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Analysis of Ignition Capability of Flammable Gases from Small Arms Propellant Gases

Przemysław BADUROWICZ[1*], Adam WIŚNIEWSKI[1], Dawid PACEK[1], Marcin JASIŃSKI[2], Krzysztof SZCZUROWSKI[2], Marek WOLIŃSKI[3], Tadeusz BARTKOWIAK[4]

[1]*Military Institute of Armament Technology,*
7 Prymasa Stefana Wyszyńskiego Str., Zielonka, Poland
[2]*Warsaw University of Technology,*
Faculty of Automotive and Construction Machinery Engineering,
84 Narbutta Str., 02-524 Warsaw, Poland
[3]*The Main School of Fire Services,*
Faculty of Safety Engineering and Civil Protection,
52/54 Juliusza Slowackiego Str., 01-629 Warsaw, Poland
[4]*Center of Shooting Technology, shooting ranges – design, construction, equipment*
Tebbex2 Łukasz Bartkowiak,
2H Naftowa Str., Zielona Góra, Poland
[*]*Corresponding author's e-mail address and ORCID*:
badurowiczp@witu.mil.pl; https://orcid.org/0000-0002-6110-0035

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Abstract. The article presents the results of tests on the temperature of propellant gases shortly after the bullet leaves the barrel. The temperature and movement of these gases were recorded with thermal cameras and a high-speed camera. Weapons with and without muzzle devices (flash suppressor, silencer) were used. The aim of the research was to check the capability to ignite flammable gases located in the vicinity of the propellant gases produced during firing. Comparison of the maximum temperature of the propellant gases and the ignition temperature of the flammable gases makes it possible to determine the probability of fire. The lowest temperature of propellant gases was in the case of shooting with 9 × 19 mm bullets with the lowest kinetic energy (518 J), and the highest temperature of these gases was during shooting with 5.56 × 45 mm HC (SS109) bullets with the highest kinetic energy (1,785 J).
Keywords: mechanics, small arms, transitional ballistics, propellant gases, thermal camera

1. INTRODUCTION

There are well-known works on the phenomenon of flash and blast caused by the muzzle of propellant gases [1, 2], on flash suppressor [3, 4] and on methods of detecting the muzzle flash with optoelectronic devices for shot identification [5, 6].

The aim of this study was to measure the temperature of the muzzle propellant gases (with thermal cameras) produced during small arms shot and to record the muzzle flame with a high-speed camera and check the ignition capability of the flammable gases from the propellant gases. Recording the temperature of the propellant gases allows them to be compared with the ignition temperature of various flammable gases to determine the probability of ignition.

2. RESULTS OF THE STUDY

Weapons with and without muzzle devices (flash suppressor, jump compensator, etc.) were used in the study. Two FLIR X6580sc thermal cameras, a FLIR A6753sc and a FLIR X6901sc SLS, a Photron Fastcam SA-Z 2100K high-speed video camera (Table 1), and a weapon mounted on a ballistic mount were used to record the muzzle flash phenomenon (Figures 1÷2). These cameras were positioned perpendicularly to the barrel axis. A 400 × 300 mm metal measuring frame with 50 × 50 mm 'windows' was used to assess the muzzle flame surface.

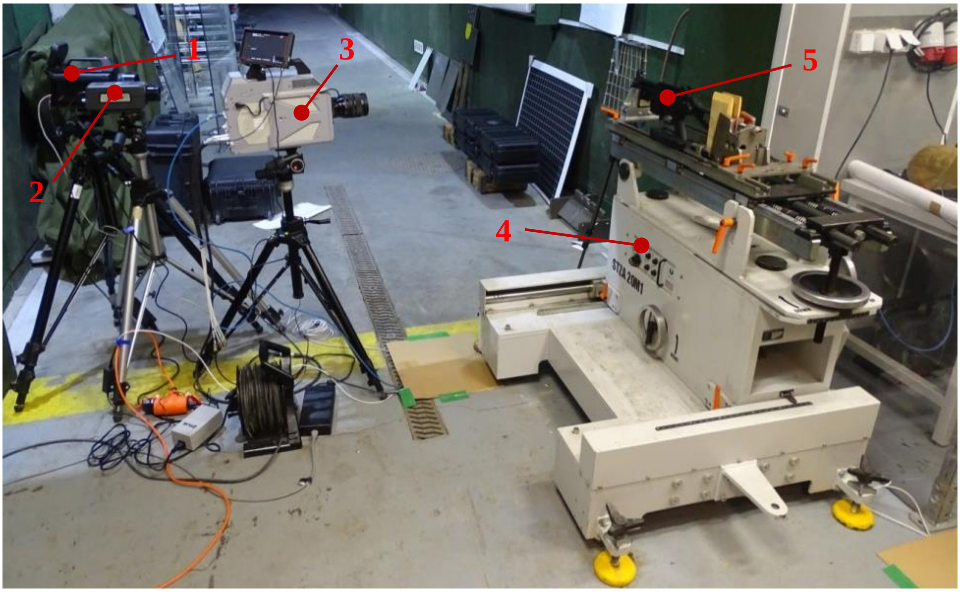

Fig. 1. The stand for small arms muzzle gases temperature test: 1 – FLIR X6580sc thermal camera, 2 – FLIR A6753sc thermal camera, 3 – Photron Fastcam SA-Z 2100K high-speed camera, 4 – ballistic mount, 5 – weapon

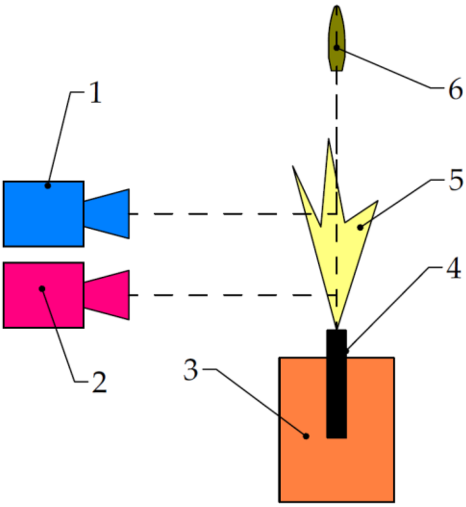

Fig. 2. Diagram of the setup, top view: 1 – thermal camera, 2 – high-speed camera, 3 – ballistic mount, 4 – weapon, 5 – propellant gases, 6 – projectile

Table 1. Specification of the used cameras

Specifications	High-speed video camera [7]	Thermal camera [8]		
	Photron Fastcam SA-Z 2100K	**FLIR X6580sc**	**FLIR A6753sc**	**FLIR X6901sc SLS**
Max. resolution (full frame)	1,024×1,024	640×512	640×512	640×512
Resolution for max. image frequency	128×8	64×8	No data	No data
Thermal Sensitivity, mK	Not applicable	< 25	≤ 20	< 40
Max. image frequency for full frame, fps	20,000	355	125	1,004
Max. image frequency, fps	2,100,000	4,700	No data	No data

The following weapons and ammunition with a muzzle energy of less than 2,000 J were used in the tests (Table 2):

1. HK UMP – submachine gun, chambered for the 9 × 19 mm Parabellum cartridge.
2. HK 416 – assault rifle, chambered for the 5.56 × 45 mm NATO cartridge.

Table 2. Ammunition used in the tests

No	Ammunition	Manufacturer	Construction description	m_p, g	V_0, m/s	E_0, J
1	9 × 19 mm FMJ	Sellier & Bellot (S&B)	FMJ (full metal jacket)	8.0	360	518
2	5.56 × 45T	Mesko	T (tracer)	4.1	865	1,534
3	5.56 × 45 mm HC (SS109)	Ruag	FMJ	4.0	945	1,785

Symbols: m_p – projectile mass, V_0 – projectile muzzle velocity, E_0 – projectile muzzle energy

The course of the tests and the results are presented in Table 3 and Figures 3÷9. One example frame each from the high-speed camera and thermal camera recordings is shown, showing the maximum flame of the configuration (weapon, muzzle device and ammunition). For each configuration, 2 to 3 shots were fired, the average temperature was calculated and the maximum temperature from those recorded is given.

Table 3. Average and maximum muzzle gases temperatures and areas of observed muzzle flames for various weapons, ammunition and muzzle devices

No.	Weapon	Ammunition	Muzzle device	Thermal camera		Flame area - high-speed camera, mm²	Flame area - thermal camera, mm²
				t_{av}, °C	t_{max}, °C		
1	9 mm HK UMP	9 x 19 mm FMJ S&B	The weapon has no muzzle device	89.31	146.6	130	400 – 22,500
2	5.56 mm HK 416	5.56 × 45 mm HC (SS109)	Silencer	165.4	165.4	1,000	45,000
3		5.56 × 45T		165.4	165.4		
4		5.56 × 45 mm HC (SS109)	No muzzle device	165.4	165.4	90,000	45,000 – 90,000
5		5.56 × 45T		165.4	165.4		
6		5.56 × 45 mm HC (SS109)	Flash suppressor	165.4	165.4	400	30,000
7		5.56 × 45T		196.7	228		

Symbols: t_{av} – average temperature from several shots, t_{max} – maximum temperature from several shots

The area of the flame recorded with the vision camera from its smallest value to its largest one is as follows:

- HK UMP submachine gun (approx. 130 mm^2);
- HK 416 assault rifle with flash suppressor (approx. 400 mm^2);
- HK 416 assault rifle with silencer (approx. 1,000 mm^2);
- HK 416 assault rifle without muzzle device (approx. 4,900 – 90,000 mm^2).

The area of muzzle gases recorded with the thermal camera from their smallest value to their largest one is as follows:

- HK UMP submachine gun (approx. 400 – 22,500 mm^2);
- HK 416 assault rifle with flash suppressor (approx. 30,000 mm^2);
- HK 416 assault rifle with silencer (approx. 45,000 mm^2);
- HK 416 assault rifle without muzzle device (approx. 45,000 – 90,000 mm^2).

In Table 2, there are major differences in the flame areas recorded with thermal camera because the extreme values come from the measurement with two different cameras.

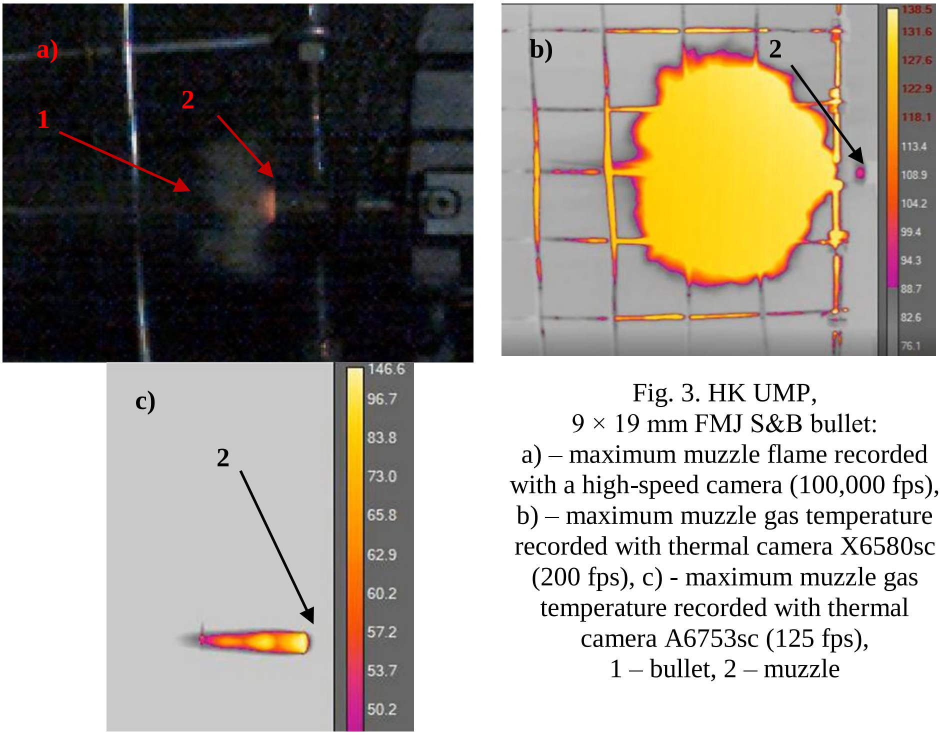

Fig. 3. HK UMP, 9 × 19 mm FMJ S&B bullet: a) – maximum muzzle flame recorded with a high-speed camera (100,000 fps), b) – maximum muzzle gas temperature recorded with thermal camera X6580sc (200 fps), c) - maximum muzzle gas temperature recorded with thermal camera A6753sc (125 fps), 1 – bullet, 2 – muzzle

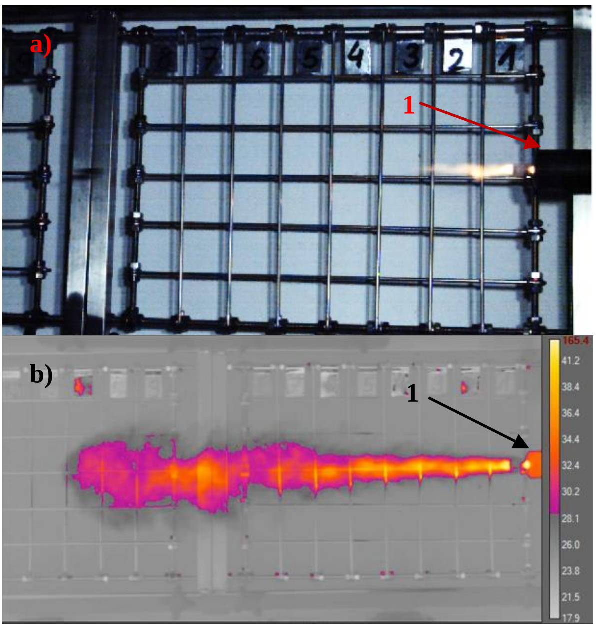

Fig. 4. HK 416, 5.56 × 45 mm HC (SS109) bullet: a) – maximum muzzle flame recorded with a high-speed camera (50,000 fps), b) – maximum muzzle gas temperature recorded with thermal camera X6901sc SLS (1,492 fps), 1 – silencer

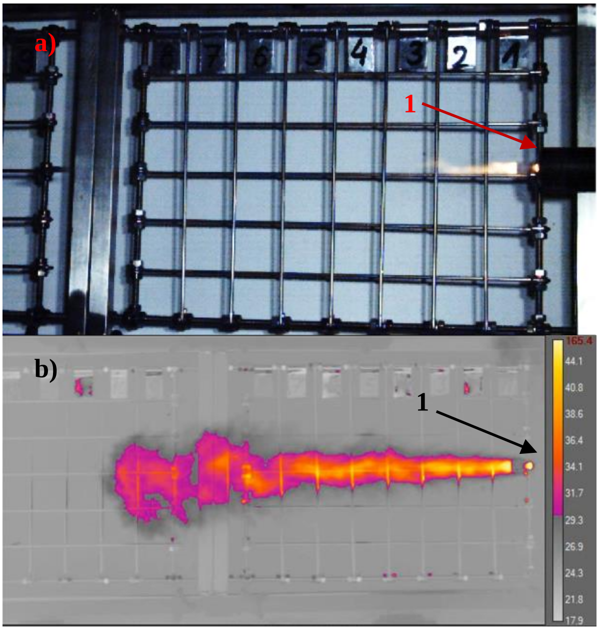

Fig. 5. HK 416,
5. 56× 45T bullet:
a) – maximum muzzle flame recorded with a high-speed camera (50,000 fps),
b)– maximum muzzle gas temperature recorded with thermal camera X6901sc SLS (1,492 fps),
1 – silencer

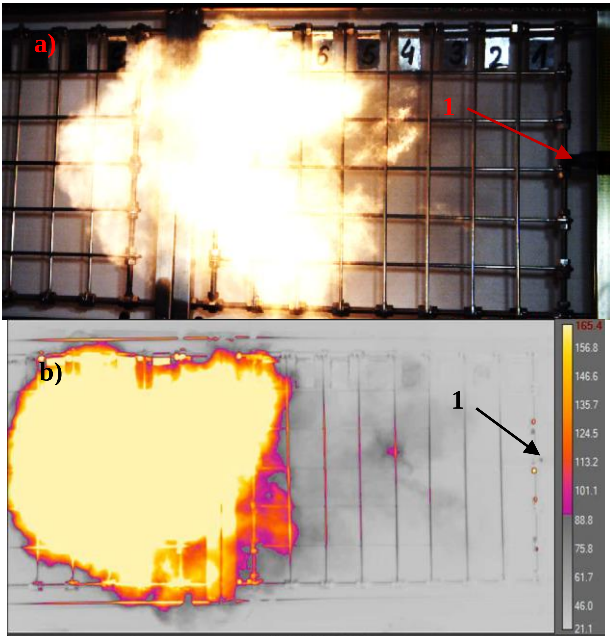

Fig. 6. HK 416,
5.56 × 45 mm HC (SS109) bullet: a) – maximum muzzle flame recorded with the high-speed camera (50,000 fps), b) – maximum muzzle gas temperature recorded with the thermal camera X6901sc SLS (1,492 fps), 1 – muzzle (no muzzle device)

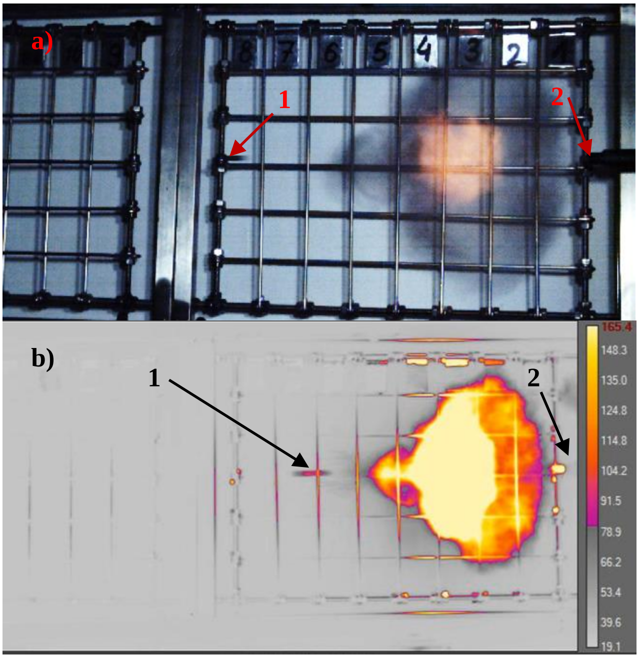

Fig. 7. HK 416, 5.56×45T bullet: a) – maximum muzzle flame recorded with the high-speed camera (50,000 fps), b) – maximum muzzle gas temperature recorded with the thermal camera X6901sc SLS (1,492 fps), 1 – bullet, 2 – muzzle (no muzzle device)

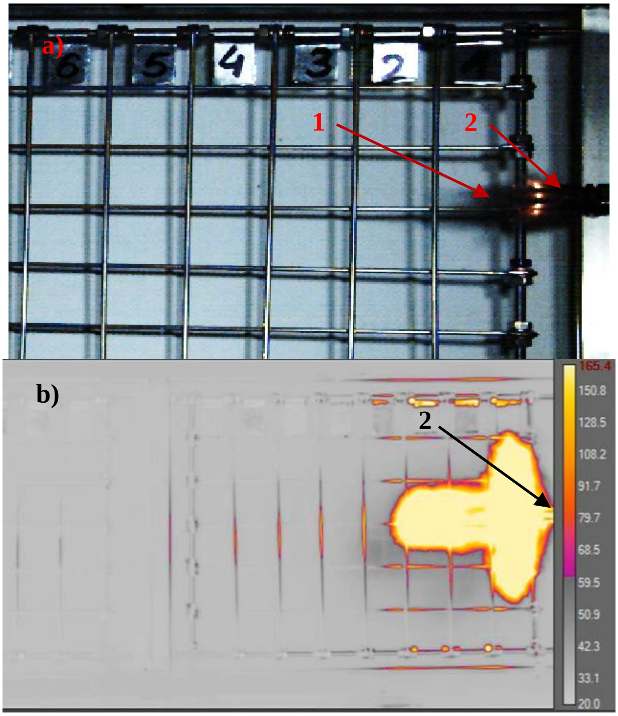

Fig. 8. 5.56 mm HK 416, 5.56 × 45 mm HC (SS109) bullet: a) – maximum muzzle flame recorded with a high-speed camera (50,000 fps), b) – maximum muzzle gas temperature recorded with the X6901sc SLS thermal camera (1,492 fps), 1 – bullet, 2 – flash suppressor

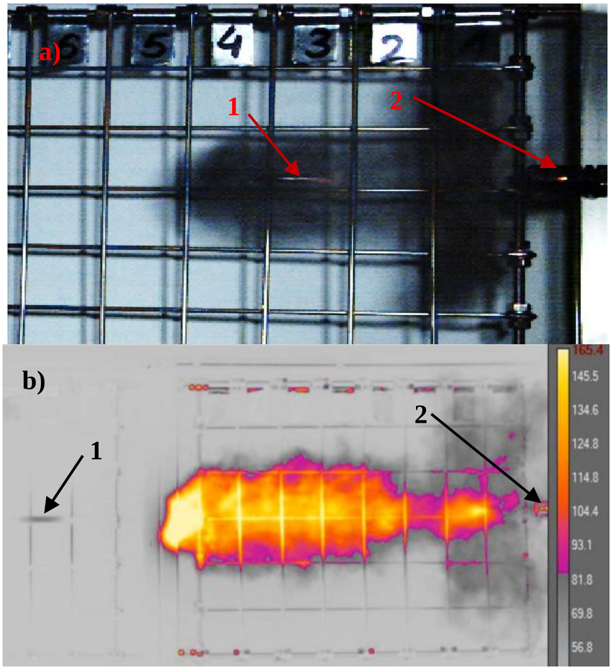

Fig. 9. 5.56 mm HK 416, 5.56 ×45T bullet:
a) – maximum muzzle flame recorded with a high-speed camera (50,000 fps),
b) – maximum muzzle gas temperature recorded with the X6901sc SLS thermal camera (1,492 fps),
1 – bullet, 2 – flash suppressor

3. IGNITION ANALYSIS OF FLAMMABLE SUBSTANCES

Table 4 shows the flash point of selected flammable substances for comparison with the muzzle gases temperatures in Table 3.

Table 4. Flash points for the selected flammable gases and vapours of liquids [9]

No.	**Name of Substance**	**Chemical Formula**	**Flash Point, °C**	**Minimum ignition energy, mJ**
1	Acetone	CH_3COCH_3	540	0.25
2	Acetylene	C_2H_2	305	0.011
3	ethyl alcohol	C_2H_5OH	425	0.4
4	methyl alcohol	$CH_3CH(OH)CH_3$	400	0.65
5	isopropyl alcohol	$CH_3CH(OH)CH_3$	400	0.65
6	automotive gasoline	-	300	0.15
7	n-butane	C_4H_{10}	430	0.25
8	Methane	CH_4	650	0,28
9	Kerosene	-	>250	0.65
10	gas oil	-	250	0.48
11	Propane	C_3H_8	500	0.22
12	trichloroethylene	$ClCH{=}CCl_2$	410	300
13	Hydrogen	H_2	580	0.018

4. CONCLUSIONS

After carrying out the above research, the following conclusions can be drawn:

1. For the HK 416 assault rifle with flash suppressor, the flame area was 225 times smaller compared to the flame area produced by the weapon without the muzzle device during video camera recording (400 mm^2 and 90,000 mm^2), while it was up to 3 times smaller during thermal camera recording (30,000 mm^2 and 90,000 mm^2).
2. There are no differences in the area of the muzzle flames recorded with the video and thermal camera when using the same: weapon, muzzle device and different types of ammunition, so there is no impact of used bullets type on muzzle flame.
3. The lowest muzzle gas temperature (t_{av} = 89.31°C) was when using 9 × 19 mm ammunition with the lowest muzzle energy of 518 J, fired from the HK UMP submachine gun.
4. The muzzle gases had a higher temperature for the HK 416 assault rifle with flash suppressor than in the absence of a suppressor or with a silencer for the 5.56 × 45T ammunition (t_{av} = 196.7°C and 165.4°C, a difference of 31.3°C, or 15.9% higher).
5. The muzzle gases of the 9 × 19 mm FMJ, 5.56 × 45T and 5.56 × 45 mm HC (SS109) cartridges are unable to initiate the burning of flammable substances, because the muzzle gases temperatures are lower than the flash point temperatures.
6. The use of tracer ammunition does not increase the temperature of the muzzle gases, nor does it increase the surface area of the muzzle gases, as the tracer mass ignites after a relatively long distance has been covered - after the muzzle gases have ceased to be effective.
7. A lot of measurements show a maximum temperature of 165.4°C, because the upper measuring range for the thermal cameras was set to this value. As part of further work, tests with a higher measuring range should be carried out. The methodology of test requires further improvements.

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Analiza możliwości zapłonu gazów łatwopalnych od gazów prochowych broni strzeleckiej

Przemysław BADUROWICZ[1], Adam WIŚNIEWSKI[1], Dawid PACEK[1], Marcin JASIŃSKI[2], Krzysztof SZCZUROWSKI[2], Marek WOLIŃSKI[3], Tadeusz BARTKOWIAK[4]

[1]*Wojskowy Instytut Techniczny Uzbrojenia,*
ul. Prymasa Stefana Wyszyńskiego 7, Zielonka,
[2]*Politechnika Warszawska,*
Wydział Samochodów i Maszyn Roboczych,
ul. Narbutta 84, 02-524 Warszawa,
[3]*Szkoła Główna Służby Pożarniczej,*
Wydziału Inżynierii Bezpieczeństwa i Ochrony Ludności,
ul. Juliusza Słowackiego 52/54, 01-629 Warszawa,
[4]*Centrum Techniki Strzeleckiej, Projektowanie, Budowa, Wyposażanie Strzelnic*
Tebbex2 Łukasz Bartkowiak,
ul. Naftowa 2H, Zielona Góra

Streszczenie. W artykule przestawiono wyniki badań temperatury wylotowych gazów prochowych w krótkim okresie po opuszczeniu pocisku z lufy. Temperaturę i ruch tych gazów rejestrowano kamerami termalnymi i kamerą szybką. Użyto broni z urządzeniami wylotowymi (tłumik płomienia, tłumik dźwięku) oraz bez nich. Celem badań było sprawdzenie zdolności zapalenia gazów łatwopalnych znajdujących się w otoczeniu wylotowych gazów prochowych powstających w czasie strzału. Porównanie maksymalnej temperatury gazów prochowych i temperatury zapłonu gazów łatwopalnych umożliwia określenie prawdopodobieństwa powstania pożaru. Najniższa temperatura wylotowych gazów prochowych była w przypadku strzelania pociskami 9 × 19 mm o najniższej energii kinetycznej (518 J), a najwyższa temperatura tych gazów była podczas strzelania pociskami 5,56 × 45 mm HC (SS109) o najwyższej energii kinetycznej (1 785 J).

Słowa kluczowe: mechanika, broń strzelecka, balistyka przejściowa, gazy prochowe, kamera termalna.