

Preparation of the porous spherical propellant by using the additives of alkali-metal salt

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ABSTRACT

This article presents the research results on using some alkali-metal salts as additives in the technological process of making porous spherical propellants and the effects of some of these additives on the porosity and some characteristics of the propellant. The porous spherical propellants are prepared using the emulsion method with additive concentrations of Na_2SO_4 , K_2SO_4 , and KNO_3 from 0% to 3%. The important characteristics of the sample were determined, such as heat of combustion (Q_v), bulk density (ω), temperature of ignition (T_{ig}), and chemical stability. The porosity is calculated and converted through bulk density and theoretical density. The results show that the sample with the Na_2SO_4 salt has the best porosity (51÷53%) at concentrations over 2%. The important characteristics of the porous propellant do not change significantly compared to the no-additive spherical propellant.

Keywords: Spherical propellant; Additive; Alkali-metal salt; Porous spherical propellant.

1. INTRODUCTION

Porous spherical propellant is a type of low-density, high-burning-rate propellant that has been effectively produced and used for various types of handgun and shotgun ammunition [1]. The porosity of the propellant greatly affects its burning rate. The higher the porosity, the faster the burning rate of the propellant [2]. High porosity is especially important for short-barreled weapons to ensure the effective use of propellant. Several types of low-density, double-base spherical propellants have been developed, such as No. 2 and Nitro 100 in Western Europe [3], as well as Sunar, Sunar SF, and Sunar SVM in Russia [4]. For instance, the No.2 spherical propellant (nitroglycerin (NG)-14%) has a bulk density of 0.65 g/cm³ and an average diameter of 0.457 mm. Nitro 100 (NG-21%) has a diameter of 1.473 mm, a burn thickness of 0.254 mm, and a bulk density of 0.505 g/cm³. Russian porous spherical propellants such as Sunar, Sunar SF, and Sunar SVM have a porosity ranging from 34 to 73% and a bulk density ranging from 0.4 to 0.6 g/cm³.

The spherical propellant is manufactured by dispersing a propellant paste solution in water under the influence of a stirring blade, with the presence of a surfactant [4-6]. The process of manufacturing the propellant is carried out in the following sequential stages: dissolving nitrocellulose (NC) in ethyl acetate, dispersing to form granules in water, distilling the solvent, dehydrating, washing, and drying [4, 5, 7]. The porosity of the propellant granules can be adjusted through various methods, such as regulating the amount of dehydrating agent, controlling the solvent evaporation rate, or adding additives [8, 9]. Among these, adjusting the porosity of the granules by adding foaming additives is an effective method.

The foaming additives for propellants must be water-soluble, create a neutral environment in water, and do not affect the chemical stability of the components. Therefore, the salts of a strong acid and a strong base are suitable. It should be noted that at the end of the manufacturing process of the spherical propellant, a certain amount of sodium carbonate is added to neutralize the acid produced during the manufacturing process. So, the cation of the additive must not precipitate with the carbonate anion. From the above reasons, it can be seen that only the salts of alkali metals meet the requirements.

This paper aims to examine the impact of certain alkali metal salt additives on the porosity and various characteristics of spherical propellants with a specific composition. The goal is to identify the most effective type and concentration of salt for manufacturing foamed spherical propellant.

2. EXPERIMENTAL

2.1. Materials

The BW nitromas are supplied by Z factory. Some of their main characteristics are shown in table 1.

Table 1. The main characteristics are the types of nitromas BW.

Nitromas	NC (%N), %	NG, %	Dinitrotoluene (DNT), %	Q _v (cal/g)
BW grade	80.3 (13.0%)	18.8	0.90	1090

The chemicals used in this work were pure chemicals (PA) and purchased on the market. Ethyl acetate, sodium sulfate, sodium carbonate, potassium nitrate, and potassium sulfate were purchased from Xilong Company, China. Arabic gum was from France.

2.2. Methods

2.2.1. Preparation of sample

150 ml of distilled water was measured into a three-neck flask of 500 ml. The additive for making porosity according to the calculated amount was added into the flask and dissolved in 10 minutes. Next, 20 grams of nitromas (dry weight) was put into the flask and stirred at 50 °C for 30 minutes. Then, 100 ml of ethyl acetate containing 0.2 grams of DPA was poured into the flask and stirred to disperse at a temperature of 58 °C for 30 - 60 minutes (when checking the particles have been formed). Next, 2 grams of gum arabic solution dissolved in 20 ml of solution were put into the flask and continued to disperse to form granules at 65 °C for more than 30 minutes until the size requirements of granules.

Then, the temperature was raised to 72 – 74 °C to distill the solvent for the first time. When the amount was 40 ml, the solvent distilling was stopped and 5 grams of sodium sulfate in 30 ml of water were added to the flask. Dehydration was carried out at 72 – 74 °C for 2 hours. Then, gradually the temperature was increased and the solvent was distilled until reaching a temperature of 100 °C.

At the end of dehydration, the sample was soaked and washed 5 times for 30 min with distilled water; the product was then transferred to the particle size classification screen in the range of 0.2 to 0.5 mm. The sample was dried in a convection oven at 60 °C for 6 hours.

2.2.2. Determination of bulk density

The bulk density of the propellant is determined by the ratio of the mass of the sample contained in a specified volume. The naturally flowing dried propellant was poured into a cup with a capacity of 10 cm³; the propellant was leveled so that the amount is even with the rim of the cup. The mass of the propellant in the cup was weighed using a precision scale with an accuracy of 0.02 grams and the bulk density was calculated using the following formula:

$$\omega = \frac{m}{V} \quad (1)$$

Where: ω – Bulk density of the propellant, g/cm³; m – Mass of the propellant, g; V – Volume of the measuring cup, cm³;

2.2.3. Calculation of porosity

The porosity of spherical propellant is determined through its density and bulk density. The porosity P of the propellant is calculated using the following formulas [10]:

$$P = \frac{\rho - \frac{\omega}{0,675}}{\rho} \quad (2)$$

Where: P - Porosity of the spherical propellant, %; 0.675 - Packing factor for spherical shapes. Theoretical density (ρ) is calculated by the formula [11]:

$$\rho = \frac{\sum m_i}{\sum \frac{m_i}{\rho_i}} \quad (3)$$

Where: m_i – Weight part of ingredient i, are taken according to table 1; ρ_i – Density of of ingredient i [10].

2.2.4. Measurement of combustion heating

The combustion heating of the propellant is determined according to standard 06TCN 889: 2019 using the Parr 6200 calorimeter.

2.2.5. Testing of ignition temperature

The ignition temperature of the propellant is measured according to standard STANAG 4491 using the DT 400 apparatus.

2.2.6. Determination of chemical stability

The stability of the propellant is assessed through the $K_{3/4}$ parameter, which is determined according to industry standard 06 TCN 588:1996 using the Cary 50 apparatus.

The chemical stability of the propellant is assessed through the volume of gas released from sample decomposition, determined according to STANAG 4556 using the Stabil vacuum stability tester.

3. RESULTS AND DISCUSSION

3.1. Effect of some additives on the porosity of the spherical propellant

The emulsion particles of the propellant, when formed during dispersion, include nitromas dissolved-colloidalized in ethyl acetate and a certain amount of water. If, during the dehydration process, this amount of water is controlled and retained at a certain level, then after all the solvent is removed and dried, the water in the particles of propellant will evaporate, leaving capillaries within the particles; thus creating porous particles of the propellant [4, 9]. Based on this theory, foaming agents are introduced during the dispersion process to create a certain amount of salt solution in the emulsion particles of the propellant. According to the theory of sphere formation, when the surface of the particles is dehydrated, a semi-permeable membrane is formed that allows water to pass through but prevents metal ions from passing through this membrane. Therefore, the dehydration process increases the salt concentration in the propellant particles; the salt concentration of the base solution decreases slowly; when the salt concentration inside and outside the particles is balanced, the dehydration process ends.

To study the impact of these additives on the porosity of the propellant, the research conducted a survey with the following common alkali metal salts as additives: sodium sulfate, potassium sulfate, potassium nitrate, and a mixture of sodium sulfate-potassium sulfate (in a 1:1 molar ratio). The concentration of these additives varied from 0 to 3%. Other technological factors were carried out as presented in the sample preparation method section. The research results are shown in table 2.

From the results in table 2 and figure 1, it can be shown that as the concentration of additives increases, the porosity of the propellant also increases. For the sample without additives, it has the highest bulk density, corresponding to the lowest porosity (15.2%). When the additive concentration increases to about 2%, the porosity of the propellant increases significantly. However, when the concentration of the additive continues to increase to 3%, the porosity of the

propellant does not increase as much. Among the additives used, sodium sulfate has the highest porous efficiency (53.1%) and potassium sulfate has the smallest porosity efficiency (43.1%). This can be explained by the smaller ion size of sodium compared to that of potassium. The porous efficiency of the mixture of sodium sulfate and potassium sulfate salts is between sodium sulfate and potassium sulfate. Comparing the porous efficiency of potassium sulfate and potassium nitrate, they are almost equivalent. It can be concluded that the foaming efficiency of the propellant depends strongly on the nature of the metal ion and weakly on the anionic form of the salt.

Table 2. The effect of the concentration of some porosity additives on the porosity.

No.	Additives	Concentration, %	Bulk density, g/cm ³	Porosity, %
1	Na ₂ SO ₄	0	0.90	15.2
		0.5	0.66	37.6
		1	0.58	45.1
		2	0.52	51.3
		3	0.49	53.1
2	K ₂ SO ₄	0	0.9	15.2
		0.5	0.78	27.3
		1	0.68	36.7
		2	0.62	41.6
		3	0.61	43.1
3	KNO ₃	0	0.9	15.2
		0.5	0.76	28.6
		1	0.67	37.2
		2	0.61	42.9
		3	0.59	44.5
4	Mixture Na ₂ SO ₄ -K ₂ SO ₄ (1:1 by mol)	0	0.9	15.2
		0.5	0.7	34.8
		1	0.62	41.9
		2	0.55	48.1
		3	0.53	50.2

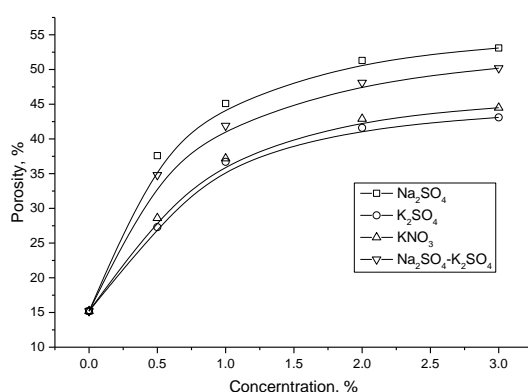


Figure 1. The effect of the concentration of some porosity additives on the porosity of spherical propellants.

3.2. The effect of additives on characteristics of porous spherical propellant

To evaluate the impact of the additive on product quality, important characteristics of the product have been identified. The samples with the highest concentration used (3%) were compared with samples without the additive. The results are presented in table 2.

Table 3. Effect of the additives on some product characteristics.

No.	Additives	Ash, %	Stability,		Q _v , cal/g	T _{ig} , °C
			K _{3/4}	V, cm ³ /g		
1	No additive	0.21	69.56	1.34	1067.6	183.6
2	Na ₂ SO ₄	0.48	69.12	1.27	1071.3	184.1
3	K ₂ SO ₄	0.45	68.71	1.36	1064.8	182.8
4	KNO ₃	0.42	69.03	1.31	1065.9	183.9
5	Na ₂ SO ₄ +K ₂ SO ₄ (1:1)	0.38	69.34	1.29	1072.1	182.7

From the results in table 3, it can be observed that after the foaming process, a certain amount of salt remains in the granules, as indicated by the ash content. Specifically, the ash content in samples with additives is higher than in samples without additives; however, the remaining amount of salt in the granules is relatively small. The analysis of the propellant's stability shows that the presence of a small amount of these salts does not negatively affect the stability of the propellant. Moreover, the values of the combustion heat and ignition temperature show no significant differences compared to the samples without additives. This is because the granules are soaked, dissolved, and washed to remove salt from the final product in the final stage. Therefore, within the most effective concentration range of the foaming additives, these additives have little to no impact on the quality of the propellant.

4. CONCLUSIONS

The porous spherical double-base propellants have been prepared by using some alkali-metal salt additives. The porosity of the propellant can be adjusted by varying the additive concentration up to 3%. The most effective additive concentration should be in the range of 2 - 3%. Among these, sodium sulfate provides the best porous efficiency, reaching approximately 53% at a concentration of 3%. These additives do not significantly affect the important characteristics of the propellant, except for bulk density and porosity.

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TÓM TẮT

Nghiên cứu chế tạo thuốc phóng cầu xóp sử dụng phụ gia muối của kim loại kiềm

Bài báo trình bày kết quả nghiên cứu sử dụng một số muối kim loại kiềm làm phụ gia trong quá trình công nghệ chế tạo thuốc phóng cầu xóp và ảnh hưởng của một số phụ gia này đến độ xóp và một số đặc trưng của thuốc phóng cầu xóp. Thuốc phóng cầu xóp được chế tạo bằng phương pháp nhũ với nồng độ các phụ gia Na_2SO_4 , K_2SO_4 và KNO_3 từ 0-3%. Các đặc tính quan trọng của mẫu được xác định bao gồm nhiệt lượng cháy (Q_v), mật độ đong (ω), nhiệt độ bùng cháy (T_{ig}) và độ ổn định hóa học. Độ xóp được tính toán và quy đổi thông qua mật độ đong và khối lượng riêng. Kết quả khảo sát cho thấy, muối Na_2SO_4 cho hiệu quả tạo xóp tốt nhất (51 - 53%) với nồng độ lớn hơn 2% và ít thay đổi ở nồng độ lớn hơn. Các đặc trưng quan trọng của thuốc phóng cầu xóp không thay đổi đáng kể so với thuốc phóng cầu không sử dụng phụ gia.

Từ khóa: Thuốc phóng cầu; Phụ gia; Muối kim loại kiềm; Thuốc phóng cầu xóp.