydrazine with green propellants so that future systems will be more sustainable and better suited for complex missions. The present work will provide an overview of the project; as well describe the results obtained on catalytic and thermal ignition.

1. Introduction

Since the 1960s the standard monopropellant for spacecraft propulsion systems has been hydrazine. The associated technological heritage is extremely large. On the other hand hydrazine has severe downsides: it is toxic and carcinogenic, thus increasing the complexity of transportation, handling, tanking and testing. The life-cycle-cost of hydrazine propulsion systems is therefore large. New regulations could restrict the use of hydrazine: in 2011 it was included in the candidate list of substances of very high concern by European Union under the Registration Evaluation Authorisation and Restriction of Chemicals (REACH) law.

Research activities are conducted worldwide to develop propellants to replace hydrazine. Liquid propellants based on ammonium dinitramide (ADN, $\text{NH}_4^+ \text{N}(\text{NO}_2)_2^-$) are considered as promising replacements. A first advantage compared to hydrazine is the easier transportation: for example LMP-103S, the ADN based monopropellant with the

highest degree of maturity, can be shipped per air cargo. ADN-based propellants are easier to handle and tank at the launch site: the tanking of LMP-103S required on third of the man-hours associated to the tanking of hydrazine [1]. The easy handling made possible to get approval to handle LMP-103S at different launch sites, so that in 2016 systems based on ADN were launched from 3 different continents. Last but not least ADN-based propellants have higher performances compared to hydrazine: both the specific impulse and the volumetric specific impulse are higher than hydrazine. During the PRISMA mission a direct comparison between a hydrazine thruster and a LMP-103S thruster was conducted: the specific impulse was 6 to 12 % higher and the volumetric 31 % [2].

Some limitations are associated with ADN-based monopropellants propulsion systems. The combustion temperature of LMP-103S is 1630 °C which is much higher than the one for hydrazine, which is around 900 °C. Currently in order to withstand the higher temperatures expensive and ITAR regulated materials have to be used for the chamber wall. A reduction of the combustion temperature would enable the use of the same materials used for hydrazine (platinum alloys) so that the same combustion chamber could be used. The possibility of reducing the combustion temperature by increasing the water content in the propellant has been studied in the project Rheform. The results have been presented in [3]. A second limitation of current ADN-based thrusters is the cold start inability. The catalyst currently used to ignite LMP-103S must be pre-heated to 350 °C. The propellant does not ignite reliably if the catalyst temperature is below this temperature. In contrast hydrazine systems allow cold start, i.e. ignition without preheating. Nevertheless preheating is often used also in hydrazine thrusters in order to extend the life of the catalyst.

2. The Rheform Project

Rheform is a project funded from the European's Union Horizon 2020 programme. The name Rheform stands for: "Replacement of hydrazine for orbital and launcher propulsion systems". The project runs from January 2015 to the end of 2017. The Rheform consortium comprises 9 entities from 4 European countries: Austria, France, Germany and Sweden. Two universities are involved: the University of Poitiers (UP) and the University of Applied Sciences Wiener Neustadt (FHWN). Three research centers are participating to the project: the German Aerospace Center (DLR), the Swedish Defence Research Agency (FOI), and the French National Center for Scientific Research (CNRS). Two small companies are involved: Lithoz and FOTEC. Finally two space companies are participating: ECAPS and Airbus Safran Launcher (ASL).



Figure 1. Rheform partners.

The following main activities are addressed in Rheform:

- Selection of two reference cases. A market analysis was conducted to select the thruster classes with the highest market volume. Based on the analysis two classes: 20 and 200 N were selected. The typical application of the 20 N thrusters is for Attitude and Orbit Control Systems (AOCS) for spacecrafts. The application of the 200 N thrusters is Roll and Attitude Control System (RACS) for launcher and deorbiting.

Based on these applications the requirements on the propulsion system and on the propellant have been defined.

- Variations on existing propellants (LMP-103S and FLP-106): calculation of amounts of water required to obtain combustion temperatures compatible with selected wall materials. . The possibility of reducing the combustion temperature by increasing the water content in the propellant has been studied. The results have been presented in [3]. Experimental characterization of the propellant variations.
- Development and testing of granulated and monolithic catalysts, aiming at reducing the pre-heating temperature.
- Development and testing of thermal igniters.
- Implementation of ignition methods in two thruster demonstrators. Once that the ignition system will be developed, they will be implemented in two thruster demonstrators. This activity will take place in the last year of the project.

The present paper will be focused on catalyst and thermal igniter development.

3. Catalyst development

As mentioned in the introduction, one of the drawbacks of the existing propulsion system based on LMP-103S is the necessity to pre-heat the catalyst to a temperature of 350 °C.

In Rheform new catalysts are considered to try to reduce the pre-heating temperature. Two types of catalyst supports are considered: granulated and monolithic. In the category “granulated supports” different shapes are included: for example spheres, beads, pellets, and extrudates. A significant application of granulated catalysts is hydrazine thrusters. Monolithic supports differ from granulated ones because the support is made of a single, monolithic, structure with channels in which the propellant flows. Typically monoliths are produced via extrusion. Although monoliths are typically used in the automotive industry, also for space applications could be interesting due to better structural stability, more control on the active surface area and lower pressure losses.

3.1 Granulated catalyst development

The first step to develop a granulated catalyst is the selection of a support. Both the geometry and the material of the support influence the behaviour of the catalyst.

Geometry of Granulated Supports

The catalyst used in propulsion applications should be as compact as possible. Therefore the aspect ratio of the granules was fixed at 1.2, as this ratio gives the highest packing density. This was shown in experimental investigations presented by other researchers such as [4].

An important parameter connected with the geometry of the support is the local void fraction, the ratio of the volume of the voids over the total volume of the area considered. This parameter influences the drop losses: areas of the catalyst with high void fraction will have lower pressure drops. This leads to the formation of preferential paths. The distribution of propellant in the catalyst should be as uniform as possible, therefore preferential paths should be minimized, i.e. the local void fraction should remain as uniform as possible across the cat bed.

A completely uniform distribution of the local void fraction is not possible due to the influence of the cat bed wall. The wall has an ordering effect, particularly on the particles close to it. This effect is influenced by the support shape and size. Based on previous theoretical works, a model was implemented to simulate the local void distribution in a cat bed. The results showed that a more uniform distribution of local voids is obtained with cylindrical rather than with spherical particles. The ratio of the diameter of the cat bed to that of the particles plays also an important role. For small values of the diameter ratio the void distribution is not at all uniform with a large area near the wall with lots of voids. The distribution becomes more uniform increasing the diameter ratio. Above a diameter ratio of 8 the changes in the distribution become marginal.

The diameter ratio plays influences also the mean void fraction of the complete catalyst bed. Small values of the ratio will lead to large mean void fractions. On the other hand, for cylindrical granules, the model indicated that the variations of mean void fraction become negligible for diameter ratio larger than 10. A smaller mean void fraction leads to a more compact cat bed, but also to a higher pressure drop. It can be seen that the selection of granulated supports is a trade-off between different aspects. Therefore a precise values for the diameter ratio is subject of further (experimental) investigation.

Material of Granulated Supports

The choice of support material is based on considerations on their resistance and specific surface area. Supports material have to be extremely resistant: they are subjected to strong thermal shocks and are in contact with reactive gases at extreme temperatures. They should have a high specific surface area, because this increases the surface of contact between the propellant and the active phase. Moreover the specific surface area should remain large for the entire life of the catalyst. Based on these requirements, different materials have been considered in Rheform. Two of the materials selected were available commercially: gamma alumina ($\gamma\text{-Al}_2\text{O}_3$), and yttria stabilized zirconia (YSZ). Two other materials were synthesized: silicon-doped alumina and two types of hexaaluminates, namely hexaaluminate A ($\text{LaAl}_{11}\text{O}_{18}$) and hexaaluminate B ($\text{BaAl}_{12}\text{O}_{19}$).

These supports materials were characterized. In order to simulate the effect of the combustion on the catalyst, the catalysts were subjected to heat treatment in air before the analysis, as listed in Table 1. X-ray diffraction (XRD) allowed the analysis of the nature of the crystalline phases. Other important information on the support as specific surface area, pore volume and pore size were determined by nitrogen sorptionometry.

The heat treatment allowed performing a preliminary selection of support materials. The material YSZ underwent substantial shrinkage after the heat treatment, and was therefore discarded. The specific surface area of the material hexaaluminate A was strongly reduced after the heat treatment and therefore this material was discarded as well.

Table 1. Specific surface area, pore volume, and pore size of selected support materials after heat treatment in air at different temperatures.

Materials, Shape	Thermal treatment	Specific surface area m ² /g	Pore volume cm ³ /g	Pore size Å
DUS 1, Powder	(1200 °C – 4 h)	92	0.247	82
Hexaaluminate A, Powder	(1500 °C – 4 h)	7	0.018	118
Hexaaluminate B, Powder	(1500 °C – 4 h)	46	0.063	64
YSZ, Pellets	(1500 °C – 4 h)	< 0.1	-	-

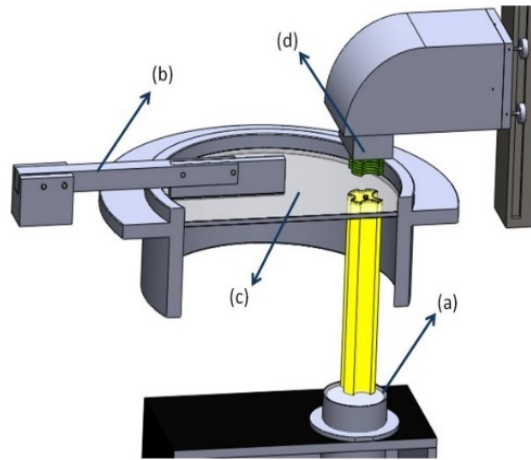
Catalyst active phase

The second phase in developing a granulated catalyst is the selection of an active phase. In Rheform numerous active phases were tested. The deposition of the active phase is carried out by impregnating the granules with a solution of the active phase precursor at room temperature. The solvent is then removed by gentle evaporation at moderate temperature. Catalysts are obtained subsequently to an appropriate heat treatment of the solid thus obtained. The search for the optimal nature and percentage of active phases is still ongoing, and more details will be published in a future work.

3.2 Monolithic Catalyst Development

A monolithic catalyst is typically made of a support structure, a washcoat layer deposited on the support in order to increase the microscopic surface area and an active phase which is deposited on the washcoat layer.

Monolithic catalytic supports are typically produced via extrusion. With this technique only straight channels can be manufactured. In the Rheform project a novel 3D printing technique was implemented, called Lithography-based Ceramic Manufacturing (LCM) developed by the project partner Lithoz [5]. This method allows the fabrications of complex support geometries. It is based on the use of photocurable suspensions which can be crosslinked when exposed to light. The parts are manufactured layer by layer. The shape of the layer printed is controlled by the shape of the light beam. The parts direct after the printing process are called “green parts”. The green parts need to be cleaned after printing and the organic matrix has to be removed in the so called debinding step. Finally the ceramic particles are sintered together in a furnace at high temperature.

**Figure 2.** Schematic principle of the LCM process: (a) Light source, (b) Coating knife, (c) Vat filled with resin and (d) Building platform, based on [6].

Three different designs were chosen for the printed monoliths, as shown in Figure 3. The first design was based on triangular straight channels. Such design allowed was also manufactured by extrusion, allowing a comparison between the monoliths produced with two different processes.

The other two designs have complex 3D structure and can be manufactured only by printing.

The so called ‘cellular’ structure was selected as in maximize the macroporosity of the design. The design was named ‘polyhedral’ structure. It is based on a basic repetition unit, in this case is a polyhedron with 26 faces. The basic idea with such a structure is the increase of the surface area inside the catalyst.

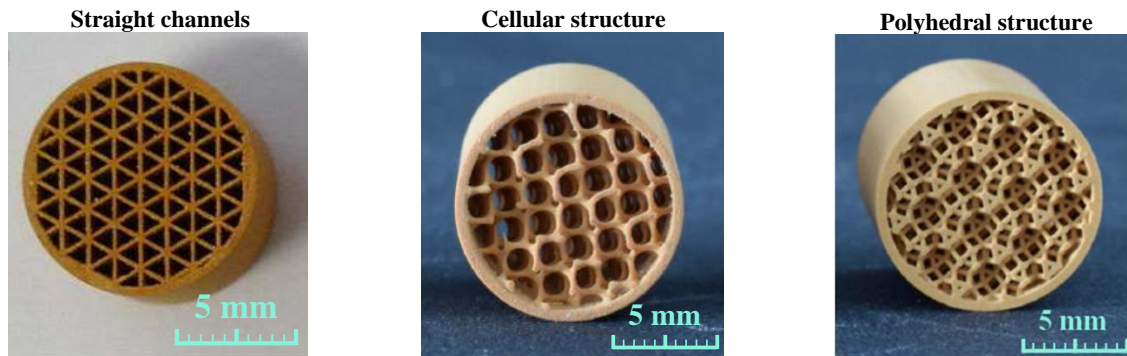


Figure 3. Designs of monolithic supports.

For the manufacturing of monoliths 4 different ceramic materials are being evaluated, cordierite ($(\text{Mg,Fe})_2\text{Al}_4\text{Si}_5\text{O}_{18}$), aluminium oxide (Al_2O_3 , alumina), magnesium oxide (MgO , magnesia) and silicon nitride (Si_3N_4).

Stable and photocurable ceramic of all tested ceramic powders suspensions were prepared. These suspensions could be processed using Lithoz’ LCM technology to print 3D green parts. Upon exposure to elevated temperatures the photopolymer was burned off and the ceramic particles were sintered together to give the final ceramic parts.

Characterisation of the samples in terms of their dimensional accuracy and precision was primarily done by conducting light microscopy. Exemplary picture material for 3D monolithic designs made from Cordierite 1 is depicted in Figure 6.

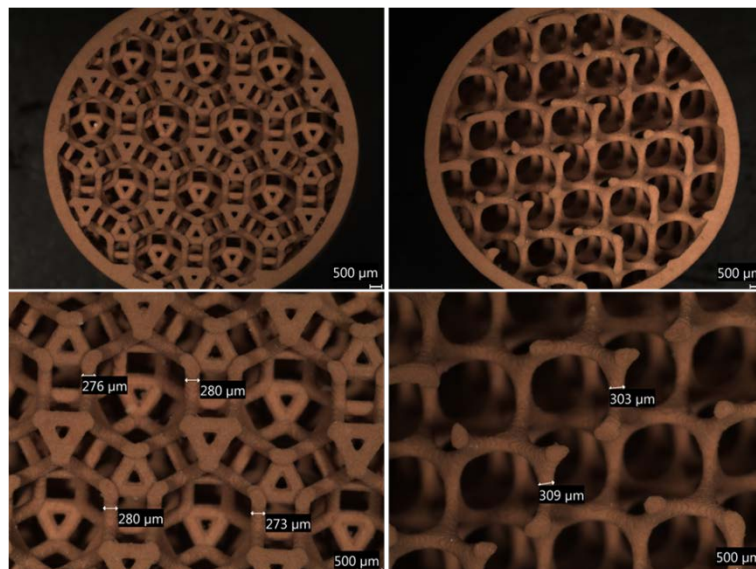


Figure 4. Photographs of a polyhedral structure (left) and of a cellular structure (right) obtained after printing and sintering of a cordierite 1 sample.

The measured data deviated slightly from the target geometry from the CAD due to two main reasons. One was the pixel array that was used to expose each layer of the monolith. Since the lateral dimension of each pixel is $40 \times 40 \mu\text{m}^2$, very fine elements are approximated by manifolds of $40 \mu\text{m}$. The other reason was light scattering by ceramic particles; since this phenomenon varies from material to material depending upon its refractive index, it cannot be completely compensated. Furthermore, since this effect only becomes discernible at the interfaces between cured and uncured material, it is relatively more pronounced for very fine elements such as the struts of the 3D designs or the walls of the linear monoliths.

In order to increase the microporosity, i.e. increase the specific surface area, a washcoating layer was applied on the 3D printed supports. Washcoatings were applied dipping the supports in colloidal solutions of aluminium, alumina and or aluminium oxohydroxide named sol AU and sol DUS. The excess material is then then gently blown. The parts are then dried at room temperature and calcined in a muffle furnace. Several parameters influence the final layer and must be controlled: the temperature, the viscosity of the washcoating suspension, the duration of the procedure, and the drying conditions.

The active phase was deposited only once the washcoating of the different monolithic materials was shown as feasible. The deposition of the active phase is carried out by impregnating the washcoated monoliths with a solution of the active phase precursor at room temperature. The solvent is then removed by gentle evaporation at moderate temperature. The activation procedure is a critical step and depends on the nature of the active phase. The activation is conducted at higher temperatures, under oxygen and/or hydrogen, depending on the nature of the targeted active phase.

4. Thermal ignition of ADN-based propellants

One of the focuses of Rheform is to reduce the pre-heating time of the thruster, making the ignition more prompt. This could be important for emergency starts. A reduction of the pre-heating time could be achieved through a thermal igniter, which can provide a large amount of power in short period of time. Therefore the suitability of thermal igniter for ADN-based propellants is investigated in Rheform. In this work the results obtained with a hydrogen – oxygen torch igniter are presented. Such igniter is extremely flexible: by changing the amount of hydrogen and oxygen it is possible to change the amount of power delivered as well as the temperature of the combustion gases generated. It can deliver a considerable amount of thermal power: the model used for the ignition tests in the present work could deliver up to 20 kW. It allows a large number of restarts, which is particularly interesting while testing. It should be noted that the goal of the tests with the torch igniter is to verify if thermal ignition and sustained combustion can be achieved with a thermal igniter. In a real application the torch could be substituted with a pyrotechnic igniter reducing the complexity and weight of the ignition system.

4.1 Experimental Setup

A schematic drawing of the setup used for the ignition tests with a torch igniter is shown in Figure 4. As combustion chamber a 1 inch stainless steel tube was selected. The internal diameter is 25.6 mm. The length was 150 mm. This gives a characteristic length L^* of:

$$L^* = \frac{V_c}{A_t} = 1.53 \text{ m}$$

In previous tests conducted at DLR with another monopropellant, a characteristic length of 1.5 allowed a complete combustion. The nozzle diameter (8 mm) was selected to have a chamber pressure of around 20 bar for a mass flow rate of propellant of 100 g/s. The geometry of the nozzle was based on the experience developed at DLR with testing in ambient condition. A conical nozzle with a rounded throat and an expansion ratio of 5 was designed. An angle of 25° for the convergent and of 15° for the divergent were selected. The expansion ratio of 5 is small enough to assure that no flow separation takes place, but it provides a more clean flow than a truncated nozzle. Commercial full cone swirl injectors from the Spraying System Co. were used. In the tests conducted with FLP-106 two different injector sizes were used: size 3 and size 2. The two injectors have similar geometries, but the former has a smaller cross-sectional area, and therefore provides a smaller mass flow rate with the same tank pressure. The tests with LMP-103S were conducted with a Swirl injector size 1. The data acquisition and control system was based on a LabView program. A regulated supply of hydrogen, oxygen and nitrogen was available at the test bench. The setup offers the possibility to flush the injector and the combustion chamber with water or nitrogen. The mixture ratio (ROF) and

power output of the torch igniter can be modified by changing the feeding pressure of hydrogen and oxygen and the diameter of the sonic orifices placed in the igniter's feeding lines.

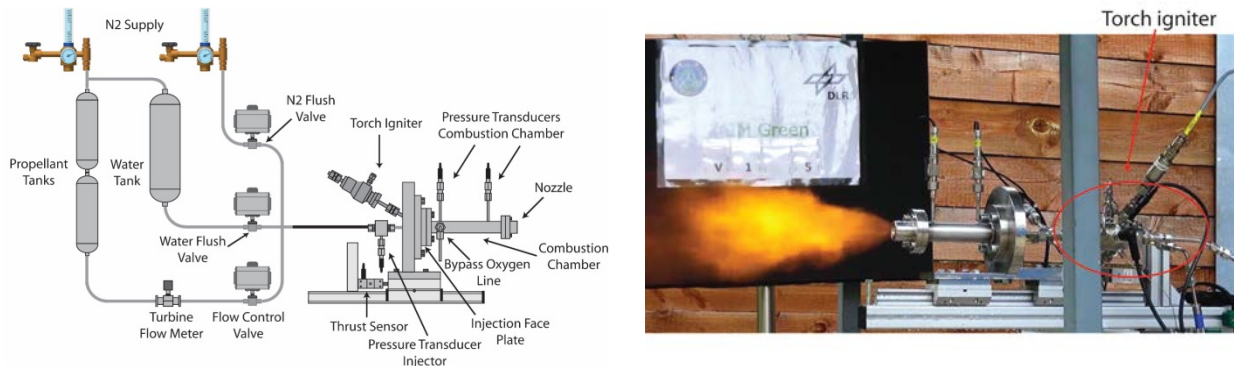


Figure 5. [Left] Schematic drawing of ignition demonstrator. [Right] Ignition demonstrator with torch igniter

4.2 Results obtained with basic chamber

The results of the tests conducted with the basic cylindrical combustion chamber, without flame (reaction) holding devices are described in this section.

The configuration of the torch igniter was kept constant during the tests: the mass ratio of oxidizer to fuel (ROF) was around 1 and the power output 16 kW. The torch was fired for 1 s. The tests were conducted with different tank pressures from 2 to 26 bar. Depending on the tank pressure, the mass flow rates of the propellant injected varied from below 30 g/s to 100 g/s. During the tests conducted with the lowest tank pressure (2 and 4 bar) the exit nozzle of the combustion chamber was removed to avoid the formation of a back pressure in the combustion chamber. The FCV was opened when the torch was already ignited (the delay between torch ignition and FCV opening was varied between 100 and 900 ms) and closed 3 s later.

Frameshots of one of the tests conducted with the basic chamber are shown in Figure 5. The results of the other test were similar. The power of the torch was sufficient to vaporize the propellant in all the tests conducted. The chamber cooled rapidly after the torch shutdown. 1 s after torch shutdown a considerable amount of propellant left the chamber in liquid form. No clear ignition was observed in the tests conducted. In the tests conducted with a nozzle the pressure in the combustion chamber remained below 2 bar, with the exception of one test during which several pressure spikes were observed.

In several tests a heating band provided a pre-heating of the combustion chamber. The heating band without the torch did not provide enough power to vaporize the propellant injected in the chamber completely.

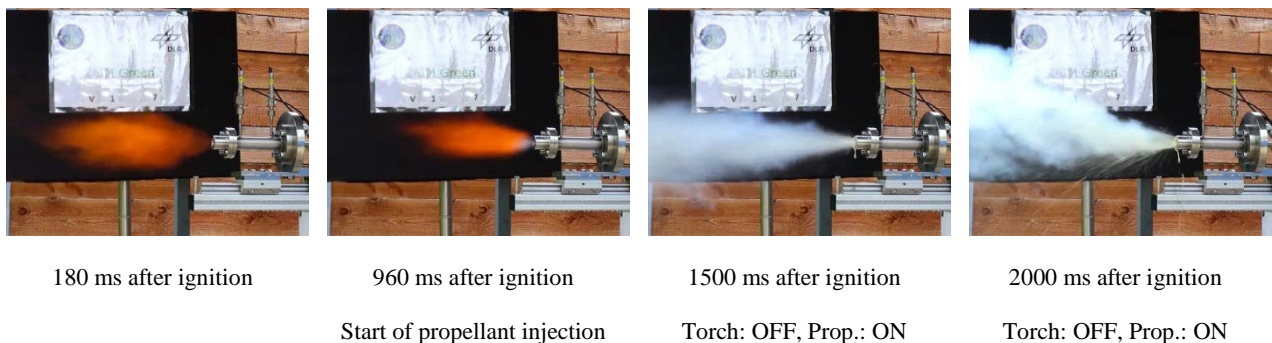


Figure 6. Frameshots of an ignition tests with the torch igniter and the basic chamber.

In the tests conducted without a nozzle, vaporization of the propellant was observed. Combustion took place outside the chamber, probably using atmospheric oxygen. In a test conducted with the lowest tank pressure (2.0 bar), the flame was much brighter than in the previous tests, probably due to the decomposition of ADN.

In the last test additional oxygen was added directly in the combustion chamber to facilitate ignition. The torch was working with a ROF of 1, and the amount of additional oxygen was selected in order to have a ROF of 6 in the chamber

Combustion was observed when the torch and the additional oxygen were still running, with the pressure in the combustion chamber around 7 bar. A frameshot of this phase is shown in Figure 6. It is not clear if ADN decomposed, but probably the additional oxygen reacted with the fuels contained in the propellant LMP-103S.



Figure 7. Frameshot of the ignition test with the torch igniter and additional bypass oxygen.

4.3 Tests with modified chamber

A hypothesis to explain the inability to ignite the propellant using the basic configuration was formulated: it is necessary to have some kind of support to facilitate the vaporization of the propellant and the decomposition of ADN. In order to verify this hypothesis the ignition demonstrator was modified. Two setups, Porous-A and Porous-B, were tested.

Setup Porous-A

The setup A was the first modification of the basic demonstrator. A schematic drawing is shown in Figure 7. A copper inlay and two porous discs were added in the chamber.

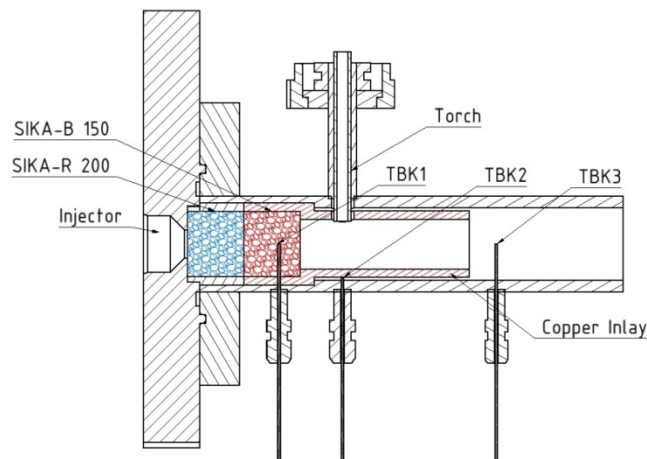


Figure 8. Setup Porous-A. TBK1, 2, 3 are thermocouples.

The goal of the first porous material (SIKA-R 200 stainless steel) was to achieve a more uniform distribution of the propellant. A limited temperature increase of the first inlay from the torch was expected, due to the low thermal conductivity of stainless steel and the fact that the hot gases from the torch do not flow through the material. The second porous material (Sika-B 150 bronze) was designed to be preheated by the torch, mainly by the heat coming from the copper inlay. The heated porous material should vaporize the propellant and act as reaction holding device. The good thermal conductivity of the bronze porous material in combination with the copper inlay should facilitate the heat feedback from the reaction zone back in the propellant. The torch igniter was placed on the side of the

chamber to heat the copper inlay and the SIKA-B 150 porous material. A microshowerhead injector was used. The combustion chamber was equipped with three thermocouples: one (TBK1) in the middle of the bronze porous material, the second (TBK2) placed on the outer side of the bronze inlay, opposite to the torch and the third (TBK3) in the middle of the chamber. The firing time of the torch igniter was limited by overheating of the parts directly in contact with the combustion products, in particular the flame tube connecting the igniter to the combustion chamber. With the configuration used with setup porous-A a maximum firing time of 3 seconds was possible.

Preliminary igniter tests were conducted. A single firing of the igniter did not heat the porous material enough. For this reason the tests with propellant were conducted according to the following sequence: torch firing 3 s, pause 40 s, torch firing 2.5 s, torch firing and FCV open 0.5 s.

The test setup did not allow measuring the mass flow rate, being below the sensitivity of the sensor used. Cold flow tests were conducted with tank pressure of 7 bar and FCV opening time of 500 ms (same condition as in the hot fire test) using water. The water was collected and weighted. The amount of water in the 3 test conducted was 5.7 g. All the subsequent tests were conducted with the same tank pressure and FCV opening time.

Using the sequence described above, tests were conducted both with water and LMP-103S. The results of two representative tests are shown in Figure 8. In the test 024, conducted with water as propellant simuli, the temperature in the porous material (TBK1) and in the chamber (TBK3) decreases suddenly after the injection of water. In the test 028, conducted with LMP-103S, a similar behaviour is observed directly after the opening of the FCV. The propellant vaporized upon injection. Corresponding to the injection of propellant a sudden decrease of combustion chamber temperature (TBK1, TBK3) was observed. For some second after the propellant injection a noticeable amount of brown smoke came out of the chamber. Associated was an increase of the temperature in the chamber (TBK3) and with some delay in the porous material (TBK1). No flame was observed. Probably only a partial decomposition of ADN took place, so explaining the increase in temperature.

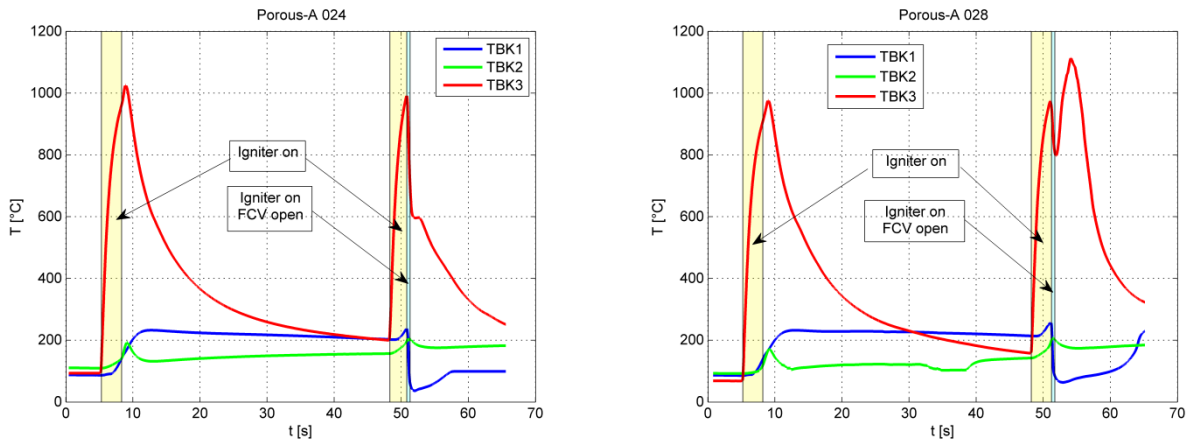


Figure 9. Results of two tests conducted with the setup Porous-A. Injected fluid: [Left] water, [Right] LMP-103S.

Similar results were obtained in the other tests conducted in the setup Porous-A with LMP-103S. No flame was observed. The formation of brown smoke for some seconds after the propellant injection was observed as well. Probably only a partial decomposition of ADN took place, so explaining the increase in temperature.

The conclusion was that the energy of the torch igniter and the thermal energy accumulated in the porous material were not sufficient to cause a direct injection of the propellant. Nevertheless the propellant left in the chamber after the closure of the FCV did decompose to some degree, leading to heat release and the production of smoke.

Setup Porous-B

The setup Porous-B was a modification to the setup Porous-A. A schematic draft of the setup is given in Figure 9. In the setup two porous materials were used: SIKA B-200 (indicated in blue) and SIKA B-150. Both were made of sintered bronze. This material has a good thermal conductivity, so that the temperature distribution in the inlay is quite uniform. The position of the torch igniter was changed with respect to setup Porous-A: the torch was mounted on the face plate. In this setup the combustion products of the torch must flow through both porous inlays. The

advantage of this setup is that both inlays material are heated substantially from the torch. The power of the torch had to be reduced to avoid melting the porous inlay.

The testing sequences for the setup Porous-B were similar to those used for the setup Porous-A with two torch firing separated by a pause. Several tests were conducted increasing stepwise the firing time of the torch to determine the time necessary for ignition of the propellant

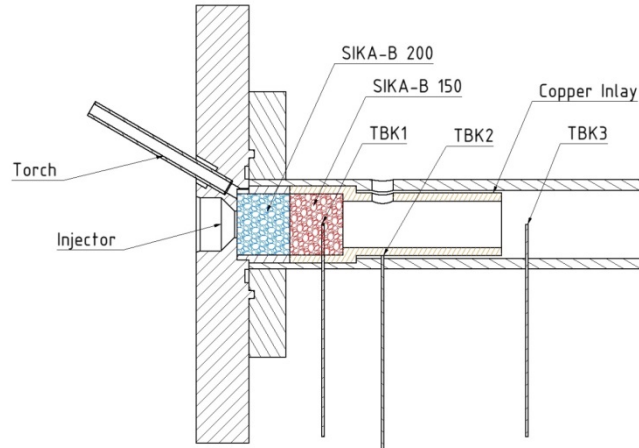


Figure 10. Setup Porous-B.

A clear ignition was obtained for torch firing time above 6 s. For example the results of a representative test (Porous-B 085) are shown in Figure 10. In this test the following sequence was used: torch firing 7 s, pause 40 s, torch firing 7 s, torch firing and FCV open 1 s.

During the firing of the torch without injection of propellant a considerable amount of white smoke came out of the chamber. This was probably water vapour generated from the torch igniter. In correspondence with propellant injection no visible flame was visible. When the FCV was open, an increase in temperature was measured by all three thermocouples, in particular by the sensor TBK1 (placed in the porous material). After the closure of the FCV a green flame surrounded the combustion chamber. Subsequently a very bright green flame anchored in the chamber. Correspondently a dramatic increase of the temperature in the chamber (TBK3) was measured. A maximum temperature of 900 °C was measured. In another tests with the same sequence a temperature of 1200 °C was measured.

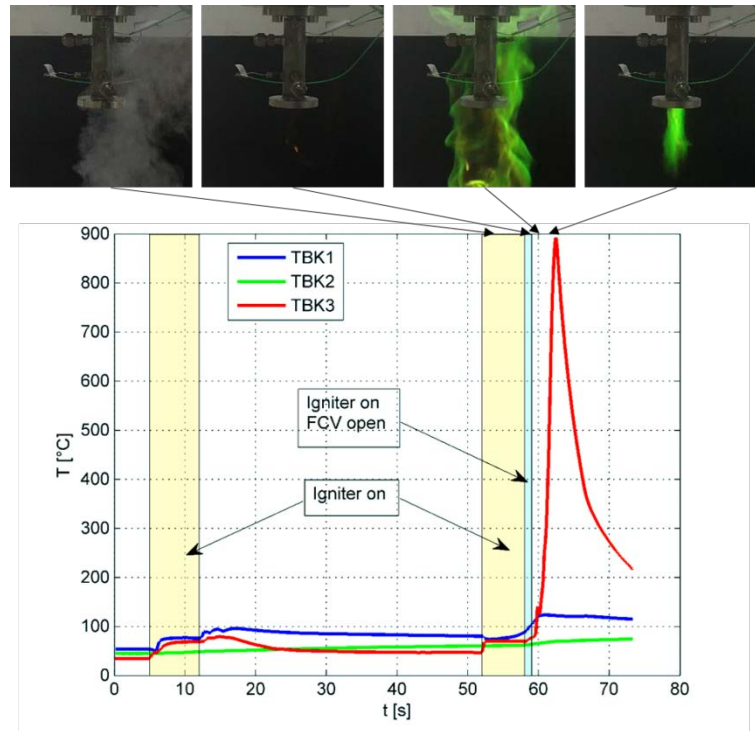


Figure 11. Frameshots and temperature traces from the test Porous-B 085. Propellant: LMP-103S.

The tests with the setup Porous-B showed that thermal ignition of ADN-based propellants is possible. Further tests will be necessary to determine if the setup is suitable to obtain sustained combustion.

5. Conclusions

ADN-based monopropellants are attractive replacements for hydrazine in propulsion applications. In the EU Horizon2020 project Rheform new technologies are developed in order to improve ADN-based propulsion systems. The present work is in particular focused on the innovative ignition methods developed in the framework of the project. Both catalytic and thermal igniters have been considered. The catalysts manufactured have two kinds of catalyst supports, granulated and monolithic. Different granulated support materials have been tested, including materials which were not available commercially and were synthesized in the project (silicon-doped alumina and two types of hexaaluminates). The supports materials were characterized through XRD and nitrogen sorptiometry. The impregnation with different active phase was successfully conducted. The monolithic supports were 3D printed with an innovative process called Lithography-based Ceramic Manufacturing (LCM). Four different ceramics were successfully printed with this method: cordierite, aluminium oxide, magnesium oxide and silicon nitride. Three different designs were implemented: straight channel, cellular structure and polyhedral structure. The monolithic supports required a washcoat layer to increase their specific surface area. Methods to apply the layer on the monoliths were developed in the project. Finally the monoliths were impregnated with different active phases. Tests on the thermal ignition of ADN-based propellants were conducted with a torch igniter. Initially a cylindrical combustion chamber without flame (reaction) holding devices was tested. No ignition with both baseline propellants (LMP-103S and FLP-106) was obtained. Based on the basic setup, two modifications were built, which include porous materials to facilitate the vaporization of the propellant and to anchor the decomposition reaction. With one of this setup it was possible to achieve ignition of the propellant. It remains to be tested if sustained combustion can be achieved with the same configuration.

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 640376.

The author would like to acknowledge the significant contributions of Marius Wilhelm, Christian Hendrich and of the project partners ASL, FOI, CNRS, FOTEC, Lithoz, and ECAPS in writing the present paper.

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