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Smoke as a component of military camouflage systems

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Abstract. This paper is a study of military optical identification and guidance solutions. The technical measures used in the Polish Armed Forces for smoke screen deployment and their relation to IR camouflage were analysed.
Keywords: reconnaissance, identification, counter-identification, counter-reconnaissance, camouflage, smoke
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Introduction

The definition of camouflage: camouflage is one of the most natural forms of military activity in combat theatres and an activity of living organisms. Nature itself is unparalleled in the mastery of camouflage, i.e. the blending of shapes and colours of living organisms with the shapes and colours of the background. Can we apply this strength of nature in human use? Not always as effectively as nature can.

The Military Tactical Rules of the Polish Armed Forces define camouflage as a component of combat security intended to: conceal friendly personnel and technical assets against identification by the enemy, confuse the enemy's reconnaissance of the locations of friendly forces and their combat operations, inhibit effective fire of the enemy against friendly forces, and inhibit the enemy's capacity for proper decision-making in combat scenarios. Camouflage is achieved by concealing the deployment and movement of military assets with the use of camouflaging characteristics of the

Fig. 1. Flounder [1]

Fig. 2. Gray's leaf insect (Phyllium (Pulchriphyllium) bioculatum) [2]

surroundings, limited visibility, engineering camouflage measures and portable camouflage materials, camouflage painting, radar-absorbing materials, ostentatiously provocative activities, installation of decoy deployment areas of personnel, positions and facilities with falsified operations of units, armament and technical assets, disinformation and information diversion, strict compliance to disciplinary execution rules, detection and removal of decamouflaging features, and combating of enemy reconnaissance assets [3].

A praxeological definition of camouflage is due. The word camouflage itself expresses a natural law of action and reaction, a reaction to identification. Identification by reconnaissance identification and camouflage are bonded with [...] ***an innate regularity of sequence of events***… [4].

In the military context, the time of action and reaction related to identification and camouflage is critical. It would be ideal for the reaction time to be negative, i.e. to anticipate the effects of identification with proper camouflage.

The precedence of identification over camouflage implies the following relations between the two processes [5]:

— the reconnaissance identification sought by the enemy is a primary act;
— the secondary act which is generated and formed in response to potential identification opportunities is camouflage;

— the types, forms and methods of camouflage depend on the known identification capabilities of the enemy and the capability of the identification target to counter positive identification;
— both identification and camouflage are improved from the moment when the subordinate systems of the two sides cannot satisfactorily meet the objectives;
— the reliability of intelligence about the identification and camouflage capabilities of both sides grows as the activity of reconnaissance (identification) systems of the two sides is increased. The intelligence (information) race features the deficit of time for identification and camouflage; this necessitates a maximum use of novel identification capabilities;
— a specific characteristic of the relations is a continuous secondariness of camouflage capabilities in relation to identification capabilities.

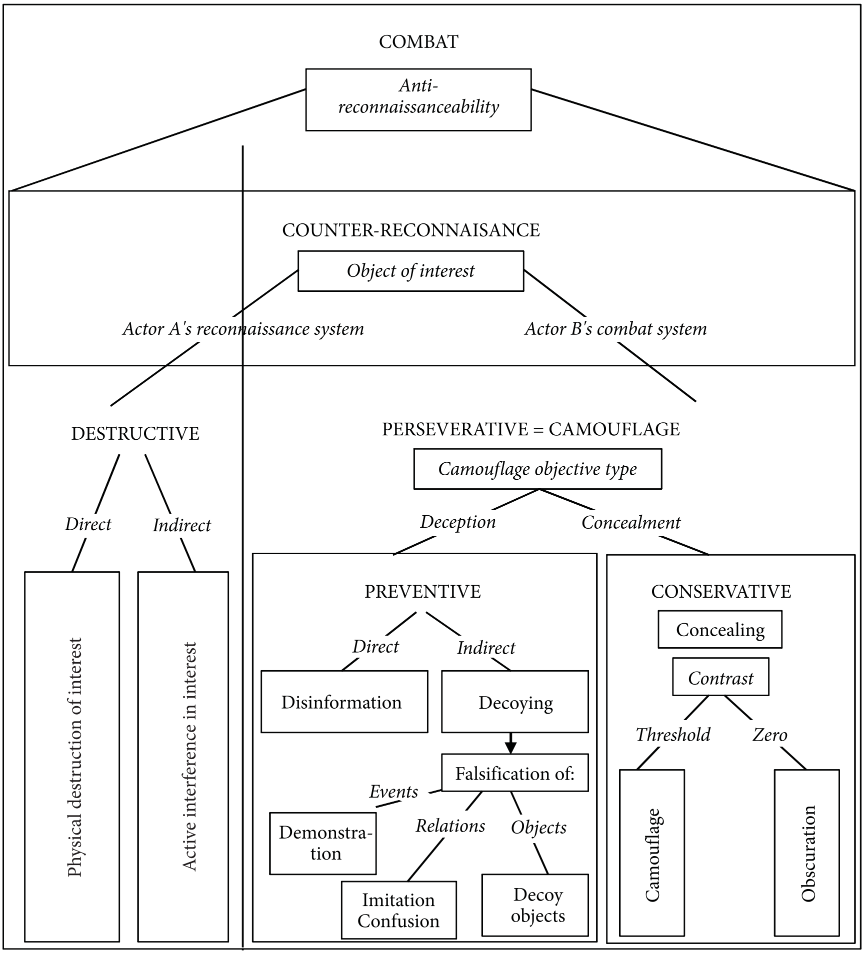

Fig. 3. Praxeological decomposition of counter-reconnaissance

The relations allow the following conclusions:

1. Camouflage organisers (commanders, staffs, etc.) must reliably evaluate the reconnaissance (identification) capabilities of the enemy.
2. The organisation of camouflage should be a task for the best experts in reconnaissance and target identification.
3. The objective of camouflage should be the maintenance of the state of negative identification of the camouflaged object by the enemy.
4. Camouflage must not be limited to military doctrine; it requires proper organisation of camouflage experts and technical counter-reconnaissance systems; hence, camouflage is a form of counter-reconnaissance, or counter-identification.

The following diagram shows the praxeological positioning of camouflage in combat [5].

1. Military optical identification and guidance solutions

The Polish Armed Forces currently perform effective combat operations with assets and armament which include a vast array of optoelectronic devices. The optoelectronic devices operate in a wide electromagnetic spectrum: from RF bands to visible light. This includes a wavelength spectrum from micrometres to centimetres. The electromagnetic waves identified by specific reconnaissance device types are presented broken down in to wavelength bands in Fig. 4.

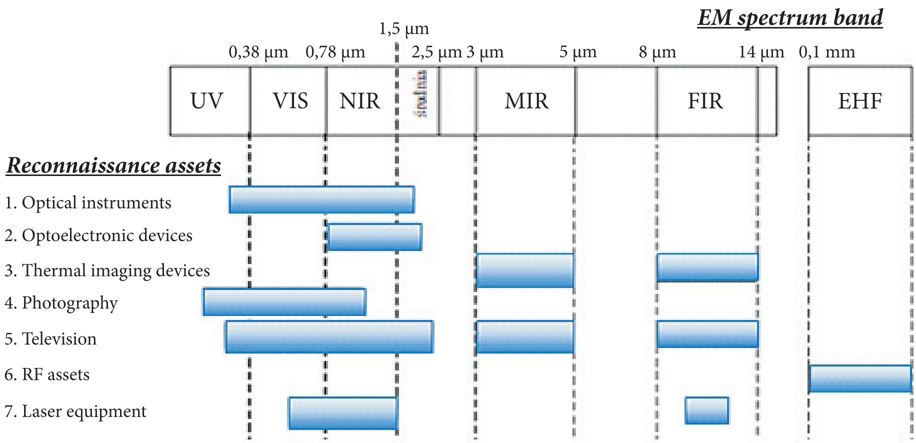

Fig. 4. Application of the electromagnetic spectrum by reconnaissance assets [6]

The operating range of optoelectronic devices is 0.38-14 µm; however, reconnaissance with their use has proven to be ineffective in certain EM spectrum areas.

The ineffective EM spectrum areas are 1.7-2; 2.5-3.5; 5–8 μm; here, the atmospheric air attenuates the propagation of EM radiation.

The operation of optoelectronic devices can be classified by the type of EM waves which reach their detectors. Fig. 5 shows the classification of optoelectronic assets by EM radiation type.

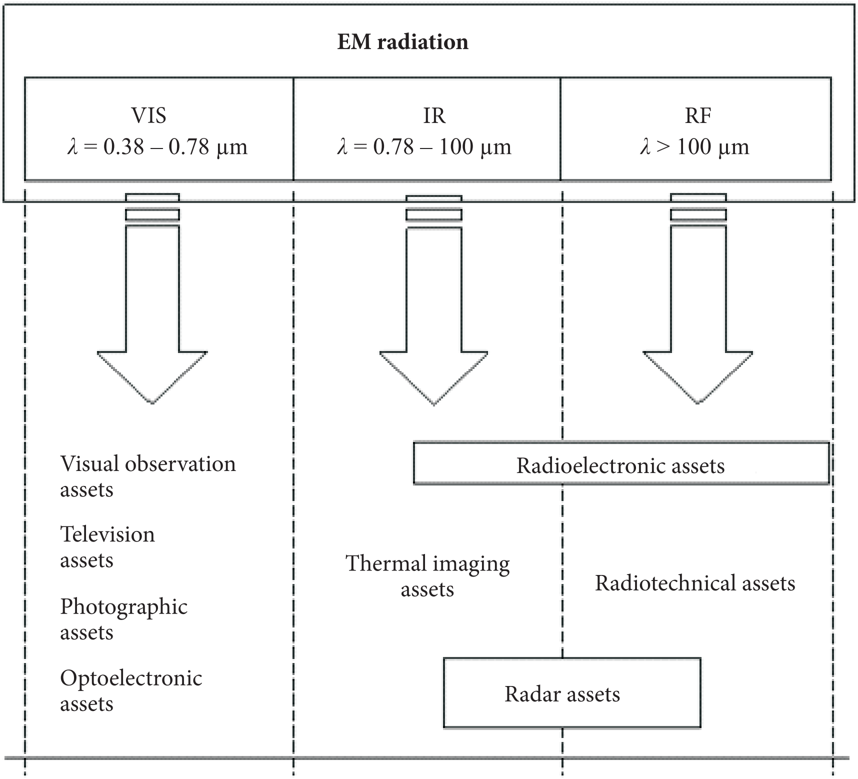

Fig. 5. Military applications of the electromagnetic spectrum [7]

To defeat an enemy, the military force must locate, identify and destroy enemy objects by target guidance. This is the foundation of combat operations. Military forces achieve these objectives with a wide range of assets essential for success. Given its application differences, military optoelectronic equipment (MOE) is classified as follows:

— Optoelectronic observation and targeting devices,
— Optoelectronic missile guidance devices,
— Laser devices,
— Technical countermeasures.

Military observation equipment is used for the least complex combat tasks. It is a less important element for improvement of combat effectiveness across the hierarchy of combat operations. Military observation equipment includes optical devices (e.g. binoculars, optical sights, periscopes, etc.) and optoelectronic devices (e.g. night-vision devices, photographic equipment, LLLTV and TV cameras, and thermal imaging devices).

Missile guidance methods can be active or passive. Passive missile guidance methods include raster guidance and reflected laser beam tracking. Active missile guidance methods include laser beam image analysis.

Fig. 6. SPIKE missile: a missile platform with a thermal imaging camera with image analysis-based homing of the projectile (according to the fire and forget principle) [8]

A laser guided homing missile uses a laser pointer which casts a laser beam on the target and the laser receiver located in the aft of the missile. The missile itself adjusts its flight trajectory to home in on a target. The laser beam is transmitted along the LOS (line of sight) and broken down into sectors varying in modulation. In the aft section of the missile is a receiver sensor which picks up a part of the reflected laser beam and measures its modulation to determine the missile's position relative to the laser beam axis in alignment with the LOS. A missile homed with laser guidance should follow the LOS between the laser pointer and the target.

This guidance principle was applied in the Russian 9M133 Kornet armour-piercing homing missile. The guidance system is insensitive to interference from adverse weather, e.g. rain, fog, or smoke. Another application example is the ASM (air-to-surface) missile systems type H-29Ł and H-25MŁ for the Su-22 and MiG-29 combat aircraft. The aircraft pilot must track the target location and keep the homing laser beam on the target.

Fig. 7. Kornet-E ATGM laser guidance system with a 9M133 AP missile [10]

2. Countermeasures

The defence against the increasingly effective and ever-improved guidance equipment requires the continuous development of appropriate countermeasures to stay the proverbial step ahead of the enemy. When investigating target identification and guidance, great advances are evident in the development of those optoelectronic devices which can be classified as countermeasures. A distinction between two groups can be made:

— Passive countermeasures;
— Active countermeasures.

2.1. Passive countermeasures

Passive countermeasures include camouflage coatings and decoys, low-contrast structures and warning equipment.

Camouflage coatings include camouflage paint, netting and mats. Examples include WPM Berberys (Multirange Layered Camouflage System). Berberys WPM is intended for direct camouflage deployment in visual, thermal imaging and radar detection ranges of technical assets, where the VIS and NIR range include wavelengths from 0.38×10^{-6} to 1.2×10^{-6} m, the thermal imaging range includes wavelengths from 3×10^{-6} to 14×10^{-6} m, and the radar range includes wavelengths from 3×10^{-3} to 1.2×10^{-1} m [11]. The assets and facilities camouflaged with WPM Berberys cannot be identified in field conditions with the naked eye by ground or air reconnaissance from a minimum distance or altitude of 1000 m, respectively, or on the scale 1:5000 and lower-scale photographs at 20 lines/mm. WPM Berberys reduces temperature-differential based identification effectiveness by distorting thermal imaging of the camouflaged objects, changes in the three-dimensional heat radiation characteristics, and reduction of the thermal contrast between the camouflaged object and its background to a differential temperature of 4°C [11].

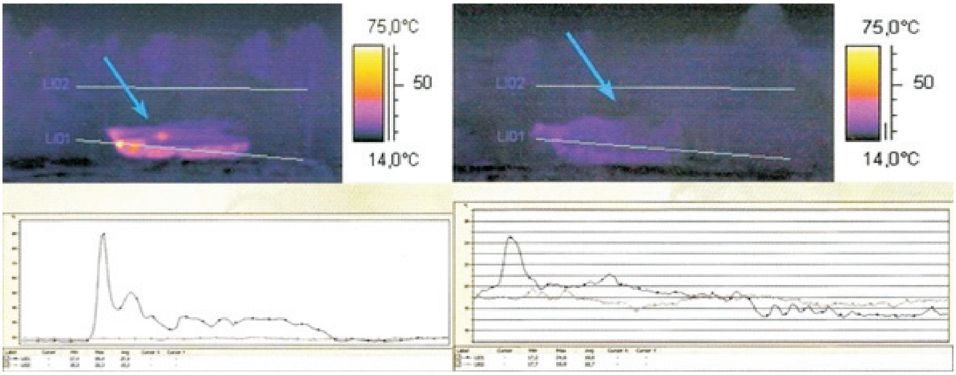

Fig. 8. IR imaging and a temperature uniformity chart; no WPM applied to the left; WPM deployed to the right [11]

Low-contrast structures are intended to reduce the temperature of the camouflaged object to a level equal to the background and thus remove the thermal contrast. Thermal countermeasures include purpose-designed camouflage mats attached to the surface of camouflaged objects, and active systems, e.g. exhaust gas cooling systems.

2.2. Active countermeasures

Active countermeasures include smoke screens, flares, jamming devices and laser dazzling.

A significant solution in the array of active countermeasures is IR flares which imitate heat signatures of targets and can misguide the target detection systems of missiles or form heat screens to conceal camouflaged objects against IR-guided missiles.

Detection prevention measures also heavily rely on dazzling lasers which work in VIS and NIR spectra. Dazzling lasers are hazardous to human eyes, night-vision devices, and TV and LLLTV cameras. The technological principle of dazzling lasers is the emission of laser radiation towards personnel and optoelectronic device; in the latter case, the laser radiation destroys the detection systems.

Effectiveness of assets in combat requires quick identification, warning and reaction. Modern aircraft, land vehicles and ships feature laser radiation warning systems, such as OBRA, to counter laser-guided strikes. OBRA detects illumination ('painting') with a laser beam, analyses the signal type carried by the laser beam and, if preprogramed threat criteria are met, fires smoke grenades toward the source of laser radiation, while deploying an anti-explosion defence system [12].

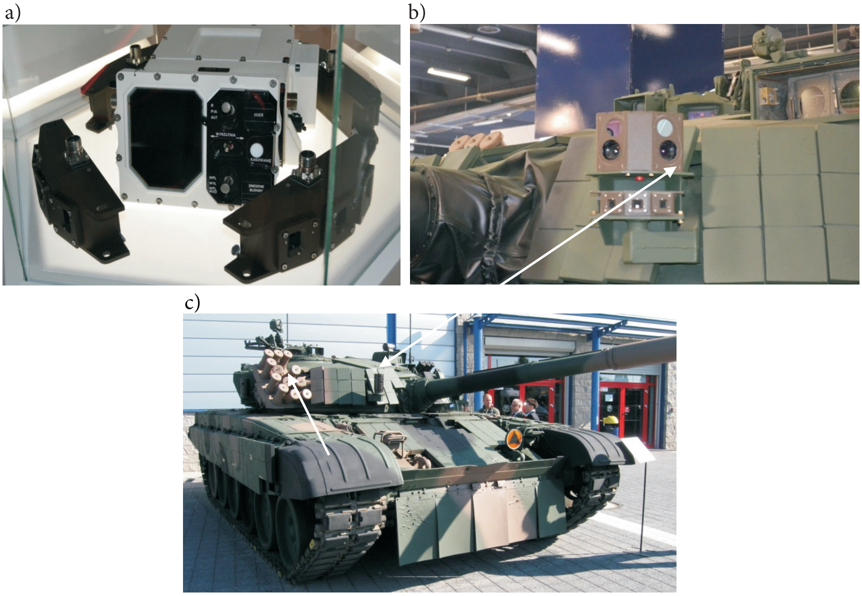

Fig. 9. OBRA, a Polish laser radiation warning system: (a) A complete SSP-1 OBRA-3 vehicle self--concealment system; (b) One of the three stationary SOD and OBRA-3 detector units for combat vehicles; (c) Smoke grenades for the vehicle self-concealment system of a tank [13]

To pre-emptively react to a strike from an enemy, smoke camouflage can be deployed to interfere with the flight trajectory or guidance controls of enemy missiles. Smoke camouflage provide multispectral effects; they react not unlike air-dispersion systems formed by release of particulates with EM emissive, absorptive and dispersive properties in a wide spectral range, from UV to microwaves. Smoke screens are in common use in all military forces around the world and very important on the modern battlefield. Research is continuing into the development of smoke formulations with an improved camouflage performance.

3. Smoke: properties and uses [14]

Smoke, in military terms, is any type of aerosol, i.e. systems comprising the finest possible particulates suspended in a gas medium. Smoke contains the dispersing medium, which is air, and the dispersed phase, which include liquid and/or solid particulates.

The behaviour of smoke largely depends on the size of the particulates suspended in the air. The particulate size directly affects the capability of smoke molecules for gravitational sedimentation. Particulates sized between 10^{-5} and 10^{-7} cm do not sediment by gravity; particulates sized 10^{-3} to 10^{-5} cm can sediment by gravity. Hence, the particulate size affects the stability (life) of deployed smoke.

Irrespective of the actual particulate size of the smoke systems within the ranges discussed above, smoke particulates always remain small enough to exhibit very specific properties. First, they exhibit constant, disorderly molecular motion, or Brownian movements. Second, they exhibit elevated specific surface area and surface energy. The high refinement of smoke particulates increases their surface areas, which accelerates relevant reactions. The surface energy of smoke particulates contributes to fast changes of the properties of a smoke system and its destruction. This simply means that smoke is unstable.

The stability (life) of deployed smoke depends on the smoke concentration, which is the quantity of the dispersed phase in the volume of a smoke cloud. There is particulate concentration, which describes the number of dispersed phase particulates, and weight concentration, which describes the quantity of the dispersed phase substance in a unit of volume.

In terms of aerosol concentration, it can be assumed that a stable, slow-precipitation smoke has a low weight concentration up to 0.1 g/m^3 and a particulate concentration between 10^5 and 10^6 particles per 1 cm^3.

Optical phenomena incessantly occur in a smoke cloud. These include light dispersion and absorption within the smoke cloud and at its interface with clear air. Both processes and the optical non-homogeneity of smoke reduce the contrast of colour and glare between the screened object and its background, while reducing visibility and clearness of observation of the screened object. Hence, the principal military application of smoke is camouflage.

3.1. Application of smoke for masking (camouflage) against modern reconnaissance identification and guidance

Smoke continues to be one of the essential components of generally understood military camouflage. According to current combat operation strategies, smoke can be deployed for effective camouflage and effective decoy operations, as well as obscuration and blinding of enemy assets.

The practical experience from past military conflicts and exercises, coupled with experimental testing, proves that smoke is and will remain effective passive countermeasures against traditional and state-of-the-art reconnaissance identification, guidance and striking assets.

This is reflected by the operations of most large military forces around the globe, including NATO. The military forces never abandoned smoke applications on the modern battlefield; indeed, this form of camouflage has been lately enjoying increased interest. This is most likely due to the low costs of smoke camouflage readiness, especially when compared to the value of modern military technical assets and facilities which, by application of suitably sized smoke screens deployed in proper advance, can be relatively effectively protected or at least largely reduce the striking effectiveness of enemy weapons, including precision guidance weapon systems.

However, tactical analysis implies that protection with smoke screens can only be effective if deployed quickly enough on a sufficiently large area and maintained for the required time. The modern battlefield is a highly dynamic environment; spatial and temporal parameters are essential fundamentals of smoke screen planning and effective use of the camouflage properties of smoke. Smoke camouflage-laying materials and equipment must be provided to arms types and military units to provide a sufficient availability and a sufficient deployment time. This principle is followed by all armed forces which deem smoke to be an important camouflage component in the security of their combat operations. The principle is embodied by enabling smoke camouflage capabilities at every tier of the chain of command, in the dynamics of combat, and at specific stationary military or national commercial facilities, selected by tactical, operating or strategic importance. This requires a suitable quantity of smoke camouflage materials and equipment with technical and tactical performance adequate to the challenges of the war theatres of today.

Smoke screens are an effective camouflage method. To provide an advantage on the battlefield as an effective method of camouflage, a smoke screen must be deployed quickly enough on a sufficiently large area and maintained for a sufficiently long time. It is most effective to gain a negative balance of time between identification and camouflage. Effective camouflage which prevents identification and detection would provide a substantial advantage to friendly forces.

In order to stimulate the higher effectiveness of smoke camouflage, the smoke materials require specific attention. It is necessary to use smoke materials which provide the best camouflage performance.

Smoke materials are smoke delivery systems filled with smoke compositions which are important to combat operations due to their offensive and defensive advantages. Smoke materials provide the expected effects when they meet specific parameters. Another factor decisive for the effectiveness of smoke use in camouflage operations are topographical and weather conditions which have an immense impact on the behaviour of deployed smoke clouds [15].

A smoke screen features several components, which are shown in Fig. 10.

The most distinctive components include:

— The smoke-laying line: a line across a field along which smoke-laying units are deployed.

— The length of the smoke-laying line: the distance between the outermost smoke-laying units on the smoke-laying line (it should be 2 to 3 times longer than the length of the operating front being camouflaged).
— The smoke screen front: the front perimeter of the smoke screen.
— The smoke screen width: the distance between the flanks of the smoke screen front.
— The smoke screen depth: the distance of the smoke-laying line to the smoke screen front.

Multiple types of smoke screens are classified [16]. The classification is provided in Fig. 11.

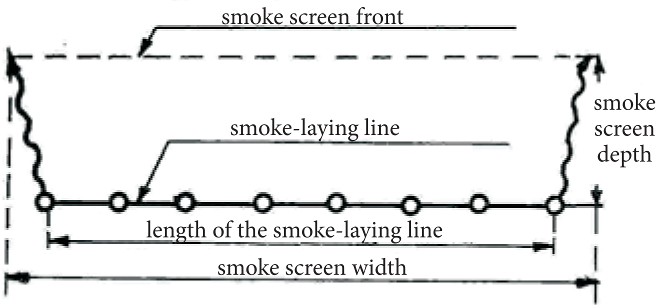

Fig. 10. Components of a smoke screen

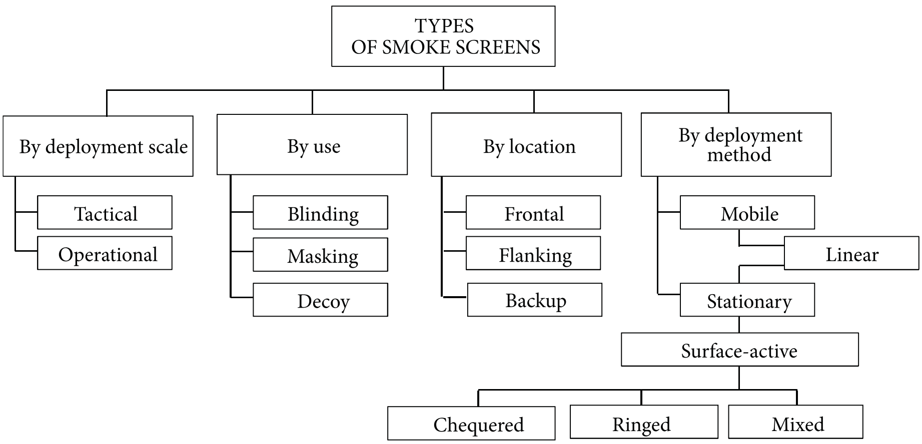

Fig. 11. Smoke screen types [16]

The classification by deployment scale includes tactical and operational smoke screens. *Tactical smoke screens* are laid by individual operatives, combat vehicles and units; *operational smoke screens* are laid by dedicated units across a wide front of operations or in an extensive area of land, following a detailed plan developed on an operational level.

The classification by use includes the following smoke screens [17]:

— ***Masking smoke screens**:* deployed between friendly forces and enemy forces, and in the vicinity of friendly forces or facilities to provide camouflage against enemy observation and fire.
— ***Blinding smoke screens**:* deployed in the vicinity of observation posts, weapon positions or combat groups of the enemy to prevent or inhibit effective observation and effective firing, and to disorganise operations.
— ***Decoy smoke screens**:* deployed to deceive and confuse the enemy about the actual direction of combat action, size and type of combat groups, and the functioning and/or position of high-value facilities or assets.

The classification by location relative to friendly forces include the following smoke screens [17]:

— ***Frontal smoke screens**:* laid ahead of friendly forces or in front of enemy groups with the smoke-laying line parallel to the front of friendly forces.
— ***Flanking smoke screens**:* deployed on the flanks of friendly forces to maintain the smoke-laying line perpendicular or diagonal to the front of friendly forces.
— ***Backup smoke screens**:* deployed deep within a friendly element, in the areas of high-value facilities, and in the areas of military concentration and operation.

The classification by deployment method includes the following smoke screens [17]:

— ***Stationary smoke screens***: the smoke-laying line is stationary.
— ***Linear smoke screens*****:** the smoke materials are deployed along a line and within a single or multiple smoke-laying lines.
— ***Surface active smoke screens**:* the smoke materials are deployed on a large surface area in the vicinity of a facility or a military concentration.

The classification by military operation includes the following smoke screen applications [18]:

Offensive:

— Masking of forces along regrouping routes and on attack / charge positions;
— Creating deception about the main vector of the offensive;
— Blinding the weaponry of the enemy;
— Concealing a manoeuvre;
— Shielding the flanks during advance;
— Masking and shielding the forces during construction and negotiation of water crossings;
— Reduction of the effectiveness of target tracking and fire control systems;
— Circumvention and isolation of heavily fortified facilities or areas.

Defensive:
- Deceiving the enemy (to prevent a successful identification of defensive positions or locations of friendly forces along the grounds and areas);
- Reducing the manoeuvre speed of the enemy and disorganising the movement of enemy forces;
- Reducing the losses in technical and personnel losses from enemy fire;
- Countering the detection, identification and tracking of targets by the enemy;
- Masking / camouflaging water and terrain crossings or retreating forces;
- Concealment of friendly delaying operations or stealthy advance and draw out of forces for an attack;
- Isolation of the attacking waves of the enemy.

3.2. Analysis of modern smoke camouflage forms

Given the essential objective of smoke camouflage applications, which is screening electromagnetic radiation in the 0.4-12 μm spectrum, NATO armies have been using multispectral smoke materials for decades. Multispectral smoke materials are effective against more than one spectral range (i.e. UV, VIS, NIR, MIR, FIR, and microwave bands). The multispectral smoke materials are manufactured in a wide range of delivery systems and forms: smoke canisters/grenades, smoke candles, smoke artillery shells, smoke bombs, aerial smoke-laying systems, smoke generators, and more. The smoke materials can be classified as shown in the diagram in Fig. 12:

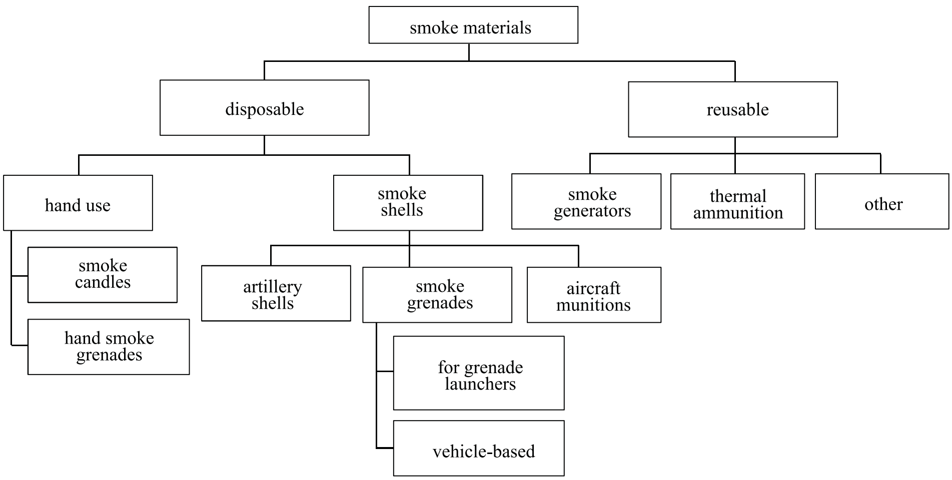

Fig. 12. Classification of smoke material types [14]

3.2.1. Disposable smoke materials

Smoke candles are used for:

- Impairment of visibility and clearness of observation;
- Masking of operations of military units and individuals;
- Filling of gaps in smoke screens;
- Creation of decoy fires;
- Blinding of enemy weaponry and reconnaissance systems.

The Polish Armed Forces currently use four standard-issue smoke candle forms: two small smoke candle types (DM-11M and DM-2B), and large smoke candle types, BDSz-5 and its floating version, MDSz-5. Only the DM-2B smoke candles meet the modern IR camouflage criteria.

Fig. 13. DM-2B small smoke candle [14]

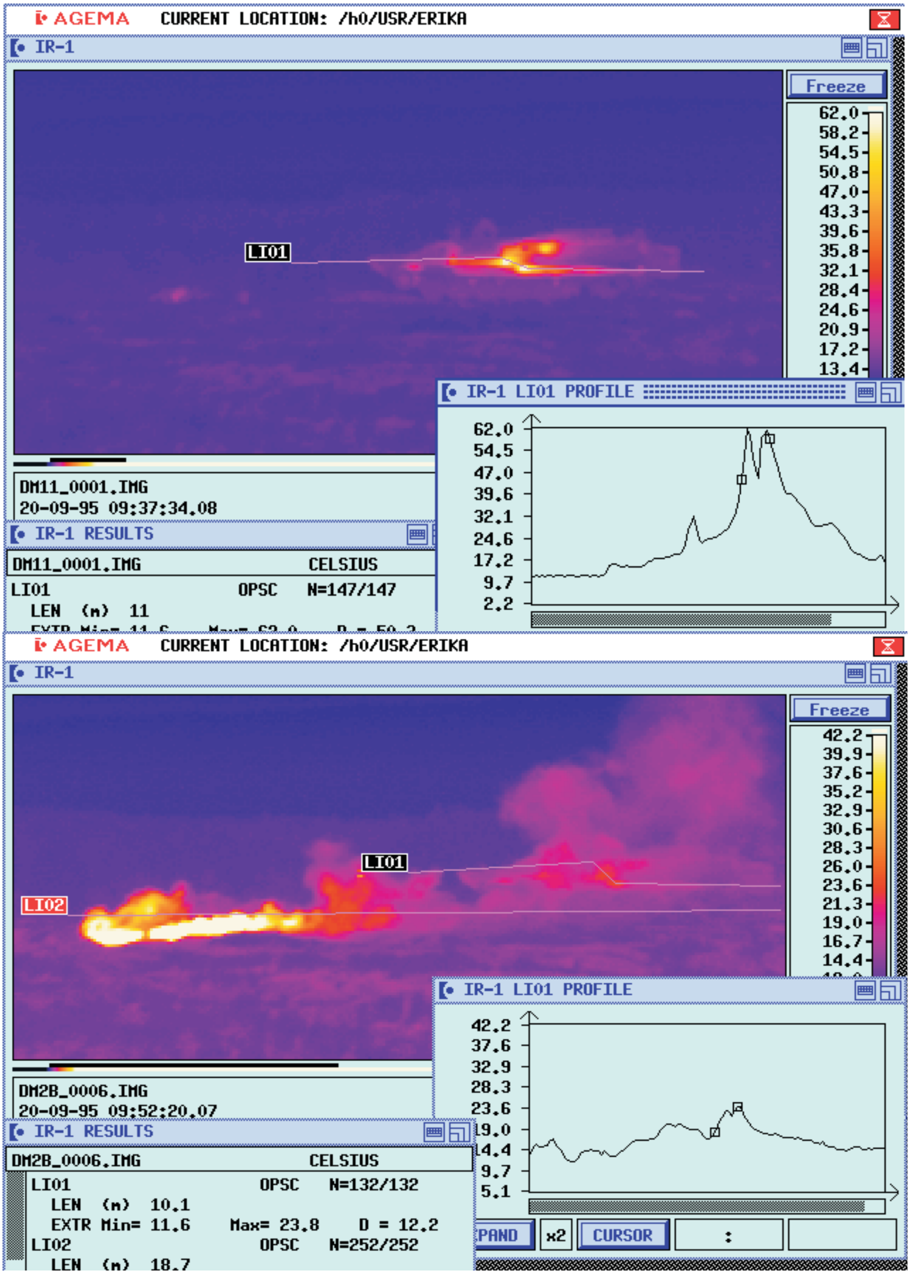

Fig. 14. IR camouflaging with a DM-2B smoke candle (a) Test object in IR imaging (8–12 μm) without any smoke screen deployed. The test object is perfectly detectable and identifiable. The chart reveals temperature differences up to 50°C. (b) Test object in IR imaging (8–12 μm) and concealed by a smoke screen laid with a DM-2B smoke candle. The test object is non-detectable. The chart reveals that the background and test object temperature levels become equal [14].

Fig. 15. Smoke screen shown in visible light as generated by a DM-2B small smoke candle. A laser transmission meter unit is shown in the foreground [14].

Hand smoke grenades

The RGD-2 hand smoke grenades are standard issue in the Polish Armed Forces and their uses depend on the colour of smoke deployed. White smoke is for blinding enemy firing positions, temporary smoke screening for masking of group and individual actions, and for filling of gaps in larger smoke screens. Black smoke is used for deception by creating decoy (false) fire of assets.

The RGD-2 grenades can also be fired from 7.62 mm-calibre GN carbines [19] with a grenade stabiliser and UNM ammunition rounds [20]. In 2004, the Military Institute of Chemistry and Radiometry (Wojskowy Instytut Chemii i Radiometrii) in Poland successfully completed a research and development program for a new-generation hand smoke grenade designated RGD-3. The RGD-3 features:

— an improved IR camouflage performance;
— deployment by firing from GN carbines.

RGD-2db hand smoke grenade [21]

a) b)

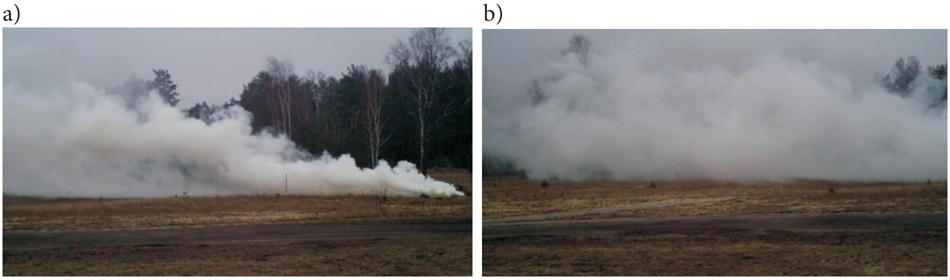

Fig. 16. (a) Smoke screen in visible light: the first smoke screen section with a length of up to 25 m. The test objects are invisible. The smoke screen height 10 m from the smoke origin; (b) Smoke screen over 40 m in length in visible light. The smoke screen section between 25 and 40 m of length is shown. The test objects are invisible. The smoke screen height is over 5 m at 30 m of length

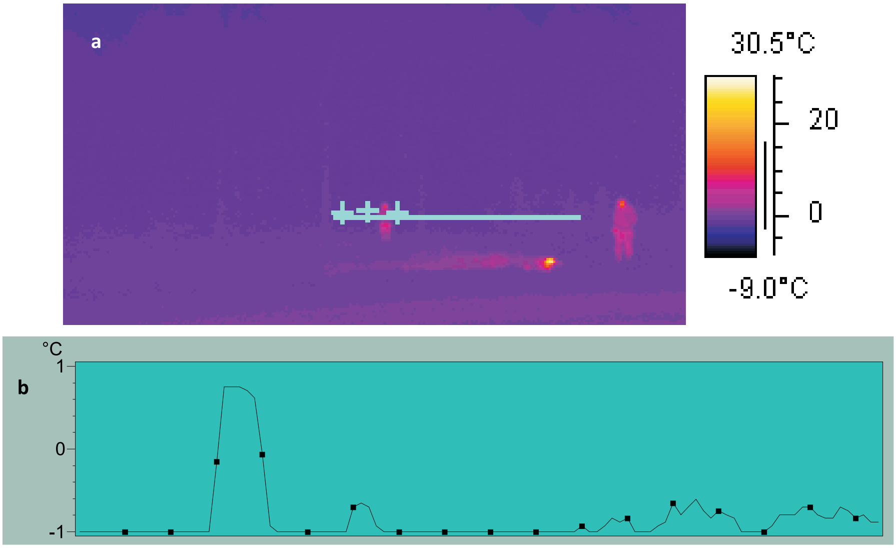

Fig. 17. (a) Thermal image of the test object; (b) Temperature profile for Fig. 18a [21]

The test object is visible. The temperature profile shows a clear increase of temperature originating from the test object.

The test object remains visible after 20 s of smoke laying. The temperature profile shows a clear increase of temperature originating from the test object.

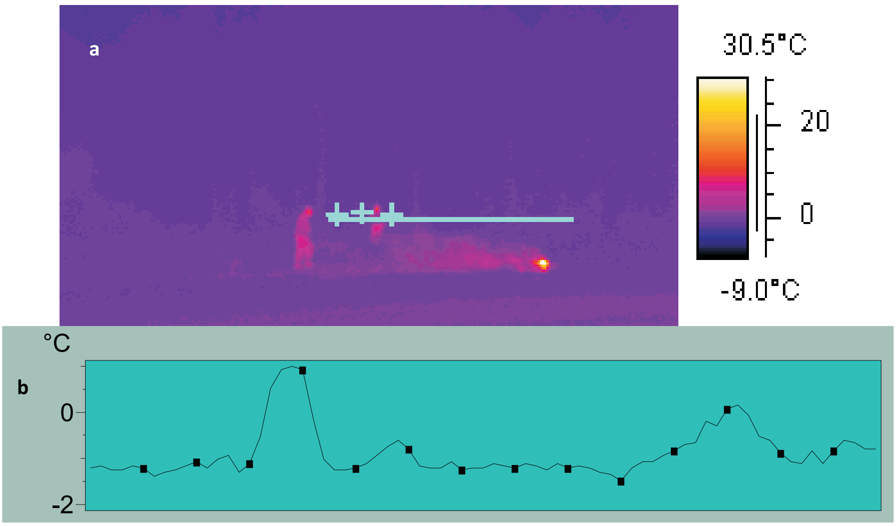

Fig. 18. (a) Thermal image of the test object after 20 seconds of smoke laying; (b) Temperature profile for Fig. 18a [21]

RGD-3 hand smoke grenade

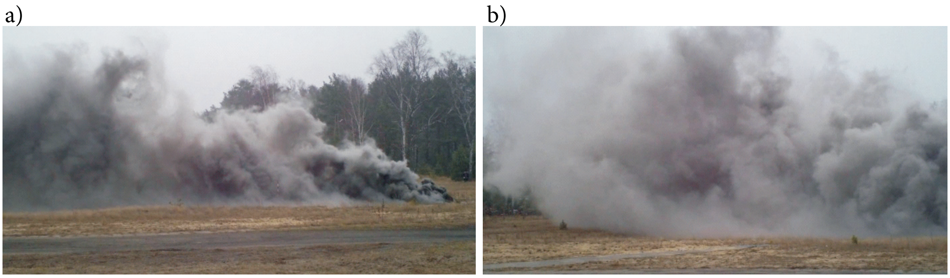

Fig. 19. (a) Smoke screen in visible light: the first smoke screen section with a length of up to 25 m. The test objects are invisible. The smoke screen height is ca. 5 m at 10 m from the smoke origin; (b) Smoke screen over 40 m in length in visible light. The smoke screen section between 25 and 45 m of length is shown. The test objects are invisible. The smoke screen height is over 5 m at 30 m of length [21]

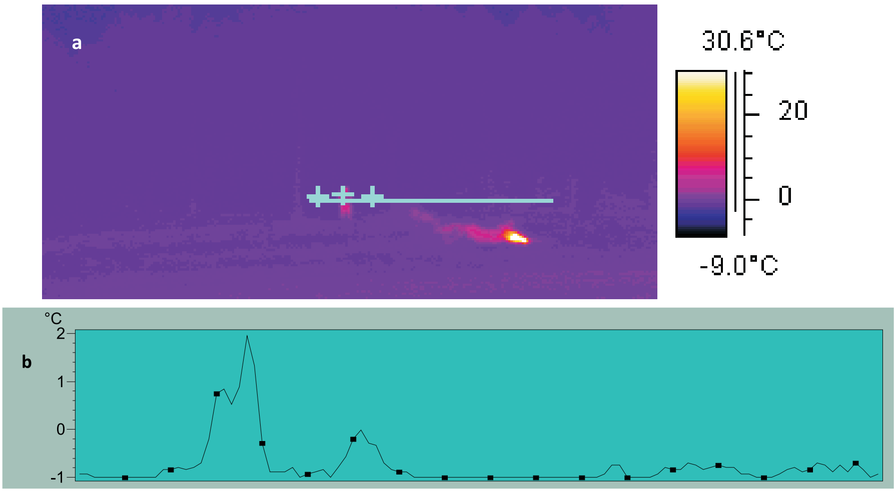

Fig. 20. (a) Thermal image of the test object approx. 25–30 m from the wind axis at the start of smoke laying; (b) Temperature profile for Fig. 20a [21]

The highest peak originates from the test object without a smoke screen. The test object is identifiable.

The test object is indistinguishable from the background after 20 s of smoke laying. The distinctive peak disappeared and the smoke increased the background temperature.

The test object is indistinguishable from the background after 25 s of smoke laying. The temperature profile features no discernible peak; there is a marked reduction of the background and test object temperatures by the smoke.

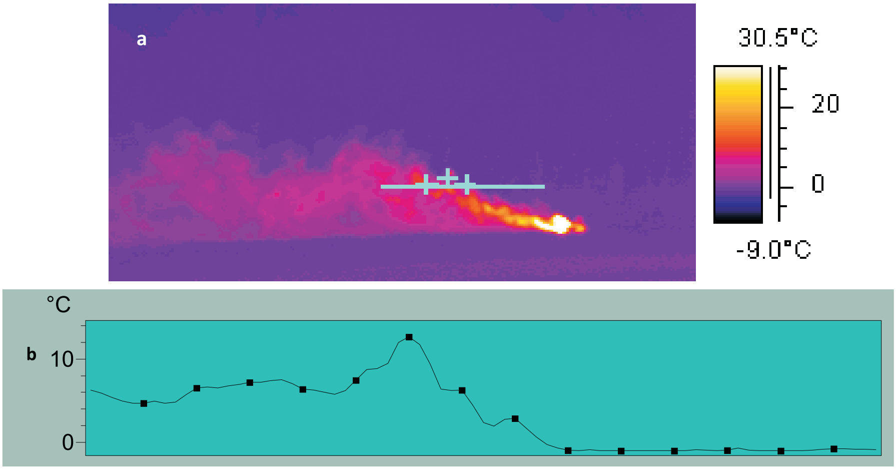

Fig. 21. (a) Thermal image of the test object behind the smoke screen after 20 seconds of smoke laying; (b) Temperature profile for Fig. 21a [21]

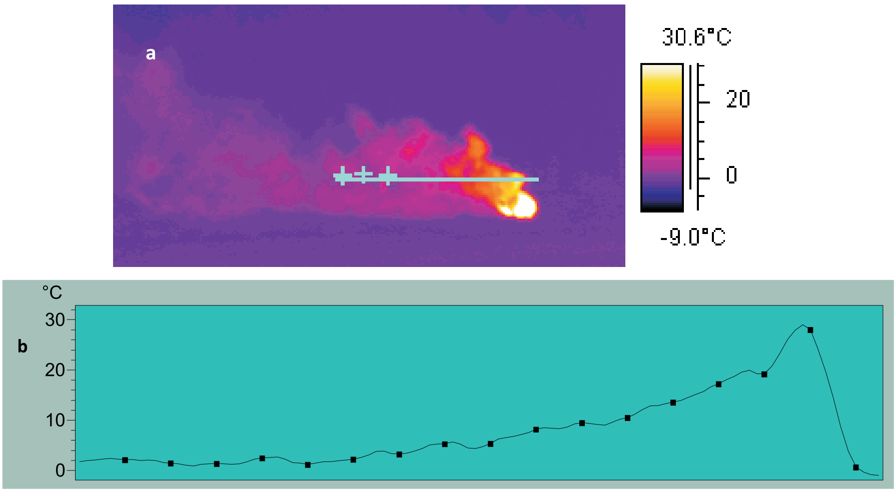

Fig. 22. (a) Thermal image of the test object behind the smoke screen after 25 seconds of smoke laying; (b) Temperature profile for Fig. 22a [21]

Despite its excellent technical and tactical performance, the RGD-3 hand smoke grenades are not manufactured.

Smoke grenades for armour-piercing grenade launchers are used for fast smoke laying at a long distance (up to 2 km) from the laying unit. A grenade designated DG-7M has been developed for the RPG-7 anti-tank rocket-propelled grenade launcher in Poland. Unlike other grenade-launcher-deployed smoke grenades, the DG-7M does not generate a smoke screen with an explosive propellant, but by linear combustion of two sections of the smoke generating charge, projected to over dozen metres from one another; this provides a considerable size of the smoke screen. When the smoke generating charge falls on the ground, it is fragmented. The DG-7M can also lay a smoke screen even if it is buried completely in the soil upon impact on the ground.

Fig. 23. DG-7M smoke grenade for the RPG-7 [22]

Fig. 24. Smoke screen generated by the DG-7M and observed in visible light

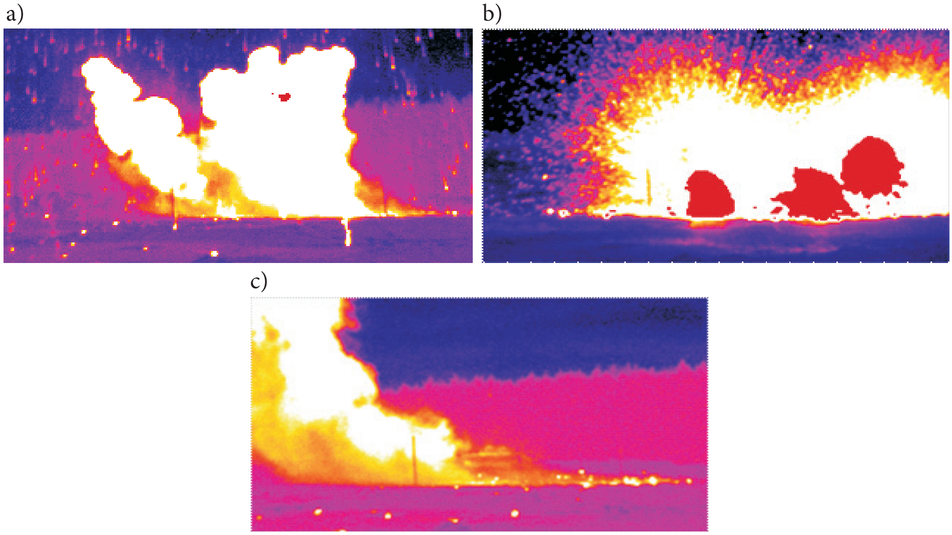

Fig. 25. IR camouflaging of a test object with the DG-7M a, b, c — The test object is camouflaged and invisible [22]

Vehicle smoke grenades**:** vehicle smoke grenades are deployed from dedicated launchers installed on combat personnel carriers and tanks. They are intended to secure and conceal the vehicle against enemy anti-tank weapons and/or blind enemy firing and observation positions, depending on the specific grenade type. Vehicle smoke grenades can be fired manually or by automatic control, by response to a laser radiation warning system. The main advantage of the smoke grenades is fast laying of large smoke screens after short-delay firing from the dedicated launchers. Another advantage is the effectiveness of smoke screen laying irrespective of the weather. A disadvantage is the very short life of the smoke screen which varies from 10 to 30 seconds.

The smoke clouds from vehicle smoke grenades can be generated with several deployment methods:

- Multi-stage smoke deployment: in multistage smoke grenades, the smoke screen being formed is replenished by successive incineration of smoke compound bricks deployed by a section of the smoke grenade head (examples include the French Galix 13 and the Czech DGO-3), the other section generates smoke by explosive deployment.
- Explosive smoke deployment: the smoke compound is violently expelled from the smoke grenade shell (as in the U.S. M-76 and M-81 smoke grenades) or by explosive fragmentation of the smoke grenade shell with the smoke compound, which forms a very hot and dense smoke screen in contact with atmospheric air (as in the Polish WGD-1 and WGD-2M smoke grenades) [23,24].

Fig. 26. WGD-2M smoke grenade

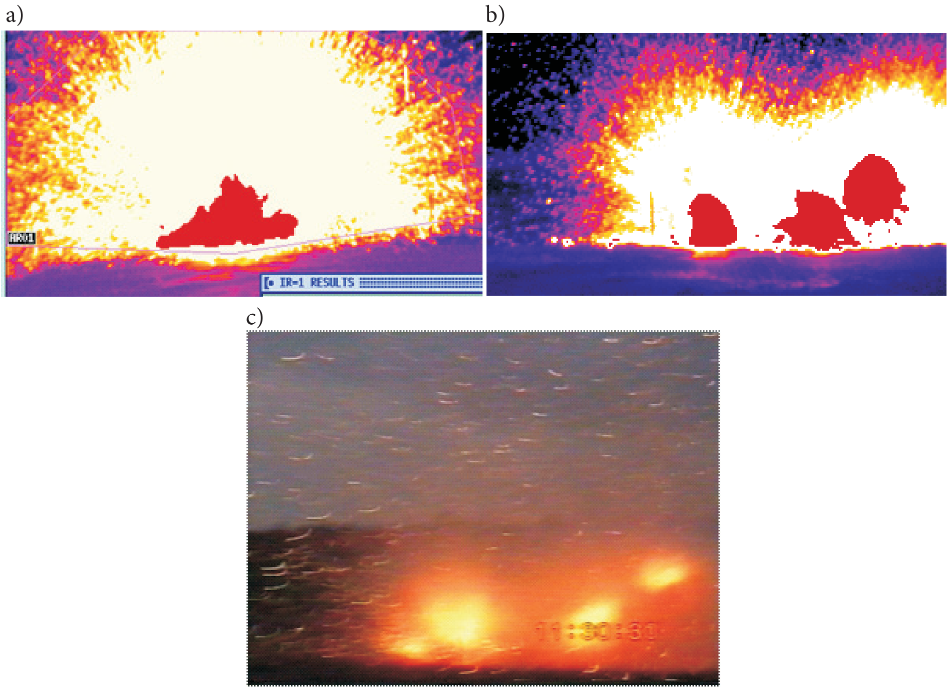

Fig. 27. (a) Smoke screen from a single grenade, IR imaging; (b) Volley of 3 smoke grenades, IR imaging; (c) Volley of 3 grenades, visible light imaging

Artillery shell and aircraft munition delivery systems are used to inhibit enemy efforts at regrouping, observation, and combat actions. These classes of smoke materials lay smoke screens outside of friendly positions. The smoke materials comprise white phosphorus and feature a long effective range. The smoke materials explode in air directly above the ground or at direct impact of the shell / bomb with the ground. ***The Polish Armed Forces have no artillery shells and aircraft munitions with smoke-laying capabilities.***

3.2.2. Reusable smoke materials

Combat vehicle thermal smoke delivery systems

Combat vehicle thermal smoke delivery systems lay short-lived smoke screens during combat operations. The smoke generating compound is Diesel fuel from the engine fuel system. The smoke laid with these delivery systems can be deployed any time to conceal friendly personnel and technical assets from enemy attack (especially with anti-tank munitions). It also provided effective protection against NIR and VIS systems, irrespective of the smoke generating compound.

Smoke generators

Smoke generators were traditionally used by the smoke-laying units of the chemical corps. Smoke generators were applied for continuous or intermittent area and linear smoke camouflage deployment over extensive surface areas for masking territory and friendly forces. The smoke compounds used in smoke generators include synthetic and mineral oils. The Polish Armed Forces used two smoke generator types: the GD-1 (on a single-axle trailer) and the GD-2 (on the Star 266 truck chassis as the carrier vehicle). The smoke generators became obsolete and were withdrawn without any replacement, and the smoke-laying units were disbanded from the structures of the Polish Armed Forces. The Military Institute of Chemistry and Radiometry (Wojskowy Instytut Chemii i Radiometrii) in Poland developed a turbine smoke generator designated TWD (Polish: Turbinowa Wytwornica Dymu), which still has not been implemented (despite its superior tactical and technical performance, in comparison to foreign smoke generator systems). The TWD smoke generator is a modular unit carried on a load bed of the Star 266 truck and deployable as a stationary or mobile unit with remote radio control [25].

a) b)

Fig. 28. (a) Prototype of the TWD turbine smoke generator; (b) View of an approximately 800 m long linear smoke screen laid by the TWD on the Vistula near Góra Kalwaria

a)
b)
c)
d)

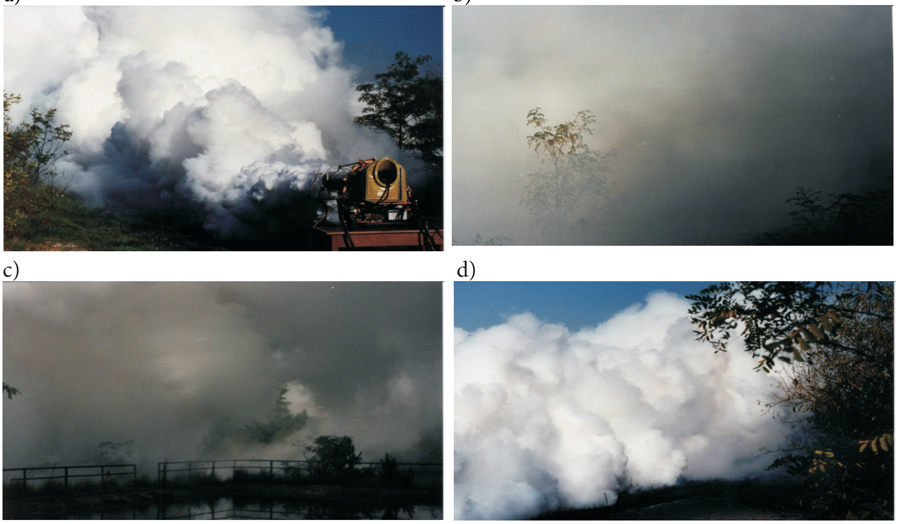

Fig. 29. TWD in testing: (a) smoke screen formation; (b) Smoke screen after approx. 1 min. from deployment; (c) Smoke screen after approx. 2 min. from deployment; (c) Smoke screen after approx. 5 min. from deployment

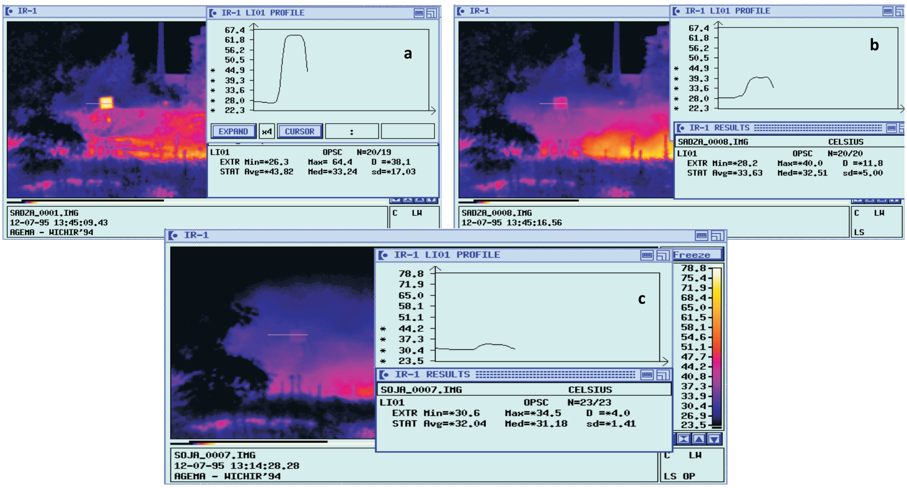

Fig. 30. TWD performance testing with IR imaging. The test thermal object is at T = 80°C. (a) Test object visible and identifiable; (b) Test object partially concealed by a dispersed part of the smoke cloud (visible and identifiable); (c) Test object obscured by the smoke cloud (invisible and unidentifiable) [25]

Helicopter-based smoke generators lay smoke screens on large areas within the concentrations of friendly forces. Smoke screen laying for camouflage with helicopters is extremely effective; helicopters can quickly reach areas to be camouflaged, especially in terrain conditions inaccessible to ground vehicles. Camouflaging with helicopter-based smoke generators is used for masking of high-value areas, water crossings, airfields, ports, and command posts. The Polish Armed Forces operate a panel smoke generator (PWD, designation PYLIA) installed on the PZL W-3A new-generation combat helicopters [26].

a) b)

Fig. 31. (a) PWD pod on a hardpoint rail of the PZL W-3A helicopter; (b) PWD smoke compound pod on a helicopter hardpoint rail [26]

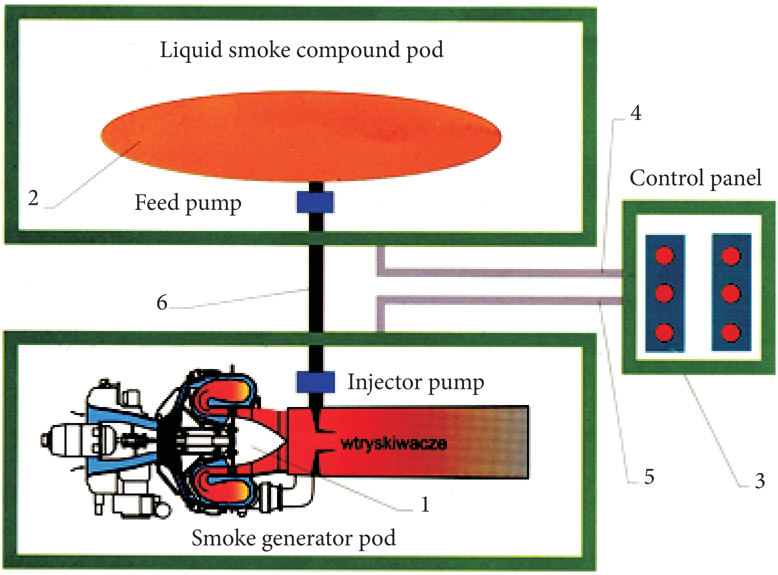

Fig. 32. PWD structural diagram:1 — PWD smoke generating pod attached to the port hardpoint of a helicopter and comprising: a turbine engine, a smoke generator unit, a turbine engine fuel tank, a battery; the gross weight is 150 kg; 2 — PWD liquid smoke compound pod attached to the starboard hardpoint of a helicopter and comprising: a liquid smoke compound tank and its feed pump; the net / gross weight is 57 kg / 325 kg; liquid smoke compound tank capacity: 335 dm^3; 3 — PWD control panel in the helicopter cabin; 4 — electrical wiring harness between the PWD control panel and the PWD liquid smoke compound pod; 5 — electrical wiring harness between the PWD control panel and the PWD smoke generator pod; 6 — hydraulic line between the two liquid smoke compound tanks [26].

The PWD is designed as a system of pods which can be attached and removed on the ground or jettisoned in mid-flight in an emergency. The main advantage of the PWD is the descent of the smoke screen on the ground by the wash of the helicopter rotor; this is effective even at relatively high smoke-laying altitudes.

Fig. 33. Object of camouflage and the object during smoke camouflaging with the PWD in visible light

Fig. 34. PWD aboard a W-3WA helicopter: an area smoke screen in deployment

Fig. 35. PWD aboard a W-3WA helicopter: a spot smoke screen in deployment

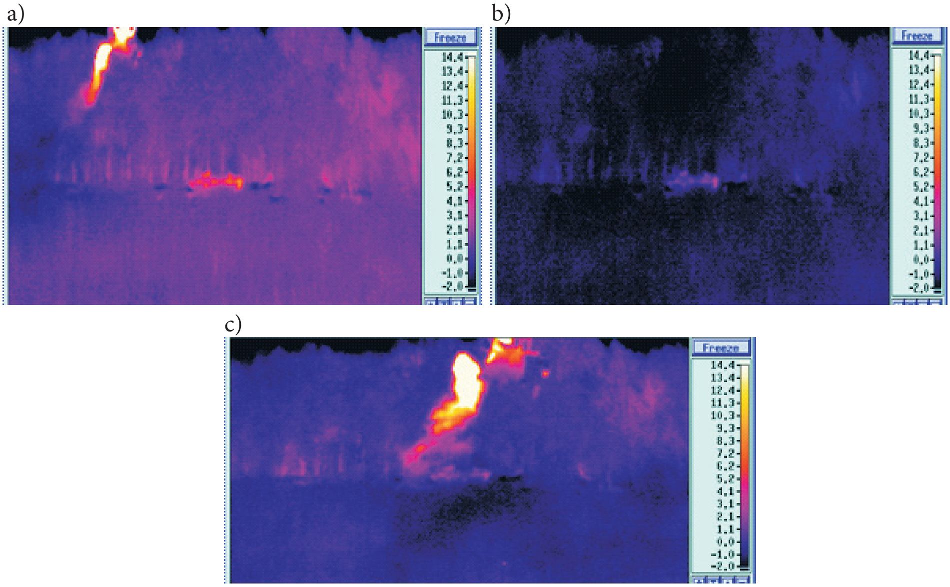

Fig. 36. (a) Thermal image of the object of camouflaging during testing of the PWD smoke generator: partial thermal image of the PWD and its helicopter shown in top left. (b) Object, shown partially in camouflage and still visible; the hot spot is the exhaust pipe. (c) Thermal image of an object masked with the smoke from the PWD; camouflage complete, the test object is invisible

4. Summary

Military camouflage use and deployment in the Polish Armed Forces is the mission of the Engineering Corps. The solutions presented in this work were developed by the research laboratories at the Military Institute of Chemistry and Radiometry and the Military Institute of Armament and Technology, which have the sufficient instruments and procedures; most of the research teams involved have been disbanded. Note that smoke masking enjoys low interest in the Polish Armed Forces, unlike in NATO. NATO is highly focused on the use and development of air dispersion camouflage systems, especially those operated in IR spectrum.

Polish research laboratories are currently developing and testing dispersive and adsorptive camouflage paint coats. Unfortunately, this research has not been published. Another component of counter-reconnaissance systems are decoy objects (like technical asset dummies) which confuse weapon guidance systems, and camouflage netting and camouflage garment for soldiers.

Tactics-wise, camouflage organisers (commanders and staff) must reliably evaluate the recon capabilities of opponents, and the camouflage organisation should be the task of the best reconnaissance experts. Camouflage must not be limited to military doctrine; it requires a proper organisation of camouflage experts and technical counter-reconnaissance systems; hence, camouflage is a form of counter--reconnaissance, or counter-identification. The analysis presented in this paper suggests that the technical level of camouflage equipment used in the Polish Armed Forces is far from the modern requirements and technical and technical capabilities. The sole exception here is the PWD panel smoke generator. It would seem that its smoke generating method and the smoke compound (which remains classified) should find use in ground-based smoke generators, as in the TWD turbine smoke generator.

Smoke has been used for masking military positions and facilities for centuries. It saw intentional use for concealment, deception and camouflage when its generation with smoke compounds was mastered. Smoke is a versatile camouflage agent and can be applied in a multitude of combat scenarios. It should be a countermeasure used in all types of combat operations and by all types of arms on every level. Smoke can also be used at a different scale and in diverse forms, depending on the objectives and applications.

5. Conclusions

1. Modern armed forces operate state-of-the-art target identification and guidance systems which work in optical ranges impervious to different types of interference. Aside from visible radiation (0.3–0.8 μm), the main operating ranges include the following spectral bands: 0.8–1.7, 2–2.5, 3–5.5 and 8–14 μm.
2. The use of smoke on the battlefield must follow defined objectives and tasks, including counter-identification, camouflage (concealment), blinding, decoying, deception and confusion, reduction of effectiveness of combat systems and measures, isolation of specific areas and directions, and psychological effects.
3. The use of IR camouflage smoke markedly reduces the range of (and often eliminates) IR combat systems. The interest of the Polish Armed Forces in this type of camouflage is limited to the military doctrine only.

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REFERENCES

[1] http://pl.wikipedia.org/ Plik:Flounder (dostęp: 01.2018).

[2] http://pl.wikipedia.org/wiki/Kamufla%C5%BC (dostęp: 01.2018).

[3] *Regulamin działań Taktycznych Wojsk Lądowych*, cz. I, Szt. Gen. 1422/94, Warszawa, 1994.

[4] Kotarbińsk T., *Traktat o dobrej robocie*, Wyd. PWN, Warszawa, 1974.

[5] Szydłowski A., *Prakseologiczne aspekty maskowania*, Myśl Wojskowa, Warszawa, nr 6, 1996.

[6] *Użycie dymów w działaniach bojowych*, Poradnik, Szefostwo Wojsk OPChem, DWLąd, 2001.

[7] Jóźwiak K., *Współczesna technika rozpoznania powietrznego*, AON, Warszawa, 1994.

[8] http://aeronauticapy.com/foro/index.php?topic=35.180/ (last accessed: 12.2017).

[9] https://gdziewojsko.wordpress.com/2015/07/30/uzbrojenie-polskich-f-16-su-22-i-mig-29/ (last accessed: 12.2017).

[10] http://www.defenseindustrydaily.com/Turkey-Orders-Russian-Kornet-Anti-Tank-Missiles-05083/ (last accessed: 12.2017).

[11] http://militarium.net/wielozakresowe-pokrycie-maskujace-berberys/ (dostęp: 11.2017).

[12] http://www.pcosa.com.pl/systemy_ostrzegania/uniwersalny_system_samooslony_pojazdu_ssp-1_obra-3-12.html/ (last accessed: 11.2015).

[13] http://www.defence24.pl/655377,mspo-2017-platformowe-systemy-termowizyjne-i-noktowizyjne-od-pco (last accessed: 01.2018).

[14] Mazierski A., *Wpływ dymów maskujących w podczerwieni na skuteczność środków rozpoznania i naprowadzania na cel na polu walki*, rozprawa doktorska, AON, Warszawa, 2004.

[15] Wojtoń A.I., *Koncepcja stosowania dymów maskujących przed współczesnymi środkami rozpoznania i naprowadzania*, praca dyplomowa, WAT, Warszawa, 2016.

[16] *Stosowanie dymów w działaniach bojowych*, Podręcznik Chem. 238/79, MON, Warszawa, 1980.

[17] *Instrukcja o stosowaniu środków dymnych w działaniach bojowych*, MON, Chem. 270/78, Warszawa, 1978.

[18] Harmata W., *Dymy, jako element systemu maskowania w obszarze taktycznym*, WIChiR, Warszawa, 1999.

[19] Mazierski A., Daniluk E., Nyszko G., Dąbrowski W., Czchowski A., *Sprawozdanie z badań kwalifikacyjnych ręcznych granatów dymnych RGD-3*, Sygn. WIChiR ONIW 989/2004.

[20] *Instrukcja „7,62 mm karabinki AKM (AKMŁ), AKMS (AKMSN), AK, kbkg wz. 1960 i kbkg wz. 1960/72 Opis i użytkowanie. Sposoby i zasady strzelania*", Uzbr. 2447/86.

[21] *Sprawozdanie z badań WIChiR, na zlecenie Zakładów Boryszew S.A. Oddział Nylonbor w Sochaczewie*, Sygn. WIChiR ONIW nr 15, 1680, 2014.

[22] Mazierski A. i in., *Sprawozdanie z badań kwalifikacyjnych partii prototypowej granatów dymnych DG-7M*, Sygn. WIChiR ONIW 419/1996.

[23] Maziejuk M., S*prawozdanie z badań kwalifikacyjnych partii prototypowej granatów dymnych WGD-1*, Sygn. WIChiR ONIW 379/1996.

[24] Mazierski A. i in., *Sprawozdanie z badań kwalifikacyjnych partii prototypowej granatów dymnych WGD-2M*, Sygn. WIChiR ONIW 418/1996.

[25] Harmata W., *Dymy, jako element systemu maskowania*. Prace Wojskowego Instytutu Chemii i Radiometrii w ostatnim dziesięcioleciu, materiały z sympozjum: X Lat Obrony Przeciwchemicznej, Sygn. AON 5249/2000, AON, Warszawa, 2000.

[26] Marciniak W., Różycki Cz., Harmata W., Daniluk E., *Materiały z realizacji pracy o kryptonimie „PYLIA*", WIChiR, Warszawa, 1994 –1997.

WŁADYSŁAW HARMATA

Dymy jako element systemu maskowania

Streszczenie. W niniejszym artykule przeprowadzono analizę wojskowych środków rozpoznania i naprowadzania pracujących w zakresie optycznym. Poddano analizie środki techniczne istniejące w SZ RP stosowane do stawiania zasłon dymnych z uwzględnieniem maskowania w podczerwieni.
Słowa kluczowe: rozpoznanie, przeciwrozpoznanie, maskowanie, dymy
DOI: 10.5604/01.3001.0012.6600