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Influence of energetic characteristics of double-base propellants on internal-ballistics parameters

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Abstract:

Solid propellant rocket motors for shoulder launched infantry weapon systems are characterized by short working time, high combustion pressure and large range of designer solutions for rocket motor structure and geometry of propellant charge. Internal-ballistics parameters of impulse rocket motors depend on many factors: design of rocket motor structure, shape of propellant charge, type of connection between propellant charge and rocket motor body, type and position of ignition system, type of motor rotation and nozzle(s) design. Considering the fact that these rocket systems should be operative in a broad range of ambient temperatures (from -40 ℃ to +60 ℃), types of rocket propellant and ignition system play important role. In published literature there are no available models which describes in detail process of design of solid propellant rocket motors and there is very limited number of public references with information regarding types of rocket propellants (double-base or composite) used in these rocket systems. Experimental research were conducted in order to investigate influence of ambient temperature, small changes in energetic characteristics of double-based propellants, and small changes of propellant mass and age of propellant on internal-ballistics parameters of impulse rocket motors.

Keywords: impulse; solid propellant; rocket; internal ballistics

1 Introduction

Typical representatives of shoulder launched infantry rocket weapons are Light Anti-Armor Weapon or M72 LAW, Apilas, Shoulder-launched Multipurpose Assault Weapon (SMAW), Light Anti-armour rocket weapon 64 mm M80 ZOLJA or RPG-18, Multipurpose assault rocket weapon 90 mm M79 OSA, Light Anti-Armour Weapon LAW 80, B-300, RPG-22, RPG-26, Shipon, etc.

For unguided shoulder launched infantry weapon systems, solid propellant grain must be burnt while a projectile is still inside the launcher because of operator's safety requirements. A common feature of LAW is rocket motor with extremely short burning time, measured in milliseconds. The shoulder launched infantry weapon systems represent firepower for the individual fighter and it is not specialized for a single mission [4].

Design of solid propellant rocket motors for LAW munitions is considerable more complex compared to most of the rocket motors for other purposes. Specific requirements for such rocket motors are following [2]:

- Short burning time,
- Launch rocket motor must not be active at the launch tube muzzle,
- High pressure inside the rocket motor chamber,
- Environmental conditions when used from -40°C up to +60°C,
- Low temperature sensitivity of the solid propellant,
- Reliable ignition,

- Short ignition time,
- Short ignition rise time,
- High safety requirements, because LAW is fired from operator's shoulder.

2 Objective and subject of researching

Available published papers describe specific methodology for design of short time rocket motor and analyses of influence of individual parameters on rocket motor internal ballistics are quite rare.

Extensive testing of rocket motors with system Light Anti-Armor Weapon 66 mm M72 LAW, Light Anti-armor rocket weapon 64 mm M80 ZOLJA and Multipurpose assault rocket weapon 90 mm M79 OSA show extraordinary influence of small changes of propellant's energy characteristics, ambient temperature and the process of ignition on the short time rocket motor internal ballistics [2].

Double-base rocket propellant at short time rocket motors because of its specific design of motor (small dimensions, very short time of combustion, special demands for reliability and function safety for shoulder launching, very high combustion pressures, small mass of structure etc.) requires continuous control of production process and tight tolerances of propellant performances and dimension of grains.

It is necessary to control thermal potential of rocket motors, without changing ballistic performances or combustion burning rate.

Thermal potential of double-base rocket propellants in short-time rocket motors ranges from 4.600 – 5.440 J/g, and in the rocket motors combustion pressures achieved are around 300 – 700 bar (it is required that those pressures are lower). Existing military standards define permitted change of value for thermal potential of double-base propellants during the production process about ±1,25% [1].

One of the main designer requests is decreasing of maximal combustion pressure inside the impulse rocket motors with fulfillement of internal ballistics performances.

Objective of research was to determine influence of small changes on propellant M7 energy characteristics, small changes on the propellant mass, ambient temperature and ignition process on short time rocket motors internal ballistics 66 mm M72 LAW. Concept of research was based on approach that with the change of thermal potential of double-base rocket propellant with addition of energy inert additive (vaseline) in the range and without modification of combustion rate, possibilities for regulation of maximum combustion pressure are explored and reliable and safe function of rocket motors during the movement through launching tube.

Research subject was double base propellant M7 that is used in rocket motors of LAW 66 mm M72 (table 1).

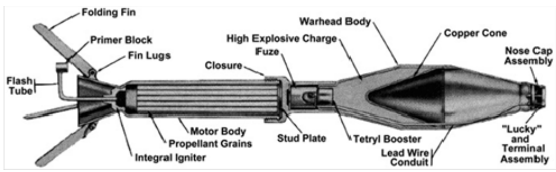
3 Experimental research

Basic composition of double rocket propellant M7 is consisted of 59,15% NC with 13,15 % N (Nitrocellulose) as a binder, 31,4 % NG (Nitro-glycerine) as plasticizer, 1,0 % EC (Ethyl Centralite) as stabilizer and 7,9 % Potassium Perchlorate and 0,58% Carbon Black [5, 6, 7].

Modification of energy potential of double base propellant is achieved with the addition of vaseline. Thermal potential of propellant M7 according to the standard MIL–P–14737, has to be in the range from 5.275 – 5.400 J/g. Chemical composition for all four groups of rocket propellant had same chemical components and corrections of thermal potential of rocket propellant were carried during the final mixing in the mixer by adding different amounts of vaseline.

First group of propellants did not consist vaseline (basic composition of propellant) and measured thermal potential for this group of rocket propellant was Q = 5.412,5 J/g .

Table 1: Performance of rocket motor 66 mm M72 [3, 5, 6, 7]

Mass of rocket motor, g	304	Internal diameter of grain propellant, mm	3,9
Type of double propellant	M7	Length of grain, mm	144
Mass of propellants, g	62,7	Thrust at 21^0C, N	18.905
Configuration of grain	CP (central perforation)	Burning time, ms	7-15
Number of grains	19	Temperature limits	-40^0C do 60^0C
External diameter of grain propellant, mm	5,8		

At second group of propellant, beside basic additives during the mixture of propellant, 0.3% vaseline was added and measured value for thermal potential was Q =5.380 J/g.

At third group, 0,6% of vaseline was added to the basic composition and measured value for thermal potential was Q =5.298 J/g .

At fourth group of propellant, to the basic composition 0,9% vaseline was added and achieved thermal potential was Q = 5.267 J/ g.

Pressing of charge for propellant, cylinder type, with central perforation was carried on vertical hydraulic press, and drying of propellant is achieved with the use of hot air.

3.1 First phase of testing

For testing an influence of the changes of energy parameters on the internal-ballistics parameters for all four groups of propellant, testing of five rocket motors was planned on temperature from -40^0C and $+60^0$C. Standard rocket motors 66 mm M72 are used with original ignition system. Changes of the pressure as a function of time for every rocket motor were measured (from figure 1 to figure 8).

In the first phase of testing, the mass of double-base propellants (58,0 g) was less than the mass of propellant from the rocket motor series. This is done because of the safety of solid rocket motors structures during testing. In the second phase of testing rocket engines were used with original mass of 62,4 g of propellant.

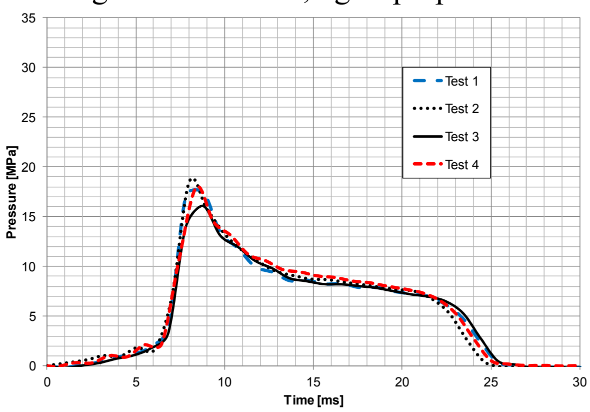


Figure 1: Change of p=f(t) in rocket motor with basic composition of propellant, group 1, at ambient temperature -40^0C

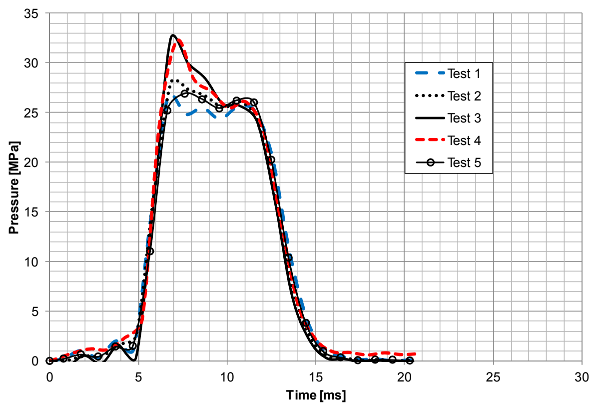


Figure 2: Change of p=f(t) in rocket motor with basic composition of propellant, group 1, at ambient temperature 60^0C

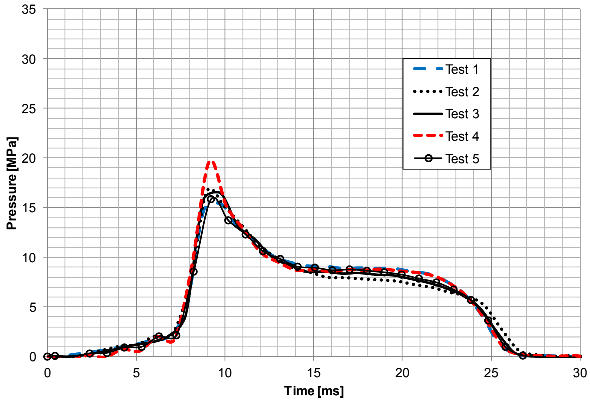


Figure 3: Change of p=f(t) in rocket motors with addition of 0,3% vaseline to the basic composition of propellant, group 2, at ambient temperature -40^{0}C

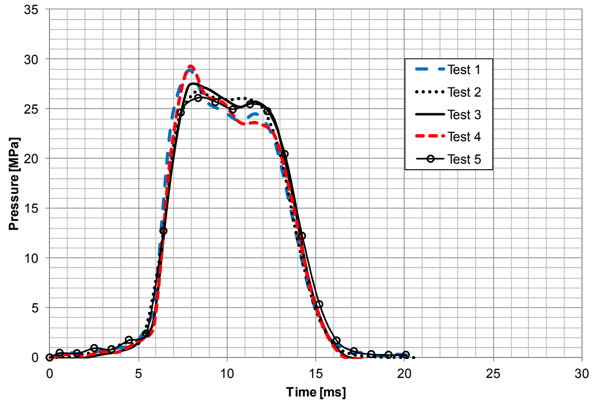


Figure 4: Change of p=f(t) in rocket motor with addition of 0,3% vaseline to the basic composition of propellant, group 2, at ambient temperature 60^{0}C

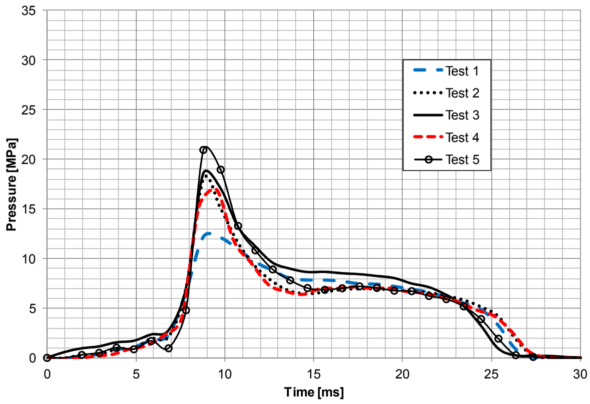


Figure 5: Change of p=f(t) in rocket motors with addition of 0,6% vaseline to the basic composition of propellant, group 3, at ambient temperature -40^{0}C

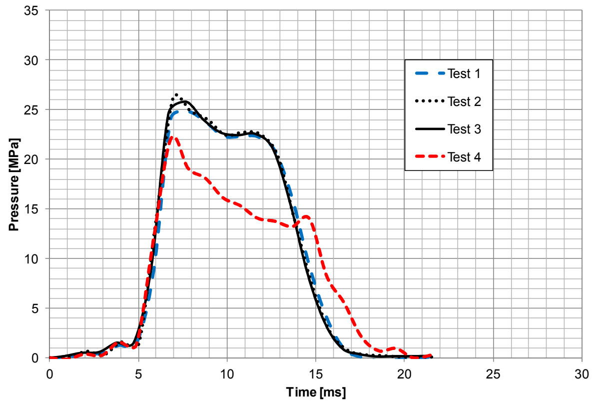


Figure 6: Change of p=f(t) in rocket motors with addition of 0,6% vaseline to the basic composition of propellant, group 3, at ambient temperature 60^{0}C

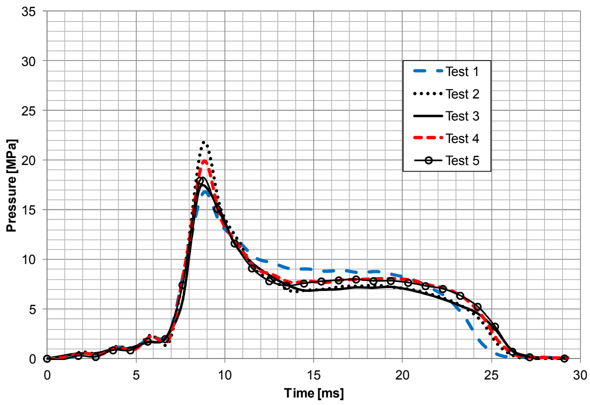


Figure 7: Change of p=f(t) in rocket motors with addition of 0,9% vaseline to the basic composition of propellant, group 4, at ambient temperature -40^{0}C

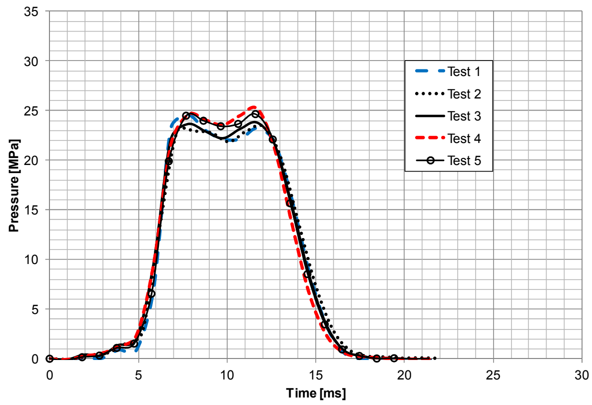


Figure 8: Change of p=f(t) in rocket motor with addition of 0,9% vaseline to the basic composition of propellant, group 4, at ambient temperature 60^{0}C

Testing of propellant from the group 3 that consisted of 0,6% vaseline in the basic composition of propellant, indicated significant deviations in character changes p=f(t) and larger deviations in the values of maximal pressures. Tests of propellant from the group 3 were repeated, and results of testing were very similar.

When comparing the values of maximum pressures at the propellant's groups 3 and 4, stabilization of values of maximum combustion pressures in rocket motors was determined whenever there was increase of vaseline in the basic composition of propellant or decrease of thermal potential of propellant Q.

3.2 Second phase of testing

For propellant from group 2 good reproduction of values of maximum combustion pressure was achieved and good agreement of character changes p=f(t) inside of the rocket motors group. Because of that, production of propellant for the following group was carried where it was added 0,4 % vaseline to the basic composition of propellant. Thermal potential of the new group of propellant (group 5) was Q= 5.372 J/g.

Values of maximum combustion pressures in the rocket motors during the testing of the first four group were significantly below permitted maximum values of pressure for the motor's structure; for this group the mass for the propellant charge was increased from 58,0 g to 62,4 g. Testing at the ambient temperatures 40^{0}C, 0^{0}C, 21^{0}C and 60^{0}C were expanded, with five rocket motors for every ambient temperature.

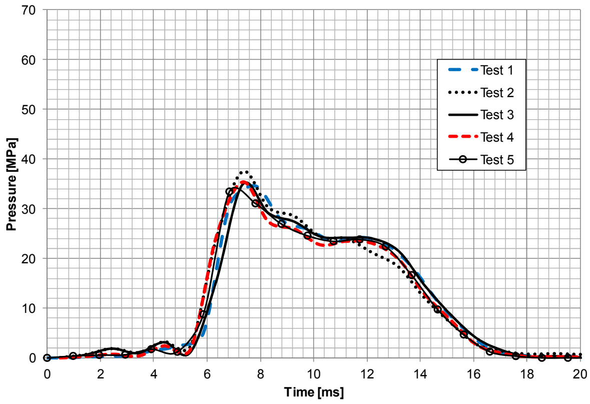


Figure 9: Change of p=f(t) in rocket motors with addition of 0,4% vaseline to the basic composition of propellant, group 5, at ambient temperature -40^{0}C

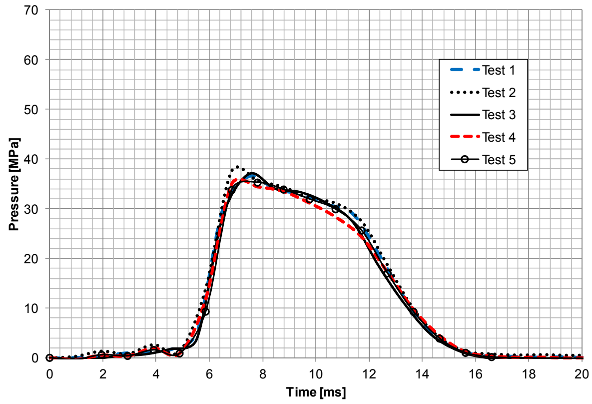


Figure 10: Change of p=f(t) in rocket motors with addition of 0,4 % vaseline to the basic composition of propellant, group 5, at ambient temperature 0^{0}C

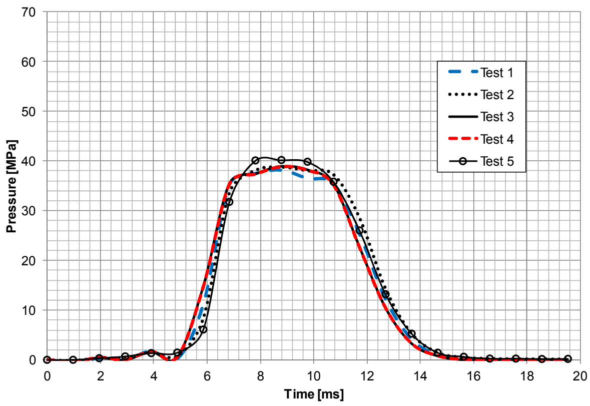


Figure 11: Change of p=f(t) in rocket motors with addition of 0,4% vaseline to the basic composition of propellant, group 5, at ambient temperature 21^{0}C

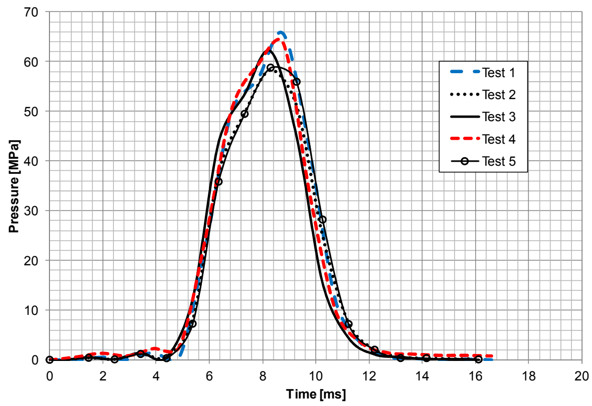


Figure 12: Change of p=f(t) in rocket motors with addition of 0,4% vaseline to the basic composition of propellant, group 5, at ambient temperature 60^{0}C

3.3 Third phase of testing

In this phase of testing, comparison of results for testing of standard rocket motors 66 mm M72 was carried with the propellant that was two and twenty-seven years old with results of testing of rocket motors with the propellant from the group 5.

The objective comparison of results of testing these groups of rocket engines needs to indicate the influence of the time production factor on rocket motors internal-ballistic parameters, specially on the values of maximum combustion pressure and the combustion time of rocket motor.

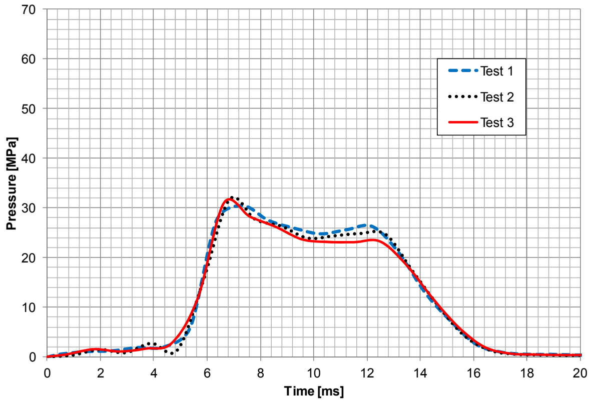


Figure 13: Change of p=f(t) in rocket motors with the propellant produced two years old, at ambient temperature -40^{0}C

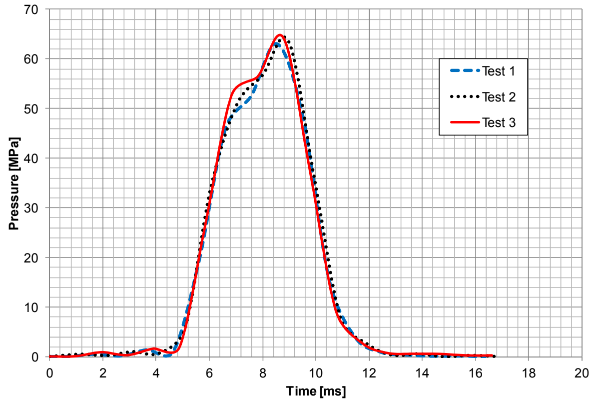


Figure 14: Change of p=f(t) in rocket motor with the propellant produced two years old, at ambient temperature 60^{0}C

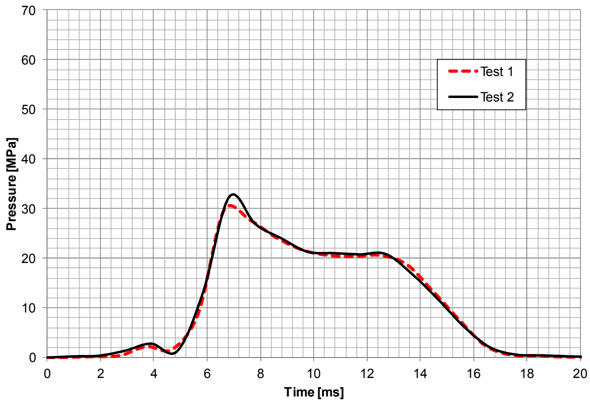


Figure 15: Change of p=f(t) in rocket motors with the propellant produced twenty-seven years old, at ambient temperature -40^{0}C

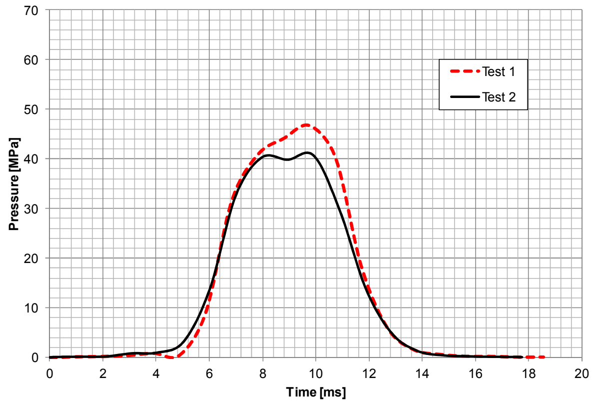


Figure 16: Change of p=f(t) in rocket motor with the propellant produced twenty-seven years old, at ambient temperature 60^{0}C

4 Analysis of researching results

4.1 Influence of the small changes on propellant's energy potential

Testing of groups of propellant M7 with the different parts of inert additives, such as vaseline, it was observed that it is possible to correct propellant's heat potential Q (Fig. 17) and in accordance with it, to achieve possibility to decrease the value of maximum pressure at the ambient temperature 60^{0}C (Fig. 18). With the addition of 0,4 % vaseline, it is possible to decrease maximum combustion pressure for about 10% at the ambient temperature 60^{0}C.

Addition of 0,4 % vaseline in the basic composition of propellant M7, significant effects are achieved on internal-ballistic parameters such as maximum combustion pressure, combustion time of rocket motors and integral pressure-time. Further increase of the vaseline percentage does not provide significant change of mentioned sizes (Fig. 18 to Fig.20).

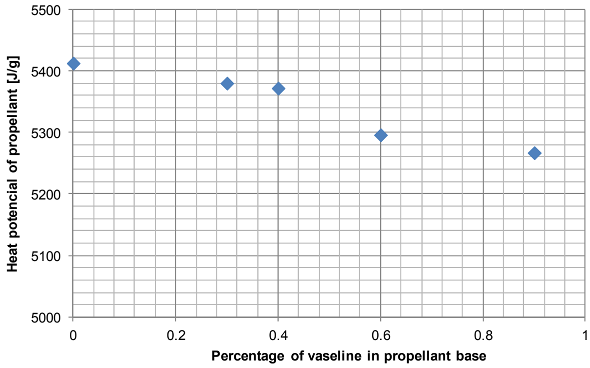


Figure 17: Change of heat potential with the small percentage of vaseline in the basic composition of propellant

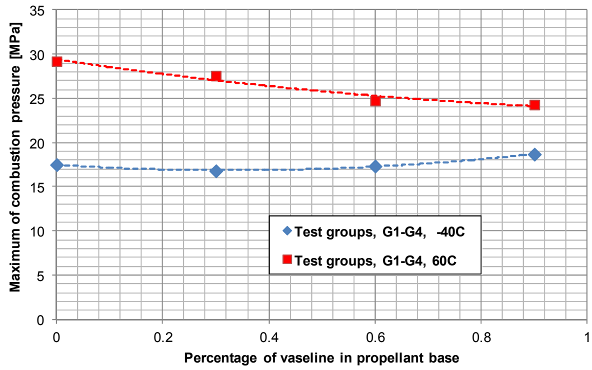


Figure 18: Change of maximum combustion pressure in rocket motors depending on small percentage of vaseline in the basic composition of propellant

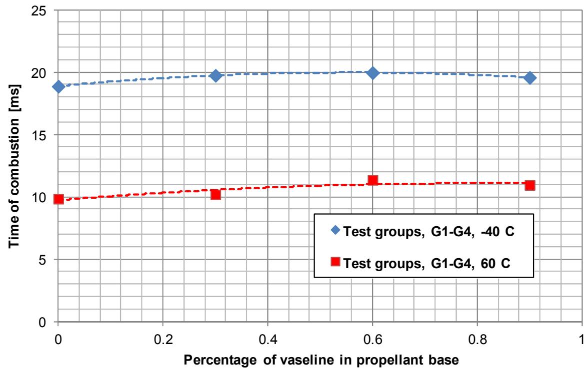


Figure 19: Change of combustion time in the rocket motor depending on small percentage of vaseline in the basic composition of propellant

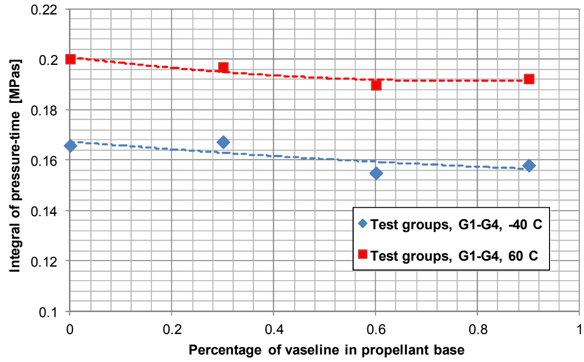


Figure 20: Change of integral pressure-time in the rocket motor depending on small percentage of vaseline in the basic composition of propellant

4.2 Influence of temperature

During the research of internal-ballistics parameters of the system LAW 64 mm „Zolja" and LAW 90 mm „Osa", significant effect of changing ambient temperature was observed on internal-ballistics parameters of the propellant [2]. That effect was reflected on large differences in the values of maximum combustion pressures and combustion time of rocket motors at ambient temperature -40^{0}C and 60^{0}C.

The same effect was observed during the the testing of rocket motors LAW 66 mm M72 (Fig. 21 to Fig. 23).

Difference between maximum combustion pressures can be up to 100 %.

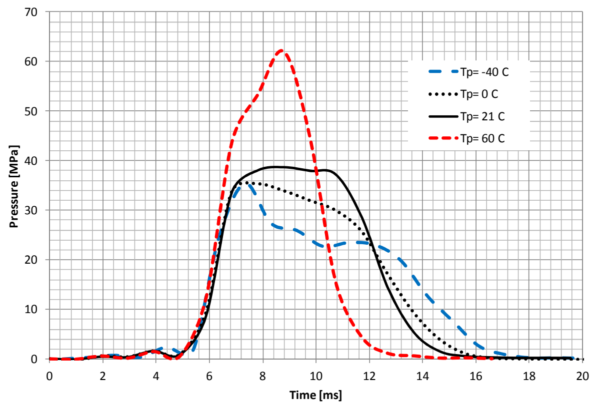


Figure 21: Influence of ambient temperature on the shape of curve of combustion pressures p(t) at test groups of rocket motors.

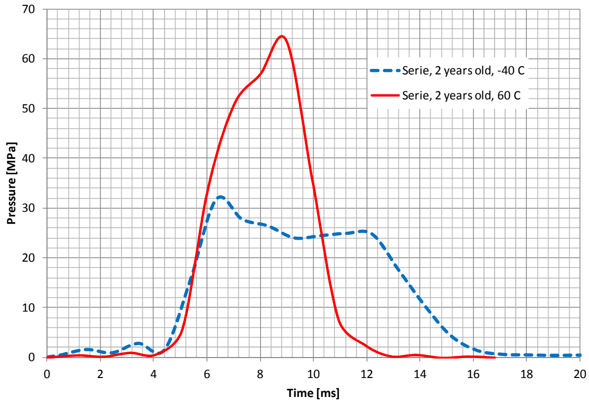


Figure 22: Influence of ambient temperature on the shape of curve of combustion pressure p(t) for rocket motors from series two years old

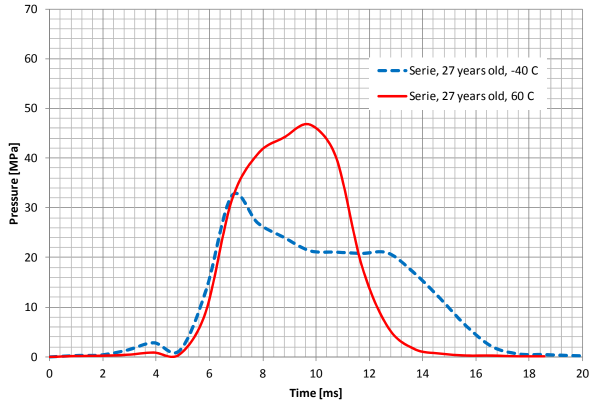


Figure 23: Influence of ambient temperature on the shape of curve of combustion pressure p(t) for rocket motors from series twenty-seven years old

4.3 Influence of the small changes of ratio of mass propellant and the free volume of the chamber rocket motor

During the production of several series of propellant charge, type CP (central perforation), it is not possible to achieve completely identical dimensions of the propellant charge, density and energy potential of the propellant in narrow boundaries. Criteria for receiving this type of solid rocket propellant that during the combustion process in rocket motor, maximum pressure of combustion and time combustion does not exceed the limit value and speed of rockets at the exit of the launcher must have the prescribed minimum value.

In serial production of propellant, minor deviations are allowed in density of propellant, or length of charge. These parameters from serial production influences on small changes of ratio of mass propellant and the free volume of the chamber rocket motor.

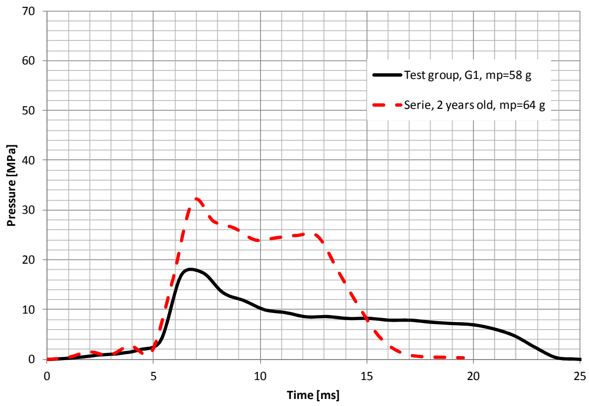


Figure 24: Influence of the small change of ratio of propellant mass and the free volume of the chamber rocket motor on the shape of the curve p(t) at ambient temperature -40^{0}C

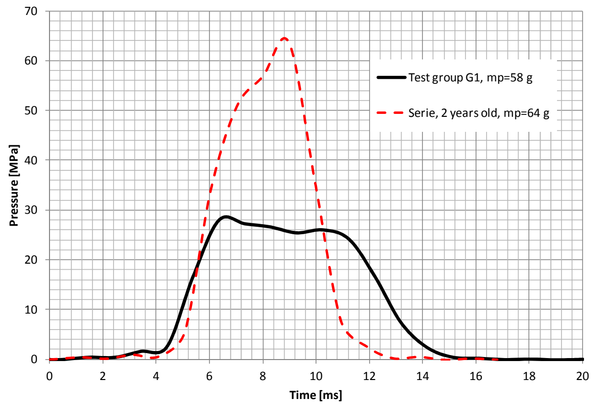


Figure 25: Influence of the small change of ratio of propellant mass and the free volume of the chamber rocket motor on the shape of the curve p(t) at ambient temperature 60^{0}C

In the study we researched the influence of small changes of ratio of mass propellant and the free volume of the chamber rocket motor on internal ballistics characteristics of rocket motors. With the change of propellant mass by 10 % (Δm= 6 g), increase of maximum combustion pressure in the rocket motors of 130 % at the ambient temperature 60^{0}C is achieved, or for about 70% at the ambient temperature -40^{0}C. That effect is extremely dangerous at ambient temperature of 60^{0}C, because it can lead to the destruction of rocket motor.

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4.4 Influence of the propellant's lifetime

Based on the results of testing groups of the propellant G1 (without addition of vaseline), group of motors from series with the propellant produced twenty-seven years ago (fig. 26 and fig. 27), influence of propellant's lifetime on internal-ballistic performances are clearly visible.

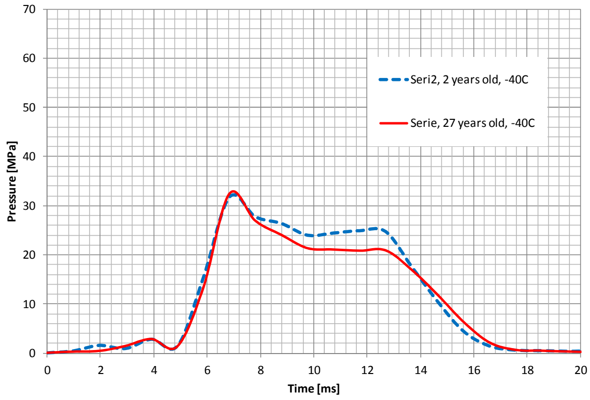

Figure 26: Influence of propellant's lifetime on the character changes p(t) at ambient temperature 40^{0}C

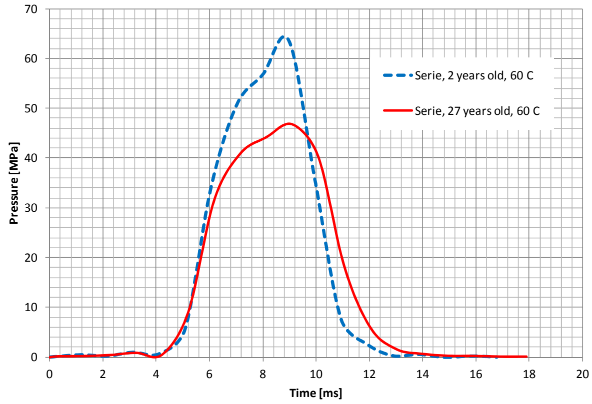

Figure 27: Influence of propellant's lifetime on the character changes p(t) at ambient temperature 60^{0}C

For twenty-seven years old propellant the greatest influence on the character of pressure change vs time (fig. 27) were observed during the testing at ambient temperature of 60^{0}C. Combustion pressure was decreased for 30 % (fig. 28), and combustion time was extended (fig. 29) and the value of integral of combustion pressure vs time (fig. 30) was decreased.

Mentioned influence are probably caused by the lost of nitroglycerin part and presence of denitration process during the time of storage of rocket motors with the propellant and surely will be reflected on external-ballistic performances of rocket projectile 66 mm M72.

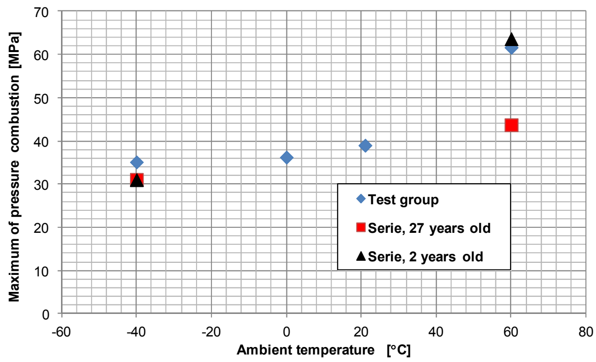

Figure 28: Influence of propellant's lifetime on the values of maximal pressure at different ambient temperatures

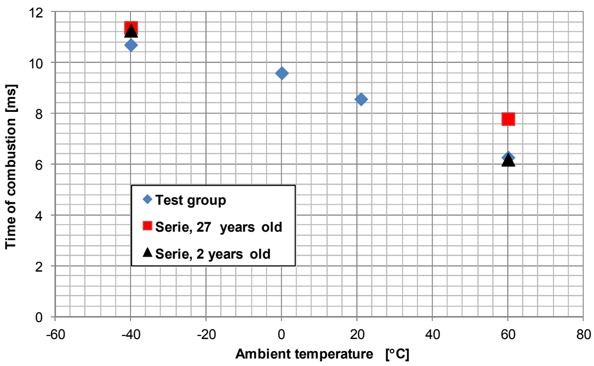

Figure 29: Influence of propellant's lifetime on the change of combustion time of rocket motor at different ambient temperatures

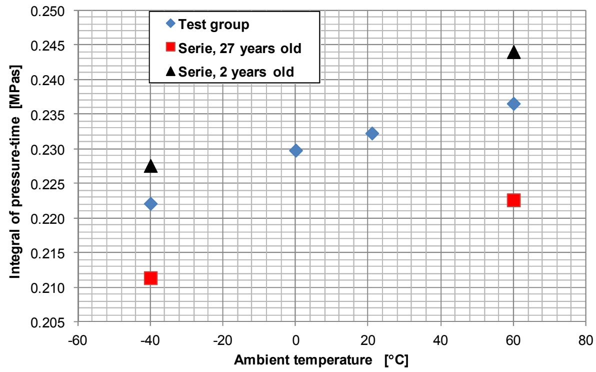

Figure 30: Influence of propellant's lifetime on the change of integral pressure-time of rocket motor at different ambient temperatures

5 Conclusion

Small changes of energy potential of propellant M7 are possible to achieve with addition of small amounts of inert additive such as Vaseline into basic composition of propellant. With addition of Vaseline up to 0,4 % into basic composition of propellant M7, it is possible to achieve significant effects on internal-ballistic parameters such as maximal combustion pressure, combustion time of rocket motor and integral pressure-time. Further increase of Vaseline percentage can not provide significant changes of mentioned sizes.

Significant effect of ambient temperature change on internal-ballistic parameters of propellant was observed, and it is specially reflected on large differences in the values of maximal combustion pressure and combustion time of rocket motors at ambient temperatures -40^{0}C and 60^{0}C. Difference in maximum combustion pressures can be up to 100 %.

For serial production of propellant, minor deviations are possible to appear in density and energy potential of propellant, or in the mass and length of charge. Possible occurrence of small changes of ratio of mass propellant and the free volume of the chamber rocket motor. Increase in the of ratio of mass propellant and the free volume of the chamber rocket motor causes increase of maximal combustion pressure in the rocket motor specially at the ambient temperature 60^{0}C. Increase of maximum pressure can be extremely dangerous, because it can lead to the destruction of the rocket motor's body.

Ageing of the rocket double base propellant causes lost of the nitro-glycerine percentage and leads to the process of denitration during the time of storage of rocket motors with propellant. It certainly reflects on the external-ballistic performances of the rocket projectile 66 mm M72 (decrease of maximum combustion pressure, extended time of combustion and decrease of the integral value of combustion pressure vs time) i.e. rocket has lower velocity at the exit from the launcher and increased accuracy at target.

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