UDK: 662.351:662.312.1
COSATI: 21-09, 14-07

Life-Time Prediction of Double-Base Propellants in Accordance with Serbian and NATO Standards

Ljiljana Jelisavac[1]

This work presents the investigation of the procedure of life-time predictions of two types of double-base rocket propellants samples, NGR-176 and NGR-316, in accordance with SORS 8069/91 national standard and NATO standards: STANAG 4527 and AOP-48 Ed. 2.

The samples of the examined double-base propellants were subjected to accelerated ageing in heating blocks at temperatures 80°C, 70°C and 60°C. Consumption of the ethyl centralite stabilizer in propellant samples, as a function of temperature and time, was measured by the gas-chromatography method. The experimental results of ethyl centralite consumption were mathematically described by different kinetic models. By applying the Arrhenius equation, the kinetic parameters were determined. Life-times of rocket propellants were calculated at 25°C, as the storage time, after which the critical stabilizer depletion was reached. The critical value of the stabilizer depletion is 50% of the initial stabilizer content.

By comparing the results of life-times prediction of double-base propellants in accordance with different standards, the most real results were obtained in accordance with NATO standard AOP-48, Ed.2., with the description of stabilizer consumption with a kinetic expression of nth order.

Key words: **rocket propellant, double-base rocket propellant, ethyl centralite, life-time prediction, chemical stability, gas chromatography, standards.**

Introduction

DOUBLE-BASE rocket propellants are nitrocellulose (NC)-based energetic materials with a tendency towards slow, but constant thermal decomposition during aging. Because of the potential dangers of spontanoues combustion of NC propellants in Warehouse ordnance, which could be with disastrous consequences, a series of procedures was developed in order to control their chemical stability. Methods and methodologies of testing chemical stability and life-time of propellants are defined by the standards of particular countries.

The aim of this work was to compare the results of the life-time prediction of NGR-176 and NGR-316 propellant samples which were obtained in accordance with:

- currently valid national standard SORS 8069/91 [1];
- STANAG 4527 [2] and
- AOP-48, Ed.2 [3] test.

Development of science imposed permanent amendments to existing standardized tests in the field of chemical stability of energetic materials. Consequently, the currently valid standard of our country cannot be viewed in isolation from the standards worldwide.

In recent years several new, improved NATO standards in the field of chemical stability of powders and propellants have been adopted [4, 5].

The currently applicable standard SORS 8069/91 for monitoring the chemical stability of NC propellants describes the stabilizer consumption by an exponential expression for the reaction rate of the first order. The appropriate STANAG 4527 test, in addition to exponential expression [6], offers a possibility to apply a linear expression for the zero-order reaction rate, depending on which expression is more suitable for describing the stabilizer consumption in an examined propellant sample.

The NATO member states use the new standard AOP-48, Ed.2, which includes all STANAG tests in the area of chemical stability and life-time prediction of propellants. This standard further recommends the application of a kinetic expression which assumes that the consumption of the stabilizer in the accelerated age NC propellants has been performed in accordance with the reaction of nth order.

An exponential-linear kinetic model of the consumption of stabilizers was examined, verified and widely accepted, but this model has not been included in the standards of the NATO member countries because of its calculation complexity. In Table 1, there are kinetic expressions (1-12) for the description of the stabilizer consumption and the life-time prediction of NC propellants in accordance with SORS 8069/91 and NATO standards.

Table 1. Kinetic models of the stabilizer consumption and the life-time prediction of NC propellants

SORS 8069/91 - the first order	
$\ln\frac{C_S(0)}{C_S(t,T)} = k_1(T)t$	(1)
$Ea = \frac{333\cdot 343}{343-333}R\ln\frac{k_1(70^\circ\mathrm{C})}{k_1(60^\circ\mathrm{C})}$	(2)
$t_{Y_S}(T) = \frac{\ln\left(\frac{1}{Y_S}\right)}{k_1(20^\circ\mathrm{C})365}$	(3)

---

[1] Military Technical Institute (VTI), Ratka Resanovića 1, 11132 Belgrade, SERBIA

STANAG 4527 - the first order	
$\ln\frac{C_S(0)}{C_S(t,T)}=k_1(T)t$	(4)
$t_{Y_S}(T)=\frac{1}{k_1(T)365}\ln\left(\frac{1}{Y_S}\right)$	(5)
STANAG 4527 - the zeroth order	
$C_S(t,T)=C_S(0)-k_0(T)t$	(6)
$t_{Y_S}(T)=\frac{C_S(0)(1-Y_S)}{k_0(T)365}$	(7)
AOP-48, Ed. 2 - the n th order	
$C_S(t,T)=C_S(0)[1-(1-n)k(T)t](1/1-n)$	(8)
$k(T)=\frac{k'(T)}{C_S(0)^{1-n}}$	(9)
$t_{Y_S}(T)=\frac{1-(Y_S)^{1-n}}{k(1-n)365}$	(10)
Exponential-linear kinetic model– 0+1 order	
$C_S(t,T)=-\frac{k_0(T)}{k_1(T)}+\left[\frac{k_0(T)}{k_1(T)}+C_S(0)\right]\exp[-k_1(T)t]$	(11)
$t_{Y_S}(T)=\frac{1}{k_1(T)365}\ln\left(\frac{1+\frac{k_0(T)}{C_S(0)k_1(T)}}{Y_S\frac{k_0(T)}{C_S(0)k_1(T)}}\right)$	(12)

where:

$C_S(t,T)$	- the stabilizer content in propellants as a function of time and temperature, mass %;
$C_S(0)$	- initial stabilizer content, mass %;
$k_1(T)$	- reaction rate constants of the first order of stabilizer consumption, at temperature T, 1/day;
$k_0(T)$	- reaction rate constants of the zero order of stabilizer consumption, at temperature T, mass %/day;
$k^{\prime}(T)$	- reaction rate constants of the nth order of stabilizer consumption, at temperature T, 1/day;
t	- time, day;
n	- reaction order;
Y_S	- degree of stabilizer degradation, $Y_S=\frac{C_S(t_{Y_S})}{C_S(0)}$;
$C_S(t_{Y_S})$	- the content of stabilizer in propellants at given Y_S, mass %;
$t_{Y_S}(T)$	- the times to reach the stabilizer content $C_S(t_{Y_S})$ at temperature T, years;
E_a	- activation energy of stabilizer consumption reaction, J/mol;
R	- universal gas constant; R = 8.314 J/mol·K.

Predictions of the life-time of NC propellants in accordance with SORS 8069/91 methodology

The standard prescribes the procedure of accelerated aging samples of propellants in heating blocks, at two temperatures, 60°C and 70°C. In accordance with this standard, the experimental results of the stabilizer content determination during the ageing of propellant are described by an exponential expression for the reaction rate of the first order [7].

SORS 8069/91, as the life-time predicts time to spend 50% of the stabilizer initial content, at the storage temperature of 20°C. Therefore, the equation for the life-time prediction uses the values of degree of degradation stabilizers Y_S = 0.5 and k (20°C).

Predictions of the life-time of NC propellants in accordance with STANAG 4527 methodology

STANAG 4527 prescribes the NATO methodology of propellant life-time prediction. The propellant samples are subject to accelerated ageing to at least three temperatures in the temperature range from 40°C to 80°C. In accordance with this standard, the consumption of stabilizer in a function of time, is described by the expresions of the first or zero order. The calculation of propellant life-time is done using the expressons that describe better the experimental results of stabilizer consumption.

The description of stabilizer consumption by the exponential expression (first order) has dissadvantages such as:

- Stabilizer content in the practice decreases to zero faster than it is predicted by the exponential expression;
- there is a deviation from the exponential behaviour at low concentrations of the remaining stabilizer in propellants; the equation is not acceptable for the description of low concentrations of the remaining stabilizer, $Y_S \leq 0.3$;
- the equation has no ability to predict the time for complete stabilizer consumption t_0, (as t_{Y_S} at Y_S = 0), since t_0 $(T) \to \infty$.

In order to eliminate these disadvantages of the exponential model, the following improved kinetic models of stabilizer consumption were developed:

1. exponential-linear model which is not applied in international standards for calculating the life-time of propellants;
2. model of nth order, which is recommended for use, in accordance with NATO standard AOP-48 Ed.2.

Exponential-linear kinetic model of stabilizer consumption in aged NC propellants

The improved exponential-linear kinetic model which combines the equations for reactions of the first and zero order is a result of numerous investigations [8-15]. The equations for reactions of the first and zeroth order do not give satisfactory results of the stabilizer consumption description, if applied separately. Therefore, by their combination a new expression was derived which is used to describe the experimental data of the stabilizer consumption during the aging process of propellants (Table 1) and which removes the disadvantages of exponential expresions.

Predictions of the life-time of NC propellants in accordance with AOP-48 Ed. 2. methodology

Besides the expressions for reactions of the first and zero order, AOP-48 Ed.2. recommended the application of a kinetic model of stabilizer consumption which assumes that the stabilizer consumption in the acceleratedly aged propellant samples is performed in accordance with the reaction of nth order.

This improved model describes more precisely the stabilizer consumption related to the exponential model [8, 16]. In comparison with the improved exponential-linear model, the time required for complete stabilizer consumption is longer, because the last part of the stabilizer consumption curve slowly approaches the time axis [8]. For this reason, AOP 48, Ed.2 does not recommend the use of the kinetic models of nth otder at the stabilizer content below 20% of initial value, $C_S(0)$.

Experiment

Double-base rocket propellant samples, NGR-176, PP-1 and NGR-316, PK 2/3, were subjected to accelerated ageing at temperatures of 80°C, 70°C and 60°C [17, 18]. About 20 grams of samples were measured in each of the 45 Pyrex tubes (150 mm long by 25 mm in diameter) closed with loosely ground glass stoppers and placed in heating blocks. The stabilizer, ethylcentralite (CI), content in the aged propellant samples was measured by the gas chromatography (GC) method [17, 19, 20] depending on the time and temperature. Then an interpolation of the stabilizer contents was made by adequate expressions with relatively good correlation coefficients, R^2.

Results and discussion

The results of the measurement of CI consumption by the GC method, depending on time and temperature, in accelerated aged samples NGR-176 and NGR-316 are shown in Table 2 and 3.

Table 2. Consumption of CI in the propellant NGR-176, aged at temperatures of 60°C, 70°C and 80°C.

80°C		70°C		60°C	
t days	c(CI) mass %	t days	c(CI) mass %	t days	c(CI) mass %
0	3.07	0	3.07	0	3.07
4	2.83	11	2.97	78	2.44
8	2.73	31	2.63	153	2.19
14	2.33	49	2.24	230	1.96
28	1.78	80	1.72	300	1.49
38	1.32	122	1.41	350	1.36
46	0.96	188	1.21	425	1.1
65	0.45	225	1.04		
95	0	325	0.05		

Table 3. Consumption of CI in the propellant NGR-316 aged at temperatures of 60°C, 70°C and 80°C.

80°C		70°C		60°C	
t days	c(CI) mass %	t days	c(CI) mass %	t days	c(CI) mass %
0	2.78	0	2.78	0	2.78
4	2.56	11	2.69	78	2.6
8	2.47	31	2.52	153	2.41
14	2.35	49	2.24	205	1.94
20	1.95	80	1.89	350	1.69
38	1.69	122	1.38	395	1.57
46	1.45	188	0.95	485	1.32
65	0.83	225	0.74		
75	0.42	325	0.22		
85	0.12				

Predictions of the life-time of propellants in accordance with SORS 8069/91 methodology

The experimental results of the GC analysis of samples of NGR-176 and NGR-316 [15] aged at 60°C and 70°C were mathematically described by the exponential expression for the reaction rate of the first order and displayed along with the kinetic parameters in Table 4.

Table 4. Kinetic parameters of the consumption of CI and the life-times of the propellants NGR-176 and NGR-316
- in accordance with SORS 8069/91 -

values	**NGR-176**	**NGR-316**
k_1 at 70°C, 1/day	0.0052	0.0055
k_1 at 60°C, 1/day	0.0023	0.0015
Ea, kJ/mol (60°C to 80°C)	77.07	122.76
k_1 at 25°C, 1/day	8.75E-05	8.20E-06
t (50%, at 25°C), years	**22**	**231.4**

Predictions of the life-time of propellants in accordance with STANAG 4527 methodology

The experimental results of the GC analysis of the samples of NGR-176 and NGR-316 aged at 60°C, 70°C and 80°C [15] were mathematically described by the exponential equation for the reaction of the first order and displayed along with the kinetic parameters in Table 5.

Table 5. Kinetic parameters of the consumption of CI and the life-times of the propellants NGR-176 and NGR-316
- STANAG-4527 - reaction of the first order -

values	**NGR-176**	**NGR-316**
k_1 at 80°C, 1/day R^2	0.0229 0.975	0.0163 0.954
k_1 at 70°C, 1/day R^2	0.0052 0.950	0.0055 0.985
k_1 at 60°C, 1/day R^2	0.0023 0.984	0.0015 0.971
Ea, kJ/mol (60 to 80°C)	111.97	116.75
k_1 at 25°C, 1/ day	1.77E-05	1.09E-05
t (50%, 25°C), years	**107.5**	**174.9 god**

The experimental results of the GC analysis of the samples NGR-176 and NGR-316 subjected to accelerated ageing were mathematically described by a linear equation for the rate of reaction of the zero order and displayed along with the kinetic parameters in Table 6.

Table 6. Kinetic parameters of the consumption of CI and the life-times of the propellants NGR-176 and NGR-316
- STANAG-4527 - reaction of the zero order -

values	NGR-176	NGR-316
k_0 at 80°C, mass %/day R^2	0.0151 0.998	0.0106 0.994
k_0 at 70°C, mass %/day R^2	0.0034 0.983	0.0034 0.942
k_0 at 60°C, mass %/day R^2	0.0017 0.985	0.0011 0.969
Ea, kJ/mol (60°C to 80°C)	106.31	110.8
k_0 at 25°C, mass %/day	1.62E-05	9.88E-06
t (50%, at 25°C) years	**259.5**	**385.4**

Exponential-linear kinetic model of stabilizer consumption in aged NC propellants

The kinetic parameters and the life-times of NGR-176 and NGR-316 [15] calculated in accordance with the exponential-linear model are given in Table 7.

Table 7. Kinetic parameters of the consumption of CI and the life-times of the propellants NGR-176 and NGR-316
- exponential-linear model -

values	NGR-176	NGR-316
k_1 at 80°C, 1/day	0.01391	0.012
k_0 at 80°C, mass %/day	0.01673	0.009
SD, mass %	0.07	0.07
k_1 at 70°C, 1/day	0.00491	0.00457
k_0 at 70°C, mass %/day	0.0024	0.00217
SD, mass %	0.19	0.19
k_1 at 60°C, 1/day	0.00188	0.00092
k_0 at 60°C, mass %/day	0.0009	0.00115
SD, mass %	0.06	0.05
Ea_0, kJ/mol	142.3	100.1
Ea_1, kJ/mol	97.8	125.9
k_1, at 25°C, 1/day	2.90E-05	4.81E-06
k_0, at 25°C, mass %/day	1.82E-06	1.44E-05
t (50%, at 25°C), years	63.7	157

The verification of the model was made by standard deviation (SD) of the used numeric procedure.

$$SD = \sqrt{\frac{\sum_{i=1}^{N_t} \left(c_{CI}^{\exp} - c_{CI}^{calc} \right)^2}{N_t - N_k}} \qquad (13)$$

where:

SD - standard deviation, mass %;

$c_{CI}^{\exp}$ - the content of CI in propellants measured in i-th time, mass %;

c_{CI}^{calc} - the content of CI in propellants calculated in i-th time, mass %;

N_t - number of times of measuring, number of calculating CI contents;

N_k - number of determined reaction rate constants.

Predictions of the life-time of NC propellants in accordance with AOP-48 Ed.2. methodology

The results of the GC analysis of the propellant samples subjected to accelerated ageing were described by the kinetic model of nth order and presented in Figures 1 - 7.

The lines in these figures represent the curves, fitted by the method of least squares in accordance with expression (8) for the reaction of nth order to experimental data (Table 1). The model was assessed using the correlation factors of the least square fit procedure as a criterion. As seen from the figures,, there is good agreement between the measured and calculated concentrations of CI, at the contents of CI under 20 % of initial value, C_S (0).

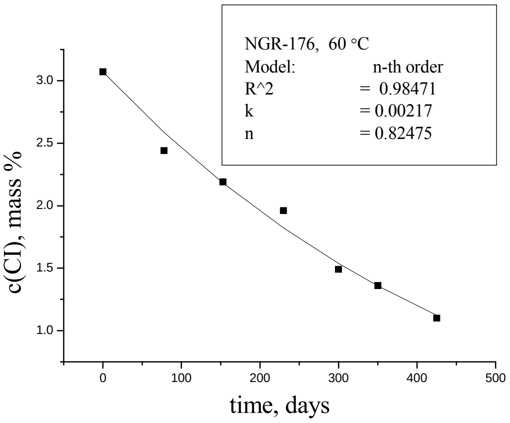

Figure 1. Consumption of CI in the propellant NGR-176 at 60°C - description by the reaction of nth order

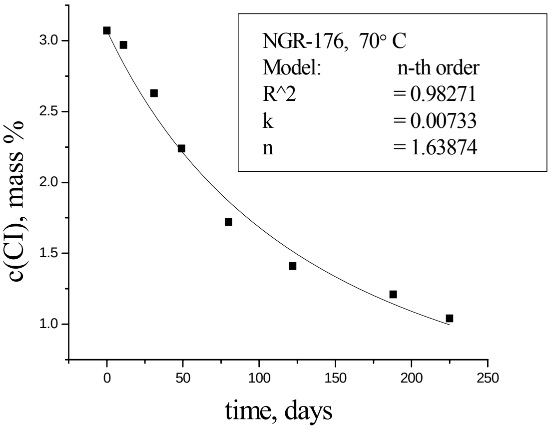

Figure 2. Consumption of CI in the propellant NGR-176 at 70 °C - description by the reaction of nth order

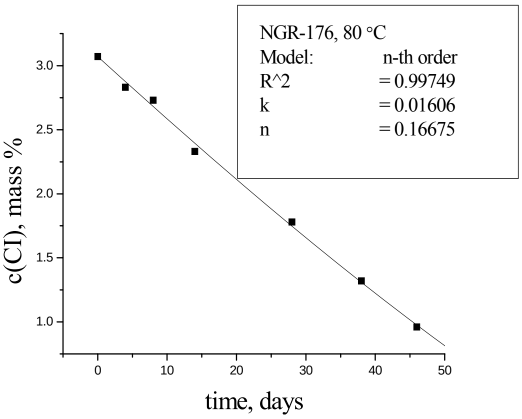

Figure 3. Consumption of CI in the propellant NGR-176 at 80°C *- description by the reaction of nth order*

The Arrhenius plots of the reaction rate constants of the consumption of CI are presented in Fig.4 for the propellant NGR-176 and in Fig.8 for the propellant NGR-316.

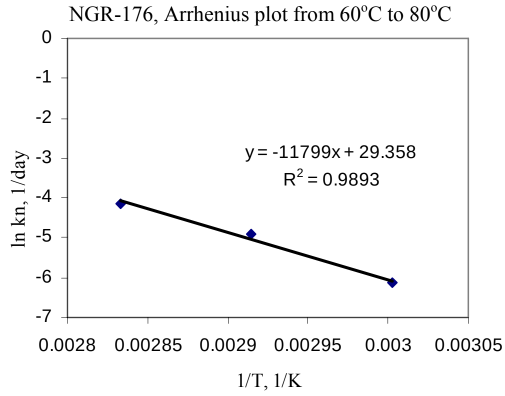

Figure 4. Arrhenius plot of the reaction rate constants of the CI consumption in the propellant NGR-176, from 60°C to 80°C *- kinetic model of nth order –*

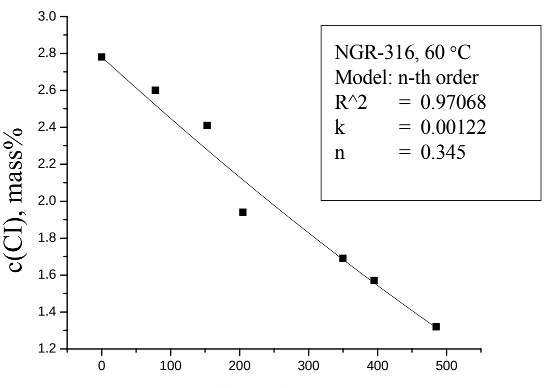

Figure 5. Consumption of CI in the propellant NGR-316 at 60°C *- description by the reaction of nth order -*

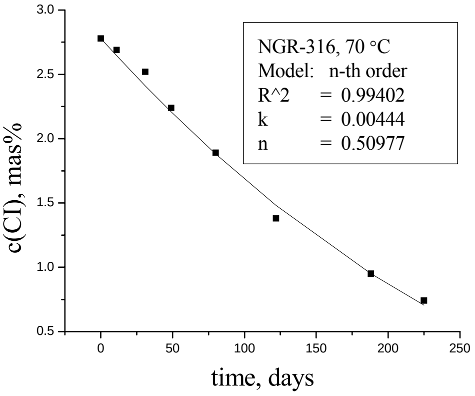

Figure 6. Consumption of CI in the propellant NGR-316 at 70°C *- description by the reaction of n^th^ order –*

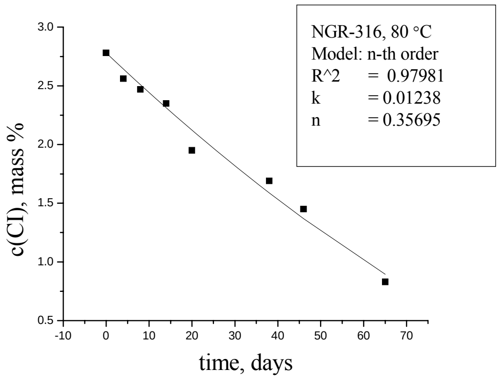

Figure 7. Consumption of CI in the propellant NGR-316 at 80°C *- description by the reaction of n^th^ order –*

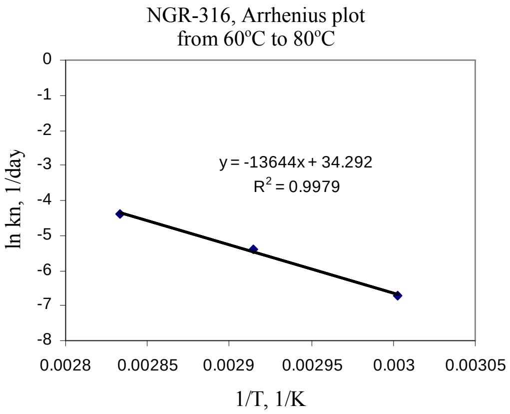

Figure 8. Arrhenius plot of the reaction rate constants for the CI consumption in the propellant NGR-316, from 60°C to 80°C *-kinetic model of n^th^ order –*

The reaction rate constants of the consumption of CI at various temperatures and the kinetic parameters of the model of n^th^ order are shown in Table 8. The reaction rate constants were calculated at a storage temperature of 25°C, too (Table 8). The life-time of the propellant was calculated as a storage time at 25°C, after which a critical value of 50% of the remaining stabilizer content was reached.

Table 8. Kinetic parameters of the consumption of CI and the life-times of propellants NGR-176 and NGR-316
- kinetic model of n^th^ order -

values	**NGR-176**	**NGR-316**
k_n at 80 °C, 1/day R^2	0.01606 0.998	0.01238 0.980
k_n at 70°C, 1/day R^2	0.00733 0.983	0.00444 0.984
k_n at 60°C, 1/day R^2	0.00217 0.985	0.00122 0.971
Ea, kJ/mol (60°C to 80°C)	98.1	113.4
$n_{average}$	0.88	0.41
k_n at 25°C, 1/day	3.59E-05	1.01E-05
t (50%, 25°C) years	**50.8**	**153.9**

Table 9 presents the final results of calculating the life-time of propellants NGR-176 and NGR-316.

Table 9. The life-times of propellants NGR-176 and NGR-316

life-times of propellants, years					
Rocket pro-pellants	SORS 8069/91	STANAG 4527		Ekspon.- lin. kinet. model	AOP 48 Ed.2.
	1. order	1. order	0. order	1+0 order	n^th^ order
NGR-176	22	108	260	64	51
NGR-316	231	175	385	157	154

The life-times of propellants were calculated in accordance with NATO tests as a storage times at a temperature of 25°C. The storage temperature by SORS 8069/91 is 20°C. In this article, all calculations were made for the storage temperature of 25°C, in the aim to compare the results.

The most realistic value for the life-time prediction was obtained for propellant NGR-176, (51 years), and the NGR-316 (154 years) in accordance with AOP-48, Ed.2. by the kinetic description of stabilizer consumption with a reaction of n^th^ order.

The high values of the life-time of the examined propellant samples can be explained by a relatively high initial content of CI in the examined samples (about 3 mass %) and their good chemical stability.

The estimated life-time of propellant NGR-316 was significantly longer than the life-time of propellant NGR-176. This can be explained by different chemical compositions of the examined propellants. A sample of propellant NGR-316 contains approximately 8.5 mass % of dinitrotoluen (DNT), which results in slower consumption of CI, and thus increased chemical stability and life-time of such double-base propellant. The samples of the propellant NGR-176 do not contain DNT.

In this reference it was shown that the interval and the number of temperatures of accelerated aging affected the values of the kinetic parameters of CI consumption and the life-time prediction of propellants. The results of the life-time prediction calculated with the parameters measured at two temperature values are presented in Table 4 and the corresponding parameters measured at three temperature values are presented in Table 5. The results of the life-times prediction calculated by the same kinetic expresions are more realistic when the ageing was carried at more temperature values (minimum three temperature values with the highest at 80°C).

Conclusion

The results of the propellants life-times prediction obtained in accordance with STANAG 4527 methodology by the expression for the rate of stabilizer consumption of the first order were more realistic than the results obtained by using the expression of the zero order. Also, the improved exponential-linear kinetic model gave more realistic results than the applied exponential model. However, it is not included in the standards due to its complexity.

The most realistic values of the life-time prediction were obtained for propellants NGR-176, (51 years) and the NGR-316 (154 years) in accordance with AOP-48, Ed.2. by the kinetic model of n^{th} order of stabilizer consumption in the propellant samples subjected to accelerated ageing.

The kinetic model of n^{th} order gave good agreement of the measured and calculated concentration values of CI in the examined double-base propellants until the stabilizer content is not lower than 20% of its initial value.

The methodology of the life-time prediction of propellants is basically the same in our and NATO standards. All tests are based on the multi-temperature ageing of propellants and the kinetic analysis of the stabilizer consumption in the given temperature interval. However, NATO tests recommended the application of reaction rate expressions of first, zero and n^{th} order and SORS 8069/91 consumption of stabilizer describes only with reaction rate expressions of the first order. The methodology of SORS 8069/91 life-time propellant prediction prescribes the procedure of accelerated aging of propellants in the heating blocks at two temperature values, 60°C and 70°C and NATO standards require accelerated aging at minimum three temperature values in the interval from 40°C do 80°C. It was shown that the interval and the number of temperature values of accelerated ageing have effects on the values of the kinetic parameters of CI consumption and on the life-time prediction of double-base propellants.

References

[1] SORS 8069/91: *Praćenje hemijske stabilnosti baruta i raketnih goriva*, Beograd, 1991.

[2] STANAG 4527 (Edition 1): *Explosive, chemical stability, nitrocellulose based propellants, procedure for assessment of chemical life and temperature dependence of stabilizer consumptions rates*, Brussels: North Atlantic Treaty Organization, Military Agency for Standardization, 2004.

[3] AOP-48 Ed.2: *Explosives, nitrocellulose based propellants - stability test procedures and requirements using stabilizer depletion*, Brussels: North Atlantic Treaty Organization, Military Agency for Standardization, 2008.

[4] JEREMIĆ,R., GRBOVIĆ,L.:*Analiza metodologije za ispitivanje hemijske stabilnosti baruta i raketnih goriva*, VTG, 2006, 4, pp.405-414.

[5] JELISAVAC,LJ.: *Hemijska stabilnost i vek upotrebe baruta i raketnih goriva, Kumulativna-naučno-tehnička informacija*, VTI, Beograd, 2009, br. 2.

[6] ANDRADE,J., IHA,K., ROCCOJ.A.F.F., PINHEIRO,G.F.M., MOREIRA,E.D., IHA,M.E.V.S.: *Lifetime of Single-Base Propellants*, Quím.Nova, São Paulo, 2008, vol.31, no.3.

[7] GRBOVIĆ,L., STOILJKOVIĆ,S.: *Analiza rezultata određivanja sadržaja stabilizatora u prirodno starenim barutima*, VTG, 2006, 2, 168-180.

[8] BOHN,M.A.: *NC-Based Energetic materials Stability*, Decomposition and Ageing, Presentation on the meeting Nitrocellulose supply, Ageing and Characterization, Aldermaston, England, 2007.

[9] BOHN,M.A.: *Modelling of StabilizerReactions in Gun and Rocket Propellants from Mallinson L.G.*, Ageing Studies and Lifetime Extension of Materials, Proceedings of an international conference on Ageing Studies and Lifetime Extension of Materials, Published by Springer, 2001, pp.449-466.

[10] BOHN,M.A.: *Prediction of Life Times of Propellants –Improved Kinetic Description of the Stabilizer Consumption*, Propellants, Explos., Pyrotech., 1994, no.19, 266-269.

[11] BOHN,M.A.: *Methods and Kinetic Models for the Lifetime Assessment Solid Propellants*, AGARD Confer. Proceed., Neuilly-Sur-Seine, 1997, 586, p. 2-1 - 2-12.

[12] BOHN,M.A., EISENREICH,N.: *Kinetic Modelling of the Stabilizer Consumption and of the Consecutive Products of the Stabilizer in a Gun Propellants*, Propellants, Explos., Pyrotech., 1997, 12, pp.125-136.

[13] JELISAVAC,LJ.: *Kinetika procesa starenja jednobaznih baruta*, Magistarski rad, PMF, Beograd, 2002.

[14] JELISAVAC,LJ., FILIPOVIĆ,M.: *A Kinetic Modelling for the Consumption of the stabilizer in single Base Gun Propellants*, 2002, J. Serb. Chem. Soc., 67, 2,103-109.

[15] JELISAVAC,LJ.: *Kinetičko modelovanje potrošnje stabilizatora etilcentralita u ubrzano starenim uzorcima DRG*, Energetski materijali, Zbornik radova, Istraživanja 2006-2008.

[16] CHOVANCOVA,M., OČKO,P., PECHOVA,A., LOPUCH,J.: *Lifetime Prediction of Propellants according to NATO Standards*, www.witu.mil.pl.

[17] JELISAVAC,LJ., DIMIĆ,M.: *Istraživanje kinetike procesa potrošnje stabilizatora i ocena hemijske stabilnosti ubrzano starenih uzoraka dvobaznih raketnih goriva*, Beograd, 2008, VTI-04-01-0528.

[18] JELISAVAC,LJ., BAJRAMOVIĆ,D.: *Procena veka upotrebe dvobaznih raketnih goriva kinetičkim modelovanjem potrošnje stabilizatora*, Zbornik radova 3. naučno-stručnog skupa OTEH 2009 sa međunarodnim učešćem, Beograd 2009.

[19] JELISAVAC,LJ.*: Analiza i izbor optimalnog kalibracionog postupka gasno- hromatografskog određivanja sadržaja etilcentralita u dvobaznim barutima i raketnim gorivima*, 2. Naučni skup "Odbrambene tehnologije u funkciji mira, – OTEH 2007", Beograd, decembar 2007.

[20] JELISAVAC,LJ.: *Determination of Ethyl Centralite Stabilizer in Double –Base Propellants by Gas Chromatography: Linearity*, Accouracy, Precision, Scientific-Technical Review, 2007, Vol.LVII, No.3-4, pp.86-92.

Received: 01.02.2010.

Procena veka upotrebe dvobaznih raketnih goriva prema srpskim i NATO standardima

U radu je istraživan vek upotrebe dva tipa dvobaznih raketnih goriva (NGR-176 i NGR-316), primenom nacionalnog standarda SORS 8069/91 i NATO standarda: STANAG 4527 i AOP -48, Ed 2.

Uzorci ispitivanih raketnih goriva, ubrzano su stareni u termo-blokovima na temperaturama 80°C, 70°C i 60°C. Potrošnja stabilizatora etilcentralita u ispitivanim uzorcima, u zavisnosti od vremena i temperature, merena je metodom gasne hromatografije. Dobijeni eksperimentalni rezultati su matematički opisani, primenom različitih kinetičkih modela. Kinetički parametri reakcije potrošnje stabilizatora određeni su primenom Arenijusove jednačine. Vek upotrebe raketnih goriva izračunat je kao vreme (u godinama) nakon koga u gorivu preostaje kritična vrednost od 50% početnog sadržaja stabilizatora na temperaturi skladištenja 25°C.

Poređenjem rezultata procene veka upotrebe dvobaznih raketnih goriva, dobijenih prema različitim standardima, najrealnije vrednostii dobijene su saglasno NATO standardu, AOP-48, Ed.2, opisom potrošnje stabilizatora primenom kinetičkog izraza *n*-tog reda.

Ključne reči: **raketno gorivo, dvobazno raketno gorivo, etilcentralit, predviđanje veka upotrebe, hemijska stabilnost, gasna hromatografija.**

Оценка срока службы двухосновных raketnwh topliv по SORS сербским и НАТО-стандартам

V nasto}|ej rabote исследован srok slu`bw двух сорт двухосновных raketnwh topliv (NGR-176 и NGR-316), применением nacionalxnого standarta SORS 8069/91 и NATO-standarta: STANAG 4527 и AOP-48, Ed 2.

Образцы исследованых raketnwh topliv ускоренно старели в термоблоках на температурах 80°C, 70°C и 60°C. Потребление стабилизатора этилцентралита в исследованых образцах, в зависимости от времени и температуры, измерено методом газовой хроматографии. Полученные экспериментальные результаты описаны математическим способом, с применением различных кинетических моделей. Кинетические параметры реакции потребления стабилизатора определены применением уравнения Арениуса. Crok slu`bw raketnwh topliv рассчитан в значении времени (в годах), после которого в топливе остаётся критическое значение 50% исходного содержания стабилизатора на температуре склада 25°C.

Сопоставлением результатов ocenki sroka slu`bw двухосновных raketnwh topliv, полученых по различным standartam, самые реальные значения получены в sootvetstvии с trebovani}mи NATO-standarta, AOP-48, Ed 2 описанием потребления стабилизатора применением кинетического выражения «n»-порядка.

Kly~evwe slova: raketnoe toplivo, двухосновное raketnoe toplivo, этилцентралит, srok slu`bw, himi~eska} ustoj~ivostx, газовая хроматография, standartw.

Estimation de la durée de vie pour les propergols bibasiques selon les normes SERBES et OTAN

On a étudié la durée de vie de deux types de propergols bibasiques (NGR-176 et NGR-316) utilisant la norme nationale SORS 8069/91 et des normes de l'OTAN: STANAG 4527 et AOP-48,ed.2. Les échantillons des propergols étudiés étaient soumis au vieillissement accéléré aux températures de 80°C, 70°C et 60°C, dans les thermo blocs. La consommation du stabilisant centralit éthylique chez les échantillons étudiés, en fonction du temps et de la température, a été mesurée par la méthode de la chromatographie à gaz. Les résultats des essais ont été décrits mathématiquement en appliquant différents modèles cinétiques. Les paramètres cinétiques de la réaction de consommation du stabilisant ont été déterminés à laide de l'équation d'Arenius. La durée de vie des propergols a été calculée comme temps (en années) après quoi dans le propergol reste la quantité critique de 50% du contenu initial du stabilisant, à la température de dépôt de 25°C. La comparaison entre les résultats de la durée de vie des propergols bibasiques, obtenus suivant diverses normes , démontre que les valeurs les plus réelles ont été obtenues selon les normes de l'OTAN,AOP-48,Ed.2, en décrivant la consommation du stabilisant par l'expression cinétique de l'ordre n-ième.

Mots clés: **propergol, propergol bibasique, centralit éthylique, durée de vie, stabilité chimique, chromatographie à gaz, normes.**