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REVIEW PAPER

Role of Smokes in Warfare

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ABSTRACT

The role of smokes in warfare is reviewed with particular reference to the world wars, and various types of smokes are discussed. The smokes that can defeat modern opto-electronics including infrared (IR)/millimetre wave (MMW) guidance and thermal imager are described. Environment-friendly non-toxic smokes are dealt with briefly. The future of smokes in these circumstances is mentioned.

1. INTRODUCTION

Use of smoke in warfare is probably as old as warfare itself. The details are certainly lost to antiquity, yet occasional references do occur in ancient texts. In addition to screening, smokes could flush out the hidden enemy from the cover of thick foliage, natural tunnels, caves, etc. For such purposes, smoke was generated by burning natural substances like grass, straw, resins, gums, and asphalt. The American Red Indians were known to be great users of smoke in a very intelligent manner. They could send a smoke signal asking for reinforcement, convey enemy strength/weaknesses and even relay the message by repetition.

Although smoke from the use of gunpowder in the battlefield was considered a nuisance, deliberate artificial generation of smoke for military purposes did not occur to anybody for quite some time. The credit for artificially generating smoke for screening goes to the German Navy which successfully used this knowledge at the battle of Jutland in 1916. Hence, both Allies and Germans developed pyrotechnic screening smokes for use on both land and sea during World War I. The tactical significance of the planned use of smoke, which was not fully realised until the close of World War I, was strongly considered early in World War II. Consequently, extensive research and development programmes were established early during World War II to obtain the information necessary to develop the tactically required smoke-producing items.

The introduction of military aircraft, especially bombers which could attack important rear-area targets, created a definitive need for large-area smoke screens for protection. Consequently much of the efforts, between the two world wars was directed towards development techniques for producing large-area smoke screens. The principal screening material used included SO_3 $-ClSO_3H$ mixture, a corrosive liquid for use in projectiles and airplane spray tanks, hexachloroethane-Zn, a burning-type filling in grenades and smoke pots, and white phosphorus for filling in grenades, bombs and projectiles. These materials were superior to those used in World War I, yet were not completely satisfactory. The efficiency of German air operations against British cities during 1940-44 was considerably reduced through the use of large-area smoke screens which prevented accurate aiming. The British protected important industrial centres with smoke pots. They later developed truck-mounted mobile smoke generators which produced grey-brown smoke by burning and vapourising crude oil.

After the World War II, there was hardly any improvement in this field. The Korean and Vietnam wars did not contribute anything. The Falkland war showed that fear of fire and smoke could claim the lives of many sailors.

1.1 Revival of Interest in Smokes

Since the end of World War II till the advent of Arab-Israeli conflict in October 1973, smoke was a

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neglected field. The importance of smoke and its capacity to give an edge at the face of sure defeat was realised by the Israelis during the heat of battle after losing 130 tanks in 120 minutes when they discovered smoke could blind the gunners of AT-3 Sagger missiles of Egyptian Infantry[1]. The Americans and Russians then gave smokes a very important role in tank warfare. After the Falkland war it has become a standard practice in many a navy to expose sailors to smoke (training exposure on board ships). With the introduction into battlefield of sophisticated opto-electronics like laser designators, range finder with fire control systems, laser/IR guidance, detection in the dark with sensitive thermal imager, TOW-tube launched optically guided weapons, surveillance satellites, and Strategic Defence Initiative (SDI), smoke appears to be the only countermeasure that can convincingly defeat all the above hi-tech.

1.2 Pyrotechnics

The art of producing smokes comes under the science of pyrotechnics, derived from the Greek word 'pyr' meaning fire and 'techne' meaning art, i.e. art of making fireworks[2,3].

1.3 Smokes

Smokes are defined as fine particles suspended in air as the medium[3,4] and come under aerosols with the particle size extending up to 10 μm.

2. GENERATION OF SMOKES

Smokes can be generated by the following means

2.1 Reacting Metal Phosphides[3,4] with Water

$$Ca_3P_2 + 6H_2O \rightarrow 3Ca(OH)_2 + 2PH_3$$
$$Mg_3P_2 + 6H_2O \rightarrow 3Mg(OH)_2 + 2PH_3$$
$$AlP + 3H_2O \rightarrow Al(OH)_3 + PH_3$$

2.2 Dispersal by Detonation

(a) Pyrophoric substances like white phosphorus[3-5], plasticized white phosphorus[3], aluminium trialkyl based formulations [7];

$$4P + 5O_2 \rightarrow 2P_2O_5$$
$$2Al(C_2H_5)_3 + 21O_2 \rightarrow Al_2O_3 + 12CO_2 + 15H_2O$$

(b) Reactive chlorides of *Ti/Si*, Chlorosulphonic acid[2-4,6];

$$TiCl_4 + 4H_2O \rightarrow Ti\,(OH)_4 + 4HCl$$
$$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$$
$$ClSO_3H + H_2O \rightarrow H_2SO_4 + HCl$$

(c) Pelleted inert substances like talc, graphite, SiO_2, TiO_2, metal flakes, metal fibres, glass fibres, carbon fibres[8-12].

2.3. Pyrotechnic Means

(a) Generating smoke from hygroscopic chlorides (*HC* smokes)[2,3,5,12] $ZnCl_2$, $FeCl_3$, $SiCl_4$, $TiCl_4$, and $AlCl_3$ formed by pyrotechnic reactions, react with the atmospheric moisture to generate smoke.

(b) Generating coloured smokes by volatilizing dyes[3-5,8-14].

(c) Generating carbon particles from carbon-rich substances[3,5,14-19]

2.4 Thermal Means

Dropping oil/organic liquid on a hot surface generates fog/oil smokes[2,4,5,20]. (The hot exhaust of internal combustion engines is a freely available heat source and is used or can be used for producing such smoke.)

3. TYPES OF SMOKES

Depending on end use, we can categorise smokes into the following:

3.1 Training Smokes

Such smokes are characterised by their inertness and lack of toxicities[20-24], and are extensively used for outdoor training/familiarisation and fire fighting training. Sailors who have familiarised themselves with smoke will not panic under real-life conditions of battle and will take appropriate steps to save themselves. Many a British sailors were drowned because of panic in the last Falkland war. KCl[20,21], NH_4Cl[2], and fog oil smokes are ideal for training outdoors/indoors.

3.2 Phosphide Smokes

Metal phosphides of *Ca*, *Al* and *Mg* react with water vigorously, releasing copious amounts of phosphine, which on spontaneous ignition gives flame and the smoke formed gives night time visibility as well[3].

3.3 Screening Smokes (Bursting Type)

White phosphorus/plasticized white phosphorus smokes are generated by dispersing the material by a burster charge. The smokes are perfectly white but last only a short while. Similarly $TiCl_4$, $SiCl_4$, and chlorosulphonic acid when dispersed by a burster give smoke suitable for screening. Here again, the duration of smoke is short.

3.4 Screening Smoke (Burning Type)

3.4.1 HC Smokes

Hygroscopic chloride (HC) smokes find extensive use the world over for screening. Here a chlorine-rich substances like hexachloroethane (HCE) or hexachlorobenzene (HCB) or chlorinated paraffins react with ZnO, TiO_2, Zn, Ti, Si, Silumin, etc. to generate metal chlorides which spontaneously react with the moisture in the atmosphere to form hydrated chloride/hydroxychloride/hydroxides to give smokes with good screening properties. TiO_2 containing formulations give an yellowish white smoke. Fe_2O_3 containing composition gives orange-coloured smoke. Longer durations are possible with burning-type compositions only.

3.4.2 Red Phosphorus Smokes

Red phosphorus-based smoke formulations give a perfect white smoke but the powerful flame limits its use by land services. However, it finds extensive use as naval markers with both day and night visibility. Recently, rubber binder based, encapsulated red phosphorus formulations have found use in rapid deployment smoke formulations for defeating laser range finders. The L_8A_1/L_8A_3 red phosphorus-rubber based formulation is used by all NATO forces fo- such purposes[1].

3.5 Day/Night Visible Smokes

The only smoke that has both day and night visibility is chemiluminescent smoke generated by dispersal by burster of an aluminium trialkyl based formulation[7].

3.6 Oil Smokes

Special vehicle-mounted smoke generators are available which generate copious amounts of grey-brown smoke by burning/vaporising crude oils. VEES (vehicle engine exhaust smoke systems) generate smoke by injecting fuel (diesel) into the hot exhaust[20]. Such smokes give visual obscuration and can cover some vital installations/troop/tank formations, etc. in a very short time.

3.7 Alkali Halide Smokes

Smokes containing inert $NaCl/KCl$ particles can be formed very easily from pyrotechnic formulations containing $KClO_4/NaClO_4$, Mg and a binder. The screening efficiency of such smokes at 50 per cent RH is rather low. At 65 per cent RH the smoke has a very good screening power. Hence these smokes are ideal for naval use[20] or for training outdoors.

3.8 Coloured Smokes

(a) Coloured smokes are generated by volatilizing coloured dyes or a mixture of dyes from a heat-generating pyrotechnic formulation. Here the fuel and oxidizer, usually sugar and $KClO_3$, generate the heat and vaporises the dye without degradation and appears as coloured smoke.

(b) Short-duration coloured smoke clouds can be generated by detonating dye-explosive mixtures.

3.9 Opto-Electronic Defeating Smokes

Modern-day hi-tech has changed completely the concept of battle. Sophisticated weapon systems have been developed with unparalleled accuracy, range and killing power using the various regions of electromagnetic spectrum for target acquisition, automatic/semiautomatic guidance. Such advances have made the ever elusive dream of first-round hit a distinct possibility. With the development of fibreoptic guidance system in NLOS (non-line of sight) weapon system, the target need not be on the line of sight of the weapon. The so-called inaccurate weapons, like mortars and rockets, of yester years have become accurate by virtue of the added on guidance–'dumb ammunition' have/can become 'smart'. The guns can launch CLGP (cannon launched guided projectiles) or SADARAM (sense and destroy armour) to take advantage of high muzzle velocity and can tackle moving targets. Even SADARM can distinguish an armoured vehicle from a truck. Obscurant materials in the battlefield environment can have a deleterious effect on the performance of electro-optical sensors. The battlefield-induced contaminants such as dust, smoke and foreign gases can degrade the atmospheric medium between a target and sensor[20]. Devices for target acquisition, ranging and identification require line of sight contact with the target and in principle can be defeated by tactical obscurants[20].

Countermeasures for tanks beating smart munitions[26] give type of sensors and the role smokes can play. The visible range of electromagnetic spectrum is 0.4-0.72 μm. TV, LLLTV, and visual guidance fall in this range. If the target is no longer visible, none of the above systems can be made operational/effective. As long as the target is invisible, it is safe by all means. Some types of smoke are capable of providing visual obscuration by virtue of complete scattering of the incident radiation[3]. The screening smoke particles cover a range of 0.05-0.5 μm and may go up to 1 μm. The screening range extends up to 1.2 μm in the electromagnetic spectrum[20]. Hence common obscurant smokes are transparent to infrared (IR) radiations beyond 1.2 μm. The operating range of *Nd-Yag* laser based range finder or designators is 1.06 μm. Hence these can be easily attenuated by any screening smoke. Although IR covers a very wide range, only two narrow windows covering 3-5 μm and 8-13 μm are useful. As none of the common obscurants is capable of performing in this range[20], extensive work has been carried out to find obscurants. IR radiations of up to 13 μm are easily obscured by fibrous carbon particles of 1-14 μm/5-20 μm lengths[15-19] generated from carbon-rich substances like naphthalene /anthracenes, styrene-butadinne rubbers, chlorine-rich substances like HCE/HCB with *Mg*.

The attenuation is a combined effect of scattering, absorption and reflection of the incident radiation[26]. The devices that can be defeated by these smokes are night-vision devices including FLIR (forward looking IR), laser range finders, laser antipersonnel weapons, and IR sensors based guidance systems of missiles. These devices can also be defeated by particulate cloud made up of metal flakes and fibres[7-11,25,27]. Pyrotechnic smokes containing $CsNO_3$ are reported[28] to be effective in attenuating in the IR region. Many a guidance system of missiles use more than one mode to sense targets more efficiently and resist countermeasures. Thus multi-spectral sensors, combination of visual/IR or IR/MMW (millimetre wave), are used. So a single obscurant smoke should have the capacity to attenuate in the extended spectral regions. The dual capability is possible[9-11,15,17,19,20,27]. These smokes have visual cum IR cum microwave/radar defeating[9,10].

These smokes, in addition to the conventional visual smoke component, release copper particles and metal/glass fibre for attenuation in the IR and microwave/radar range. Visual and IR attenuation capability is also attainable[8,15-17,31]. The US Army Grenade M 76 has[29,41] this capability. Weighing 4 lb, a plastic-bodied, electrically-initiated, propellant-launched, the grenade explosively disseminates a screening smoke cloud 30 m forward of Abrams tank capable of defeating threat weapon sensors operating from visual to far-IR. Formulations capable of this feat are available[9-11,27].

3.10 Environmentally Acceptable Smokes

With the increased awareness about the environment, the danger from smoke formulations/ingredients and smokes to the environment has been realised lately. Some of the inputs like HCE, HCB, naphthalene, anthracene and end products like $ZnCl_2$ are outright carcinogenic/toxic, or both. Some of the dyes used in the colour smoke formulations are carcinogenic. Both the USA and the UK have carried out extensive studies in this regard[12,13,24-26]. Tolerance levels of some of the ingredients have been revised and lowered from time to time. Substitutes for HCE/HCB have been found. Carcinogenic dyes can be replaced by safer ones[20,31-33]. *KCl*, and *NaCl* aerosols are completely safe and environment-friendly. Training smokes were generated earlier from a burning-type composition containing tar/pitch, KNO_3, borax and S. The smoke was suffocating and troops had to pass through it without using face masks. NH_4Cl smoke, perfectly white, generated from a composition containing $KClO_3$, sugar, rosin and NH_4Cl[33], will be the ideal substitute. Fog oil smokes are also ideal for training purposes[25]. In the UK, cinnamic acid smokes have been found suitable for training purposes[24]. Work carried out in the USA shows that chlorinated waxes, terephthalic acid, glycols and red phosphorus are safer raw materials for screening smoke generation[13,23-25,29,30,34]. Further, TiO_2/silica, zinconia can be dispersed by explosives to provide safe, non-toxic screening smoke[12,13,21,27].

4. FUTURE OF SMOKES

Diverse varieties of smoke formulations are available, there being a specific smoke for a specific purpose. Be it safer, non-toxic training smoke or millimetre wave attenuating smoke, a number of choices are available to the potential user. Visual smokes can defeat line of sight guidance[1,20] and laser-guided missiles. In the line sight guidance systems, the target should be visible to the gunner. When the target is not visible because of the obscurant smoke cloud, the gunner can no longer guide the projectile to its destination. In laser-guided missiles, the missile nose has the sensor, detecting the reflected laser energy off the target. When smoke comes in between the sensor and the target on the path of the laser energy, the smoke cloud scatters the laser radiation. As a result, the sensor can no longer sense it; hence the missile cannot lock onto the target.

Smoke formulations/weapons/manufacturing facilities are easy to plan/formulate, cheap to manufacture/fabricate, simple to use safe to store, have long shelf life, and are completely reliable as well as foolproof. It cannot be subjected to jamming or countermeasures.

The American war gaming and other similar exercises indicate that use of smoke gives an advantage by a factor of 4 in both offensive and defensive deployments[34,36]. Similarly, Russians depend heavily on the use of smoke in reducing losses in tank warfare and in countering long-range NATO anti-tank weapons[37].

Laser range finder, laser target designator, laser anti-material, antipersonnel weapons (BLW-battlefield laser weapons) are being deployed[38-41]. *Nd-Yag* laser could probably be replaced by CO_2 laser in due course[26]. Even the SDI programme visualises the use of this energy system[40]. A smoke scatters coherent energy and hence can degrade the effectiveness of such systems[20,39]. High-tech opto-electronics means high cost. For example, a copperhead missile deployed to destroy a tank costs $ 45,000 . This missile guided by *Nd-Yag* laser designator can be very easily defeated if the smoke is generated either between the laser designator and the target or missile head sensors and the target. Thus a $ 45,000 system can be defeated by smoke at less than a hundredth of the cost. Terminally guided mortar bomb (TGMB) or multi-launch rocket system with terminal guidance with SADARM – potential threat weapons for tanks—can be defeated if smoke can defeat the sensors[1,25,35,36,41]. A modern, sophisticated, hi-tech system of today can be counteracted by a more than half a century old low-tech system. And again, when new technologies are ushered in, older established ones bow out unceremoniously. Here, for a change, both new and old technologies are able to coexist on merits alone. The importance of smokes in warfare has finally been realised and the prominence given to smokes appears to be well justified and remains secure not only for this decade but probably well into the next century as well.

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Appendix A gives some smoke formulations.

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APPENDEX A

VARIOUS SMOKE FORMULATIONS

I *Screening Smoke Formulation*

A

HCE 45

ZnO 45

$CaSi_2$ 10

B

HCE 44.5

ZnO 46.5

Al 9

C

HCE 54.7

Zn 43.3

D

HCE 76.2

Mg 23.2

E

HCE 81.4

Al 18.6

F

CCl_4 40

Zn 30

$NaClO_3$ 14

NH_4Cl 9

Infusorial earth 3

II *Block Smoke*

A

$KClO_3$ 55

Anthracene 45

B

HCE 60

Mg 19

Napthalene 20

C

HCE 59

Mg 18

Anthracene 23

III *Colour Smoke*

A

$KClO_3$ 20-35

Sugar 23-35

Dye 30-54

$NaHCO_3$ 0-15

B

Dye 30-50

Carbohydrate 20-35

$KClO_3$ 22-33

$NaHCO_3$ 3-10

Paraffin oil 2-4

Infusiorial earth 0-4

Red iron oxide 0-3

IV *Alkali Halide Smoke*[30]

$KClO_4$ 65 %	$NaClO_4$ 54 %	$NaClO_4$ 79 %
$NaCl$ 10 %	$KClO_4$ 25 %	Mg 5 %
Mg 5 %	Mg 5 %	$LiCl_2$ 2 %
Li_2CO_3 2 %	$LiCl$ 2 %	Binder 14 %
Binder 18 %	Binder 14 %	

V *Smoke and Illuminating Formulation*

Mg 8

Red P 51

MnO_2 35

ZnO_3

Linseed oil 3