



## Review / Przegląd

# The malfunction of a double-base propellant gas generator *Nieprawidłowe zadziałanie gazogeneratora z paliwa dwubazowego*

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**Abstract:** The paper presents results of research aimed at determining the cause leading to the malfunction of a double base gas generator. For the purposes of this work, gas generator charges and combustion chambers were intentionally damaged in order to replicate failure conditions. Damage to the inhibitor covering the gas generator and contamination in the combustion chamber, was simulated. The damaged charges and chambers were subjected to ballistic tests.

**Streszczenie:** W pracy przedstawiono wyniki badań mających na celu ustalenie przyczyny nieprawidłowego zadziałania ładunku gazogeneratora wykonanego z paliwa dwubazowego. Na potrzeby pracy celowo uszkodzono ładunki gazogeneratora oraz komory spalania w celu odtworzenia warunków awarii. Zasymulowano uszkodzenia inhibitora pokrywającego gazogenerators oraz zanieczyszczenia komory spalania. Uszkodzone ładunki oraz komory poddano badaniom balistycznym.

**Keyword:** double-base propellant, failure scenarios, ballistic tests

**Słowa kluczowe:** paliwo dwubazowe, sytuacje awaryjne, badania balistyczne

## 1. Introduction

Quality control is one of the main elements of the production process for all types of materials. The basic elements of this process include, primarily, control of input materials, control of processing, control testing of intermediate products at specific stages of production, and acceptance testing of the finished product. As a confirmation of product quality, the manufacturer issues a quality certificate, technical specification, warranty *etc.*

In the case of special products for the army, containing high energy material in the product composition, the above requirements for quality control are decidedly more stringent. These restrictions are due to several over-arching reasons. Products intended for military use must be characterized by efficiency, safety of use and virtual 100% reliability. In connection with the above, the army maintains comprehensive supervision over the manufacture of products intended for its use, which culminates in reliability and acceptance testing.

Conducting special manufacture when using or producing high-energy materials such as explosives, smokeless powders or solid rocket propellants, therefore, requires the use of increased precautions and control. In addition to ensuring the desired performance parameters of the finished product, it is necessary to conduct tests during the full range of a product's service life, through so-called periodic examinations.

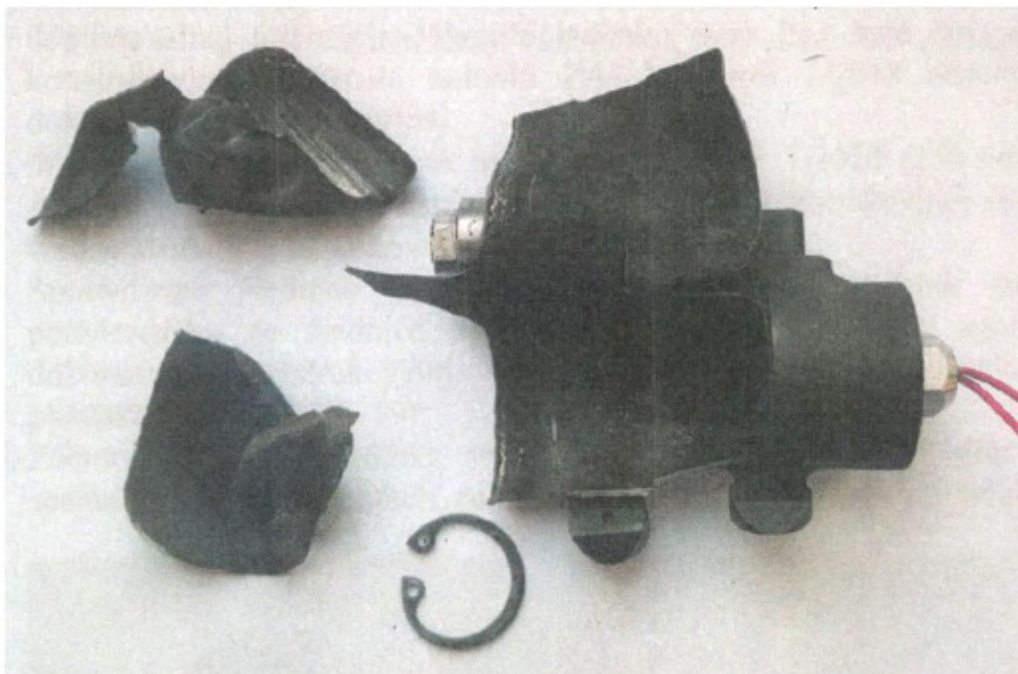
One way of conducting periodic tests is to test the properties of the product after carrying out accelerated aging. This consists of heating the test material at a constant elevated temperature for a prescribed period of time, which corresponds to an extended period of storage under normal conditions. The whole process uses the effect of accelerating chemical reactions (*e.g.* thermal decomposition) as a result of increasing the reaction temperature and is described by Berthelot's law also called the van't Hoff rule [1-5]. Guidelines for conducting accelerated aging are described in documents such as AOP-7, AOP-48 and STANAG 4582 [6-8].

Heating a high-energy material at elevated temperature carries with it a serious risk of it undergoing an uncontrolled decomposition. In addition, testing the so heated material *e.g.* by combustion, further increases this threat.

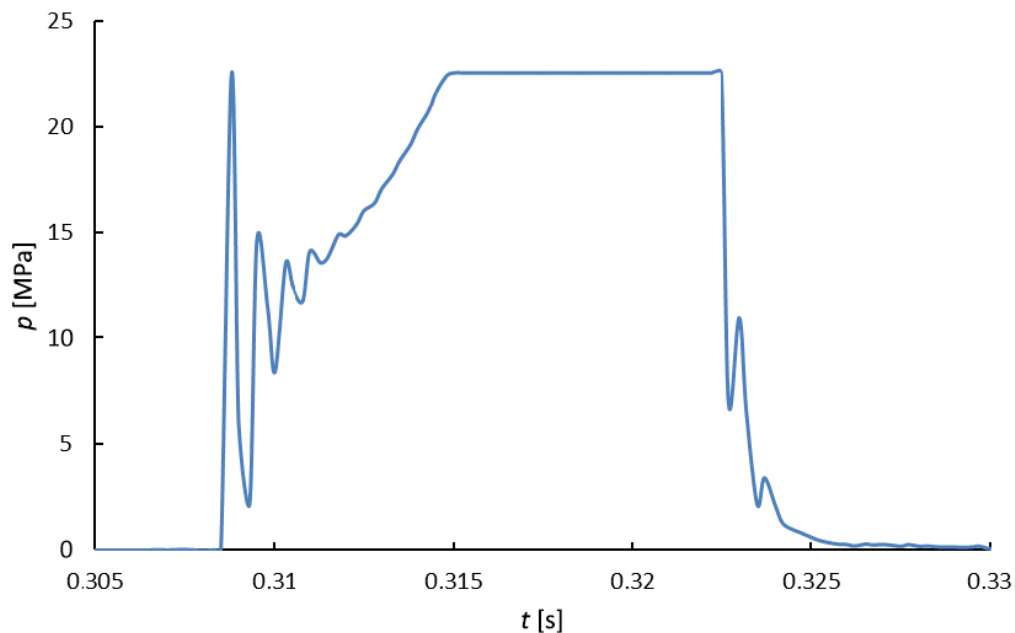
In the case of the aforementioned special production for the army, where during periodic testing the material is subjected to extreme thermal and/or mechanical exposure, unplanned incidents may occur. In the event of an incident, a Board of Inquiry is appointed, whose main purpose is to determine the reasons for the incident. In addition, the Board is required to submit recommendations, the application of which will improve product quality control, but above all will prevent similar incidents occurring in future production. The following describes the work of the Board of Inquiry in one such situation.

## 2. Failure situation

The subject of the failure was an explosion of a gas generator combustion chamber during periodic testing. During this, 14 charges of gas generator material, made of double-base propellant, were initiated. All charges had previously been subjected to accelerated aging to obtain charges aged for 12 years. 14 initiations were carried out in the following order, 7 at 55 °C and 7 at -35 °C. During the last initiation, at a temperature of -35 °C, a combustion chamber exploded. The cause of the explosion was a pressure build up which exceeded the design limit of the chamber. Figure 1 shows the combustion chamber after the incident. The relationship  $p = f(t)$ , recorded during the incident, is shown in Figure 2.



**Figure 1.** The combustion chamber after malfunction



**Figure 2.**  $p = f(t)$  during the incident

The first visible peak is the effect of the igniter. Later, pressure build-up is visible, reaching 23.5 MPa. This value represents the limit of the sensor used. The sharp pressure drop after 0.3225 s shows the moment of explosion of the combustion chamber. Analyzing the above data, it was found that the explosion occurred after 0.0143 s from the moment the igniter was activated. The analysis of this failure is the subject of ongoing research.

### 3. Explanatory research

A Board of Inquiry was set up to determine the cause of the incident. The Board decided to examine the possibility of repeating the incident by obstructing the combustion chamber nozzle and improperly operating the gas generator charge. The following potential causes of failure were reproduced, following which the gas generator charges were initiated:

- intentional damage of the inhibitor in the upper part of the charge,
- intentional damage of the inhibitor in the lower part of the charge,
- nozzle obstruction (metal plug screwed in),
- nozzle obstruction (plastic plug screwed in),
- nozzle contaminated with grease (for sealing the pressure sensor),
- flooding the nozzle with water and cooling the system to  $-35\text{ }^{\circ}\text{C}$ .

#### 3.1. Intentional destruction of the inhibitor

Figures 3 and 4 show the simulation of inhibitor charge damage in the upper and lower parts of the charge, respectively. Destruction of the inhibitor was marked. The inhibitor is a polymeric mass, which ensures that the propellant charge combusts with the prescribed geometry. Figures 5 and 6 present the  $p = f(t)$  plots registered during the combustion of the damaged charges.



**Figure 3.** Inhibitor damage in the upper part of the charge



**Figure 4.** Inhibitor damage in the lower part of the charge

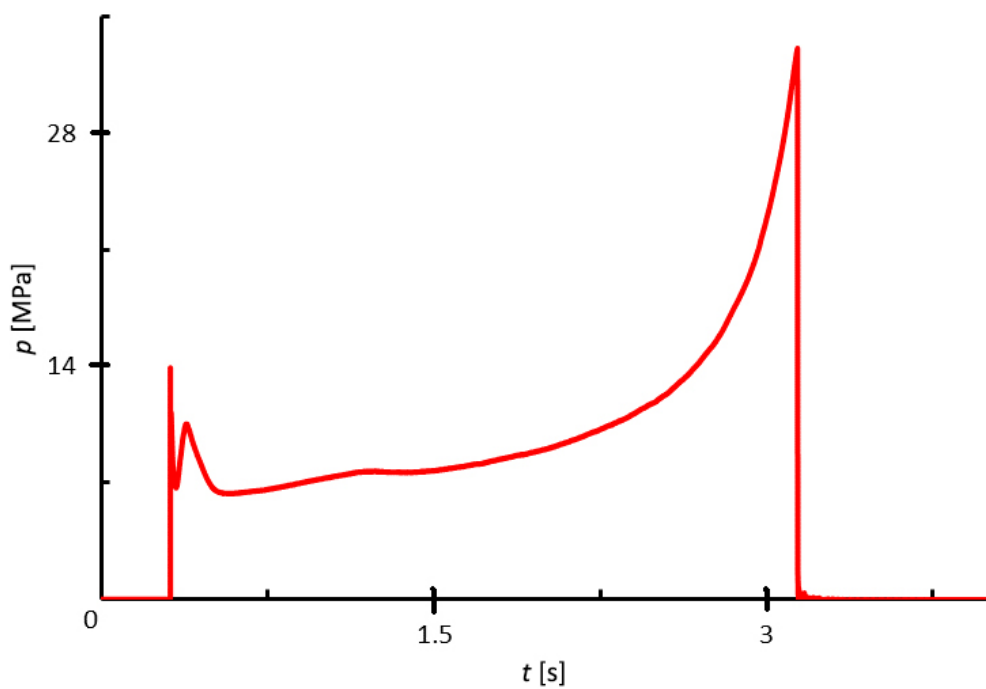


Figure 5. Plot of  $p = f(t)$  for the charge with upper part damage of the inhibitor

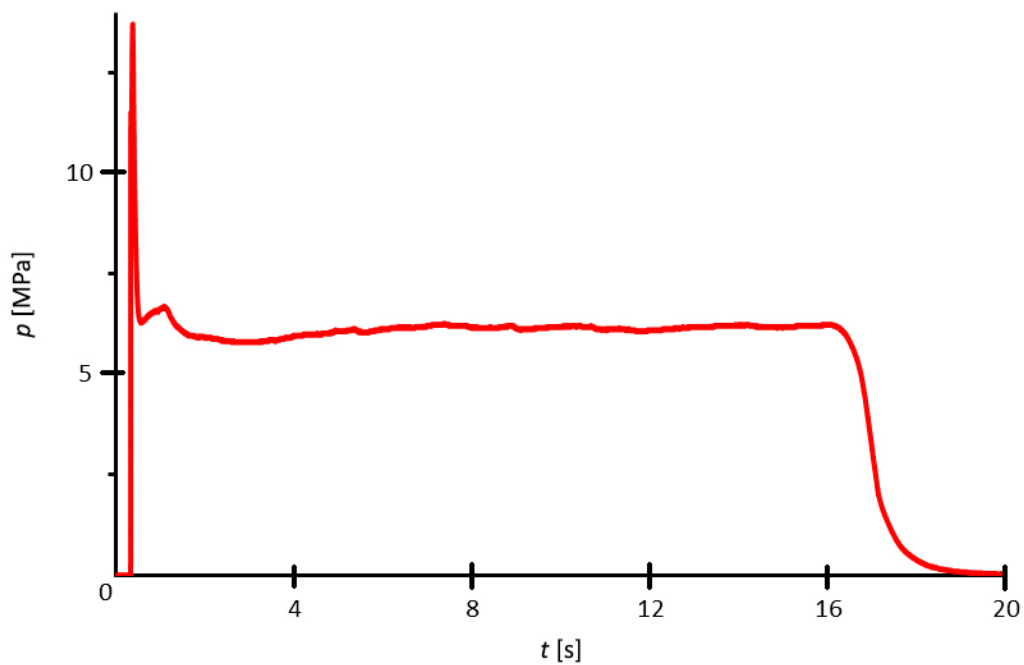


Figure 6. Plot of  $p = f(t)$  for the charge with lower part damage of the inhibitor

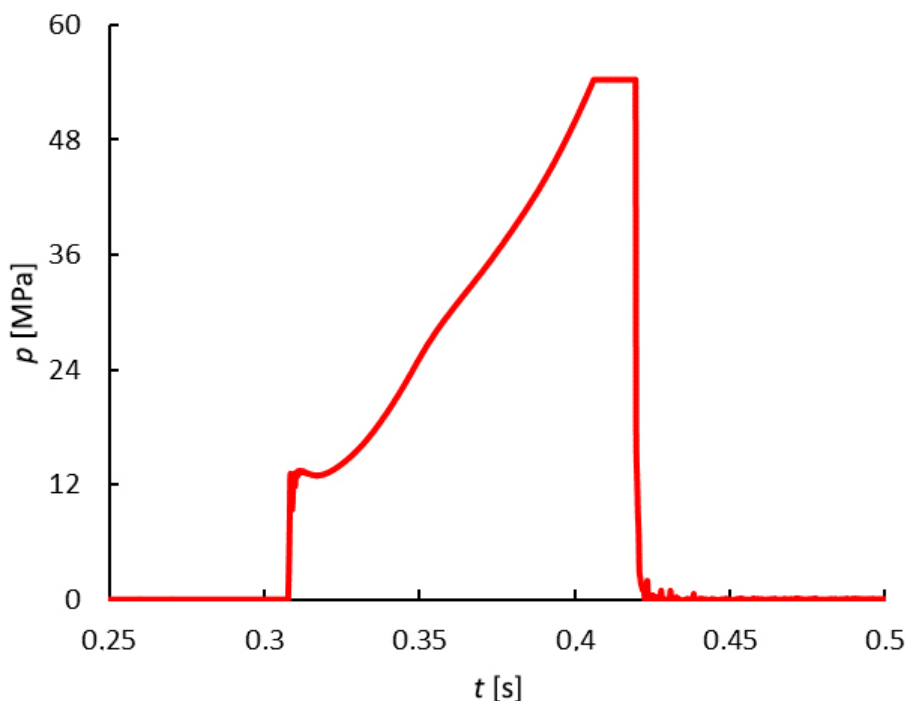
During combustion of the charge with the damaged inhibitor in the lower part of the charge, a stable combustion was obtained, presented in Figure 6. The expected effect of the chamber exploding, was not obtained. This phenomenon is interesting from the point of view of the scale of damage which the charge shows. The inhibitor damage depth made up 25% of the total charge length.

In the case of initiation of the charge with damage to the upper part of the inhibitor, the combustion chamber exploded. The graph of  $p = f(t)$  shows the build-up of pressure during combustion to a value of 32.9 MPa. The pressure build-up is caused by the increased surface area on the side of the damaged inhibitor. In Figure 5, the rupture of the chamber is evident in the sharp drop in pressure after approximately 3 s of charge operation.

### 3.2. Nozzle obstruction

The second direction of investigation was determining the effect of nozzle obstruction on the possibility of causing a malfunction. Four combustions were performed with various nozzle obstruction factors. In the case of clogging of the nozzle with a plastic plug, sealing grease and frozen water, the charges always started to function in a stable manner. Records of  $p = f(t)$  were close to that shown in Figure 6.

When the charge was combusted with the nozzle clogged with a steel plug, the chamber exploded. This experiment was designed to simulate clogging of the nozzle by large physical contamination. The plot of  $p = f(t)$  obtained during combustion is shown in Figure 7.



**Figure 7.** Plot of  $p = f(t)$  for the charge combustion with clogged nozzle

Comparing the above plot with that recorded during a malfunction, it can be seen that the time after which the chamber explosion occurs is definitely longer than in the case of the malfunction situation. For the plot shown in Figure 7, the chamber ruptured after 0.108 s of operation. However, during a malfunction, this occurred 0.0143 s after the igniter was initiated.

## 4. Summary

A series of accident scenarios during the combustion of a charge made of double-base propellant, were simulated. During these, efforts were made to determine whether the cause of the incident was damage to the charge or obstruction of the nozzle.

In the case of the first variant, it was clearly stated that the cause of the malfunction was not due to the damage of the charge inhibitor. Based on the tests, it was found that damage of the inhibitor causes other signs of failure and is a process spread over time. In order for the failure of the inhibitor to cause pressure build-up, which is the direct cause of the chamber explosion, the combustion surface of the propellants must increase. However, for combustion surface increase, damage of the inhibitor must be possible at a distance from the assumed combustion front of the charge.

Research on nozzle obstruction was also unsuccessful. Only in the case of a permanent clogging of the nozzle was a pressure build-up obtained which would cause the combustion chamber to explode. However, comparing the time at which the combustion chamber explosion occurred during tests and during a malfunction, a significant difference in this parameter is observed. During a malfunction, the chamber exploded after 0.0143 s, which means that the process was almost immediate. Considering the working times obtained during the simulation, consideration must be given whether the propellant charge started working after igniter initialisation.

## References

- [1] Bohn M.A. Prediction of Equivalent Time-Temperature Loads for Accelerated Ageing to Simulate Present In-Storage Ageing and Time-Temperature Profile Loads. *Proc. 40<sup>th</sup> Int. Annual Conf. ICT*, Karlsruhe, Germany, **2009**, 78.1-78.28.
- [2] Shekhar H. Prediction and Comparison of Shelf Life of Solid Rocket Propellants Using Arrhenius and Berthelot Equations. *Propellants Explos. Pyrotech.* **2011**, 36(4): 356-359.
- [3] Garman N.S., Picard J.P., Polanowski S., Murphy J.M. *Prediction of Safe Life Propellants*. NTIS, New Jersey, USA, **1973**.
- [4] Bohn M.A. Prediction of In-Service Time Period of Three Differently Stabilized Single Base Propellants. *Propellants Explos. Pyrotech.* **2009**, 34(3): 252-266.
- [5] Bohn M.A. *Principles of Ageing of Double Base Propellants and its Assessment by Several Methods Following Propellant Properties*. NATO, STO-MP-AVT-268, **2017**, 20.1-20.44.
- [6] NATO-AOP-7, *Manual of Data Requirements and Tests for the Qualification of Explosive Material for Military Use*. 2<sup>nd</sup> ed., **2003**.
- [7] NATO-AOP-48, *Explosives, Nitrocellulose-Based Propellants, Stability Test Procedures and Requirements Using Stabilizer Depletion*. 2<sup>nd</sup> ed., **2008**.
- [8] STANAG 4582, *Explosives, Nitrocellulose-Based Propellants, Stability Test Procedures and Requirements Using Heat Flow Calorimetry*. 1<sup>st</sup> ed., **2007**.

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