Research on the influence of M79-type propellant charge structure on bore pressure

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ABSTRACT

This paper presents the research results on the influence of M79-type propellant charge structures on the bore pressure variation law. The primary objective is to design an optimal propellant charge solution that ensures compatibility with existing chamber dimensions and barrel strength limits. By employing internal ballistic mathematical models, the study investigates key parameters, including grain geometry, loading density, and charge mass. Experimental results confirm that optimizing the charge structure effectively controls bore pressure within safe operational limits while maintaining the required design muzzle velocity. These findings provide a crucial scientific foundation for the improved design and manufacture of propellant charges for current grenade launcher systems.

Keywords: Internal ballistics; M79 propellant charge; Bore pressure; Propellant charge structure; Grenade launcher; Ballistic optimization.

1. INTRODUCTION

In the field of military pyrotechnics, mastering internal ballistics theory is the fundamental cornerstone for designing, optimizing, and modernizing weapon systems. Previous studies established a comprehensive theoretical framework governing propellant thermodynamics and combustion laws [1-4, 7]. Building upon this foundation, numerous subsequent research avenues have been pursued, including solving inverse internal ballistics problems to optimize propellant charges, investigating complex boundary conditions in specialized operating environments, and developing ballistic models that account for realistic factors, such as the incomplete combustion of propellants within high-pressure chambers [8, 9, 11, 12].

However, in the context of increasingly diverse combat requirements, developing new ammunition types with distinct combat characteristics-particularly varied warhead masses—poses significant challenges while ensuring safe deployment on existing infantry grenade launcher systems. Altering the warhead mass shifts the dynamics of pressure development and impulse within the barrel, thereby introducing two critical technical challenges: (i) the risk of exceeding structural strength limits due to elevated maximum pressure, which threatens barrel structural integrity, and (ii) an increased recoil force, which directly impacts the safety and weapon control of the gunner. For individual weapons, regulating the recoil force within permissible thresholds is a mandatory requirement to guarantee operational stability and safety, as documented.

To address these challenges, this study focuses on developing an internal ballistics model for high-low pressure grenade launcher systems, serving as a framework for designing and optimizing propellant charge structures for new ammunition types. The developed model aims not only to contain internal pressure within the structural limits of the barrel but also to modulate the pressure development profile, ensuring that the recoil force aligns with infantry operational conditions. The findings of this research provide a rigorous scientific foundation for the development of advanced

ammunition, thereby enhancing combat efficiency while guaranteeing the safety of both equipment and personnel.

2. FORMULATING INTERNAL BALLISTICS EQUATIONS FOR GUN BARRELS

Formulating the system of equations

The processes initiated after the firing pin strikes the primer, igniting the propellant charge within high-pressure chamber 1 (HPC). As the propellant burns, it generates pressure that forces the gas mixture through six nozzle orifices into low-pressure chamber 2 (LPC). The pressure inside the LPC then acts upon the base of the projectile (3), driving its motion along the gun barrel. This sequence of processes is illustrated in the schematic diagram of Figure 1.

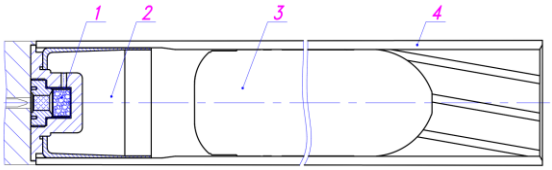


Figure 1. *Schematic diagram of projectile motion within the gun barrel.*
1. High-pressure chamber; 2. Low-pressure chamber; 3. Projectile (Warhead); 4. Gun barrel.

To formulate the internal ballistics equations for the aforementioned stages, the following assumptions are applied:

The propellant burns according to geometric laws, and the burning rate obeys the exponential burning rate law; the propellant undergoes complete combustion within the high-pressure chamber; the adiabatic exponent (specific heat ratio) and gas constant (R) are assumed to be constant; the ignition phase is neglected; the friction between the sealing cap and the cap wall is neglected; under these assumptions, the internal ballistics problem of the propellant charge is reduced to analyzing the gas states within the HPC and LPC.

The system of differential equations governing the internal ballistics during the projectile motion inside the gun barrel, according to references [1], [3] and [5], is given as follows:

$$
\begin{cases}
1.\dfrac{dz}{dt}=\dfrac{u_1}{e_1}P_c^{\nu};2.\dfrac{d\omega_c}{dt}=\omega\chi(1+2\lambda z)\dfrac{dz}{dt} \\
3.\dfrac{dW\psi_c}{dt}=\dfrac{1-\alpha.\delta}{\delta}.\dfrac{d\omega_c}{dt}+\alpha\omega.\dfrac{d\eta}{dt};4.\dfrac{dW\psi_t}{dt}=-\alpha\omega\dfrac{d\eta}{dt}+S.\dfrac{dl}{dt} \\
5.\dfrac{d\eta}{dt}=\dfrac{\phi_2 S_{th}K_0}{\omega_c}\dfrac{P_c}{\sqrt{f\tau_c}} \qquad P_c>P_{dl} \\
6.\dfrac{d\tau_c}{dt}=\dfrac{(1-\tau_c)\dfrac{d\omega_c}{dt}-(k-1)\omega\tau_c\dfrac{d\eta}{dt}}{\omega_c-\omega\eta};7.\dfrac{d\tau_t}{dt}=\dfrac{(k\tau_c-\tau_t)\dfrac{d\eta}{dt}-\dfrac{\theta\phi m}{f\omega}v\dfrac{dv}{dt}}{\eta} \\
8.\dfrac{dP_c}{dt}=\dfrac{1}{W_{\psi_c}}.\left\{f.\dfrac{d\omega_c}{dt}-fk\omega\tau_c\dfrac{d\eta}{dt}-P_c.\left[\dfrac{1-\alpha\delta}{\delta}.\dfrac{d\omega_c}{dt}+\alpha\omega.\dfrac{d\eta}{dt}\right]\right\} \\
9.\dfrac{dP_t}{dt}=\dfrac{1}{W_{\psi_t}}.\left\{f\omega k\tau_c.\dfrac{d\eta}{dt}-\theta\phi mv\dfrac{dv}{dt}-P_t.\left[-\alpha\omega.\dfrac{d\eta}{dt}+S.\dfrac{dl}{dt}\right]\right\} \\
10.\dfrac{dl}{dt}=v;11.\dfrac{dv}{dt}=\dfrac{SP_t}{\phi.m} \qquad P_t>P_0
\end{cases}
\tag{1}
$$

Where: ω: Propellant mass; u_1: Burning rate coefficient; e_1: Burning thickness; φ_1: Density of the propellant; R: Gas constant of the combustion products; S_{th}: Throat area (critical cross-sectional area) of the HPC nozzle; p_C: Propellant gas pressure inside the HPC; p_t: Propellant gas pressure inside the LPC; η: Relative amount of propellant discharged through the nozzle between two chambers; f: Propellant force; χ, λ, μ: Propellant geometric characteristics; v: Projectile velocity (m/s); S: Cross-sectional area of the gun bore; l: Projectile displacement; m: The mass of the projectile; φ is the coefficient of projectile virtual mass increase; ϕ_2: Energy loss coefficient; d_{th}: Nozzle throat diameter; n: Number of nozzles; $W_{\psi C}$: High-pressure chamber volume; $W_{\psi t}$: Low-pressure chamber volume; T_{mt}: Ambient temperature.

$K_0(K)$: Adiabatic exponent function: $K_0(K)=\left(\frac{2}{k+1}\right)^{\frac{1}{k-1}}\cdot\sqrt{\frac{2\cdot k}{k+1}}$ where k is the adiabatic exponent of the propellant gas.

Design compliance conditions for compatibility when fired from the M79 grenade launcher (shoulder-fired individual weapon), according to reference, are as follows:

$$A_S=\frac{1}{2}\frac{V^2\left(m+1,25\omega\right)^2}{M_S} \tag{2}$$

Where: $M_S=M_{Sung}+M_{Lieu}$; M_{Sung} is the mass of the launcher; M_{Lieu} is the mass of the propellant charge assembly; ω is the mass of the propellant.

The safety threshold for shoulder-fired operation based on the recoil energy A_S, according to reference [10]:

Table 1. *Safety thresholds for shoulder-fired operations.*

TT	Recoil energy, A_S *(J)*	Ammunition quantity limit
1	< 20.3	Unlimited firing
2	20.3 to 40.7	200 rounds/person/day
3	40.7 to 61	100 rounds/person/day
4	61 to 81.4	25 rounds/person/day
5	> 81.4	No shoulder-fired operation

The Runge-Kutta method is utilized to solve the system of differential equations (1), using the corresponding initial boundary conditions. The computed internal ballistics design results for the propellant charge must satisfy the safety threshold conditions for shoulder-fired operations as listed in Table 1.

3. CALCULATION RESULTS AND DISCUSSION

3.1. Input parameters for internal ballistics calculations of the projectile

Certain internal ballistics parameters of the CK59 propellant are listed in Table 2. The internal ballistics parameters for the M79 projectile are provided in Table 3, while those for the net projectile are given in Table 4.

Table 2. *Certain internal ballistics parameters of the CK59 propellant.*

No.	Parameter	Symbol	Value	Unit
1	Burning rate coefficient	u_1	9.8×10^{-5}	*dm/s*
2	Web thickness (burning thickness)	e_1	0.001	*dm*

No.	Parameter	Symbol	Value	Unit
3	Adiabatic exponent (specific heat ratio)	k	1.22	
4	Propellant force (impetus)	f	1160000	*kg.dm/kg*
5	Propellant gas co-volume	α	0.85	
6	Discharge loss coefficient	φ_2	0.85	
7	Propellant density	ρ_T	1.640	kg/dm^3
8	Propellant geometric characteristics	χ	1.044	
		λ	-0.044	
		μ	0	

Table3. *Certain internal ballistics parameters of the M79 high-explosive fragmentation projectile.*

No.	Parameter	Symbol	Value	Unit
1	Barrel length	L	4.1	*dm*
2	Projectile diameter (Caliber)	D	41	*mm*
3	Projectile mass	q	0.19	*kg*
4	Nozzle throat diameter	d_{th}	2	*mm*
5	Number of nozzles	n	6	
6	Propellant mass	ω	0.00046	*kg*
7	High-pressure chamber volume	$W_{\Psi C}$	0.0001	dm^3
8	Low-pressure chamber volume	$W_{\Psi t}$	0.0000178	dm^3
9	Nozzle sealing cap rupture pressure	p_C	150	kG/dm^2
10	Projectile forcing pressure (Shot start	p_0	6	kG/dm^2

Table 4. *Certain internal ballistics parameters of the net projectile charge.*

No.	Parameter	Symbol	Value	Unit
1	Barrel length	$L_đ$	4.1	*dm*
2	Projectile diameter (Caliber)	D	41	*mm*
3	Projectile mass	q	0.30	*kg*
4	Nozzle throat diameter	d_{th}	2.4÷2.8	*mm*
5	Number of nozzles	n	6	
6	Propellant mass	ω	0.00060÷0.00075	*kg*
7	High-pressure chamber volume	W_C	0.0002	dm^3
8	Low-pressure chamber volume	W_T	0.0000178	dm^3
9	Nozzle sealing cap rupture pressure	p_C	150	kG/dm^2
10	Projectile forcing pressure (Shot start	p_0	6	kG/dm^2

3.2. Calculation results and discussion

a. The calculation results using the propellant parameters from Table 2 and the internal ballistics parameters of the M79-VN high-explosive fragmentation projectile from Table 3 are

presented in Table 5 and Figure 2.

Table 5. *Calculated internal ballistics parameters of the M79-VN projectile.*

Maximum HPC pressure (*atm*)	**Maximum LPC pressure** (*atm*)	**Muzzle velocity** (*m/s*)	**Gun recoil energy** A_S (*J*)	**Notes**
508.4	104.6	75.8	34.06	

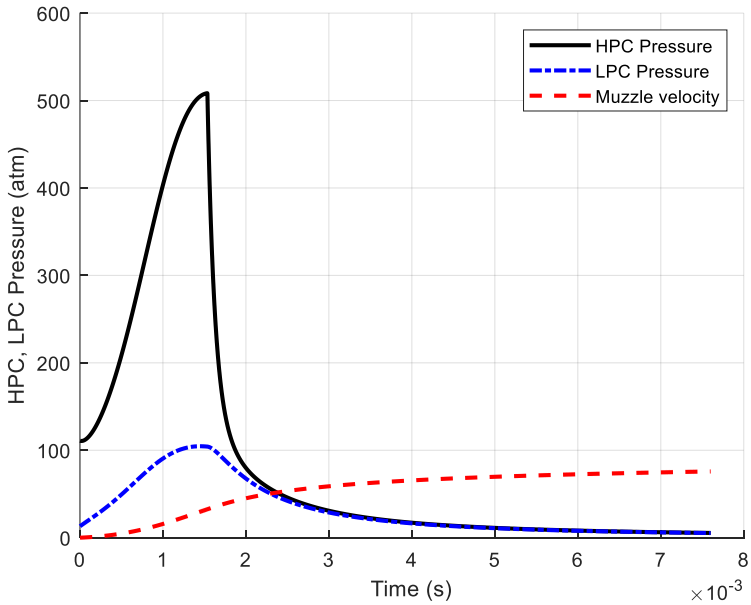


Figure 2. *Curves of HPC pressure, LPC pressure, and projectile muzzle velocity of the M79VN at an ambient temperature of T_{mt} = 15 °C.*

Remarks: The calculated muzzle velocity falls within the published experimental limit of 74±4 m/s. The LPC pressure (maximum LPC pressure) remains within the structural strength limit of the gun barrel, not exceeding 200 atm. Furthermore, the gun recoil energy aligns with the permissible threshold for shoulder-fired operations by the gunner. Therefore, these computational results confirm that the developed model is both appropriate and reliable.

b. The calculation results using the propellant parameters from Table 2 and the internal ballistics parameters of the anti-UAV infantry net projectile from Table 4 are presented in Table 6, Table 7, Table 8, Table 9, and Figure 3.

Table 6. *Calculated internal ballistics parameters of the projectile with varying propellant charge masses (throat diameter d_{th} = 2.5 mm and ambient temperature T_{mt} = 15 °C).*

No.	**Propellant mass** ω (*10^{-3} kg)	**Maximum HPC pressure** (*atm*)	**Maximum LPC pressure** (*atm*)	**Muzzle velocity** (*m/s*)	**Gun recoil energy** A_S (*J*)	**Notes**
1	0.60	312.4	99.8	68.22	61.88	
2	0.64	325.7	124.1	72.62	67.95	
3	0.68	558.3	152.8	75.73	73.92	
4	0.72	701.3	182.7	78.68	79.82	
5	0.74	778.7	198.8	79.77	83.25	
6	0.745	795.9	202.6	80.45	84.48	

Table 7. *Calculated internal ballistics parameters of the projectile with varying propellant charge masses (throat diameter d_{th} = 2.65 mm and ambient temperature T_{mt} = 15 ^oC).*

No.	Propellant mass ω (*10^{-3} kg)	Maximum HPC pressure (*atm*)	Maximum LPC pressure (*atm*)	Muzzle velocity (*m/s*)	Gun recoil energy A_S (*J*)	Notes
1	0.60	228.9	86.9	68.144	59.805	
2	0.64	303.9	106.1	71.612	66.072	
3	**0.68**	**401.3**	**129.1**	**74.849**	**72.205**	
4	0.72	514.3	156.8	77.902	78.243	
5	0.74	588.3	171.6	79.370	81.234	
6	0.745	595.9	172.6	79.502	81.509	

Table 8. *Calculated internal ballistics parameters of the projectile with varying propellant charge masses (throat diameter d_{th} = 2.7 mm and ambient temperature T_{mt} = 15 ^oC).*

No.	Propellant mass ω (*10^{-3} kg)	Maximum HPC pressure (*atm*)	Maximum LPC pressure (*atm*)	Muzzle velocity (*m/s*)	Gun recoil energy A_S (*J*)	Notes
1	0.60	203.5	81.2	67.044	59.1348	
2	0.64	268.4	98.8	70.543	65.490	
3	0.68	352.5	119.9	73.795	71.694	
4	0.72	459.3	144.9	76.855	77.787	
5	0.74	520.4	159.0	78.320	80.802	
6	0.745	537.7	163.5	78.685	81.557	

Remarks:

To ensure complete propellant combustion within the HPC and minimize fouling on the barrel wall, the required internal HPC pressure must be maintained above 350 atm. Conversely, to guarantee the structural integrity and durability of the gun barrel, the LPC pressure must not exceed 200 atm. Based on the quantitative analysis from Tables 6, 7, and 8, the propellant charge mass must be strictly regulated below 0,745 g to satisfy these operational constraints.

Table 9. *Calculated internal ballistics parameters of the projectile with varying nozzle throat diameters at an ambient temperature of T_{mt} = 15 ^oC.*

TT	Nozzle throat diameter d_{th} (*mm*)	Maximum HPC pressure (*atm*)	Maximum LPC pressure (*atm*)	Muzzle velocity (*m/s*)	Gun recoil energy A_S (*J*)
1	2.4	753.9	187.6	77.108	76.629
2	2.5	607.0	166.4	76.387	75.204
3	2.6	479.1	145.6	75.617	73.696
4	2.65	404.5	133.8	74.926	72.896
5	2.7	378.7	128.8	74.799	72.109
6	2.8	307.3	115.7	73.936	70.455

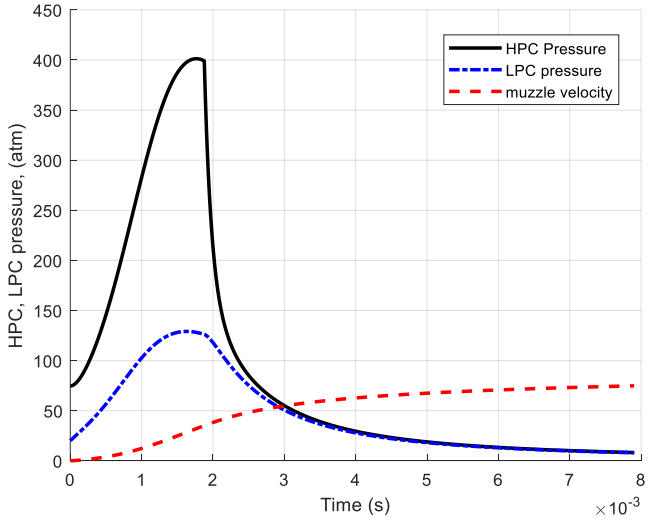


Figure 3. *Curves of HPC pressure, LPC pressure, and projectile muzzle velocity with a nozzle throat diameter of d_{th} = 2.65 mm and an ambient temperature of T_{mt} = 15 ^{o}C.*

* Remarks:

The numerical results demonstrate that increasing the propellant charge mass leads to a higher projectile muzzle velocity. However, this improvement is accompanied by a corresponding increase in gun recoil energy. When the propellant charge mass exceeds 0.745g, the recoil energy surpasses the allowable limit for shoulder-fired operation, indicating that further increases in propellant mass are impractical despite the gain in muzzle velocity.

An increase in the nozzle throat diameter leads to a decrease in the maximum pressure of both the HPC and LPC. Specifically, a 16.6% increase in the nozzle throat diameter reduces the maximum HPC pressure by 59.8% and the maximum LPC pressure by 38.3).

Increasing the nozzle throat diameter results in a 4.2% reduction in muzzle velocity and an approximate 8.1% decrease in gun recoil energy. This reduction is highly beneficial for the shoulder-fired operations of the gunner.

Through the computational analysis, the optimized design variant for the anti-UAV net projectile charge using CK59 propellant is established with the following specific parameters: a propellant charge mass of 0.68g and a nozzle throat diameter of d_{th} = 2.65 mm.

4. CONCLUSIONS

This paper developed an internal ballistics model for grenade launcher systems and applied it to the structural design problem of propellant charges for ammunition with varied warhead masses. In this study, the authors successfully achieved the following objectives:

Established an internal ballistics model capable of accurately predicting the profiles of pressure variation and projectile muzzle velocity, thereby laying the groundwork for evaluating compatibility between new ammunition types and existing weapon systems.

Conducted a comprehensive investigation into the effects of the propellant charge configurations on both the barrel pressure and recoil energy. The findings allowed the determination of an optimized charge design, ensuring that the internal pressure remains within the structural strength limit of the barrel and that the recoil force stays within safe thresholds for infantry gunners.

The results of this paper not only provide a rigorous scientific foundation and a reliable

methodology for ammunition design and manufacturing but also confirm the feasibility of developing specialized ammunition configurations with distinct combat characteristics on existing weapon platforms. These insights contribute significantly to enhancing combat capabilities while guaranteeing operational reliability and safety for personnel.

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TÓM TẮT

Nghiên cứu ảnh hưởng của kết cấu liều phóng kiểu M79 tới áp suất trong nòng súng

Bài báo trình bày kết quả nghiên cứu ảnh hưởng của kết cấu liều phóng kiểu M79 đến quy luật biến thiên áp suất trong nòng súng. Mục tiêu trọng tâm là thiết kế phương án liều phóng tối ưu, bảo đảm tính tương thích với kích thước buồng đạn và giới hạn bền của nòng súng hiện có. Thông qua mô hình toán học thuật phóng trong, nghiên cứu đã khảo sát ảnh hưởng của một số tham số kết cấu liều tới áp suất trong nòng súng. Kết quả là cơ sở để thiết kế kết cấu liều cho phép kiểm soát hiệu quả áp suất nòng súng trong giới hạn an toàn, đồng thời duy trì sơ tốc đầu nòng ổn định theo yêu cầu thiết kế. Nghiên cứu cung cấp cơ sở khoa học quan trọng cho việc thiết kế, chế tạo cải tiến các loại liều phóng ứng dụng trên các dòng súng phóng lựu hiện hành

Từ khoá: Liều phóng M79; Áp suất nòng súng; Kết cấu liều phóng; Súng phóng lựu; Đạn lưới chống UAV.