IMPROVING THE CBRN DEFENCE OF COMBAT VEHICLES AS A RESPONSE TO THE CHALLENGES OF CLIMATE CHANGE

László HALÁSZ, József PADÁNYI and László FÖLDI

Abstract: *CBRN defence continues to be an important component of the defence system of combat vehicles. On the effect of climate change the importance of examining the thermal characteristics of combat vehicles and the development of adequate air conditioners increased. After reviewing the different types of solutions the complex environment control system, containing self-regenerating filters, will be presented in details.*

Keywords: global climate change, military force, CBRN defence, reconnaissance, decontamination

1. Introduction

Several countries keep their CBRN defence abilities at a high level, and the analysis of threats indicate real danger in many cases.

CBRN defence means the protection against nuclear, biological, chemical and radiological weapons. Recently this has become a preferred abbreviation in the international terminology instead of the previous NBC defence or the classic "chemical defence". The explanation to the new four letter English abbreviation is that the analysis of threats with an altered and reassessed content established this order of the hazard categories, consequently a chemical attack, strike or terrorist act has currently the highest risk, followed by the biological and then the radiological attack, and – surprisingly – the hazards attributed to attacks using nuclear devices are considered to be the least important. Of course this is the final result and "power ranking" of a complex risk analysis which does not only include the destructive force of the given devices but also their widespread nature, the probability of possession and application, and several other parameters.

CBRN defence is based on three principles:

- avoiding contamination;
- protection (protection of individuals, units and equipment);
- decontamination (restoration of functionality).

The application of these principles makes it possible to minimise losses, protect forces and retain the speed of operation.

CBRN observation includes the information obtained on CBRN equipment, the assessment of threats and the data of early reconnaissance concerning air, water and ground. All of them are key elements for avoiding contamination.

In the narrow sense CBRN defence means the individual and collective protection, respectively. Besides air raid shelters the protective equipment installed in technical devices are classified among the equipment of collective protection.

New hazards make it necessary to reconsider CBRN defence. The abilities of terrorist groups and the widespread nature of toxic industrial substances, the possibility of creating dirty bombs and the necessity of taking into account the effects of climate change present significant challenges for the designers of combat vehicles. Therefore the protection against environmental impacts became an important priority when designing a combat vehicle.

The protection of the fighting chamber and the equipment requiring the reduction of the heat impact is ensured by carefully designing the thermal management system of the vehicles. Land vehicles are designed for a broad load range and diverse environmental characteristics. The vehicles must be functional both in extremely warm and cold weather. The thermal management system must ensure the reliable operation of various parts [1-4]. The CBRN defence system is normally installed into the vehicles as part of the environment control system, as shown on Fig. 1.

2. CBRN defence of combat vehicles

The components of the systems protecting advanced combat vehicles against weapons of mass destruction:

- a defence system reducing the impact of nuclear weapons; this is a built-in defence system consisting of several layers (mainly in armoured vehicles);
- a system protecting against toxic warfare substances and other toxic materials (gases);
- a system protecting against biological, radioactive and toxic warfare substances.

Armoured vehicles provide good protection in case of CBRN hazard. Among armoured vehicles tanks provide the best protection in most cases. Light armoured vehicles such as personnel carriers, armoured troop carriers, self-propelled artillery and some heavy technical equipment also provide satisfactory protection.

The basic protection of armoured vehicles is provided by the multilayer armour. The inner layer of the multilayer armour is a steel plate containing titanium and boron which provides protection against neutron radiation. The middle layer, being the thickest and made of ceramic (TiB_2), steel, plastic, depleted uranium and graphite composite, provides a good protection against neutrons and gamma rays. The third layer has no significant role in the protection against nuclear weapons.

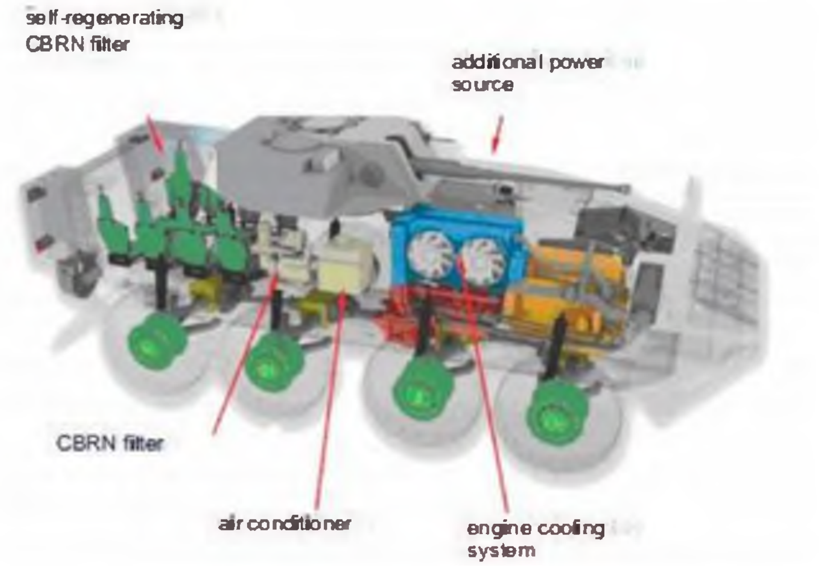

Fig. 1: Air management system of a combat vehicle.

Components of the **chemical and biological filtration system**:

- filtering-ventilation unit (contains a pre-filter, aerosol filter section and an adsorption-chemisorption filter consisting of several units);
- sensor system;
- control unit;
- accessories.

The dust and aerosol filtration system consists of two parts in order to reduce costs:

1. Pre-filter to filter out dust and coarse aerosol particles. This consists of the dust collector cyclone and a coarse filter.
2. High efficiency particle filter (HEPA) to filter out toxic substances and biological aerosol. The requirements made on filters are stipulated by STANAG 4634/AEP54 in case of 205 m^3/hour airflow:

   Particle filtering efficiency:

- between 0.1 and 0.5 μm 99.999%
- between 0.5 and 1.0 μm 99.999%
- at a grain size of 1.0 μm 99.9999%
- between 1.0 and 10.0 μm 99.9999%

The requirements made on gas and vapour filters are stipulated by STANAG 4634/AEP54.

The sensor system consists of chemical, biological and radiological detectors**.** The signals of the detectors may directly start up the CBRN defence system and give a simultaneous signal to the crew of the combat vehicle.

There are two known solutions in case of CBRN defence: the filtering system is either one-way or self-regenerating. Both systems grant overpressure protection, or protection that helps breathing, against toxic warfare agents, biological and radioactive aerosols. When designing the protection system the scope of application of the vehicle is taken into account, and the system that grants the protection of the crew during executing missions in contaminated airspace and terrain is selected.

The one-way system provides positive pressure in the fighting chamber and contains a high-efficiency (so-called HEPA) aerosol filter and a replaceable adsorption filter filled with activated carbon. The advantages of this equipment are low cost, simplicity, relatively small size and weight and low performance requirement. The disadvantage of the equipment is that filter replacement is required in every 24 or 48 hours (depending on the mission) which is a considerable logistics task. The treatment of exhausted filters is a further problem. Filter replacement significantly increases the operational costs of the system. In conventional systems **pressurized** or **hybrid systems** are used.

The pressurized system conducts the cleaned air into the fighting chamber at higher pressure. The system filters out toxic gases, small particles and other CBRN contamination from the air.

The positive pressure prevents that polluted air enters the closed area. The crew enters and leaves through a safety exit. An airlock prevents the entry of contamination into the fighting chamber. The disadvantage of the system is that it does not give protection against gamma and neutron radiation in itself. The group of positive pressure equipment that can be installed subsequently, producing filtered air. The system consists of a safety airlock, gas and particle filter and fan modules. It is easy to fit to wheeled vehicles and crawlers.

The hybrid system combines overpressure in the fighting chamber with individual breathing protection devices that have air supply. The system may operate by using only overpressure or with the air supply of the individual breathing equipment, or by applying both options simultaneously.

The hybrid system provides protection to the crew of combat vehicles and trucks. In case of closed openings the system can be applied by using overpressure, or – when the openings are open – using respirator masks. The purpose of the overpressure system is to reduce the volume of polluted vapours and gases entering from the outside. If the pollution enters the fighting chamber the system helps clean the air of the internal space from harmful contamination.

Individual respirator mask

The air filtering and supply system supplies filtered air to the masks of the operators. The filtered positive pressure air reduces the resistance of breathing through the mask and helps evaporate sweat. Besides all that it can supply warm air to the face in case of cold weather.

Cooling system

Two types of cooling systems are in use, one cools the fighting chamber, and the other the protective clothing. The latter is used when the crew wears protective clothing.

Cooling reduces the interfering circumstances caused by the heat generated in the fighting chamber. The soldier performing combat missions often has to execute his duties in extremely warm and/or humid environment. The operators' gear significantly increases body temperature which justifies the use of the cooling system. The cooling of the fighting chamber supplies improved quality cooled/heated air into the fighting chamber. Individual cooling cools the clothing of the operators. The selection of the cooling system depends on the type and primary duty of the vehicle. State-of-the-art tanks contain both the individual and the fighting chamber cooling systems.

3. Response to the climate change

Climate change contributed to the accelerated development of integrated systems. Integrated systems contain both air conditioners providing warm or cold air and one-way filtering devices for chemical defence. (see Fig. 2.) This system can widely be deployed in different combat vehicles, from tanks to (and including) small armoured vehicles. Research and development work continues to increase the efficiency of filters, to develop automatic control systems and sensors indicating that the filter cartridge is exhausted.

Fig. 2: Combat vehicle equipped with integrated Environmental Control System
http://www.bioquell.com/applications/vehicle-environmental-control, download: 28.03.2013.

An important direction of development is the reduction of size, weight and energy requirement. Creating new nano-filter types is a new development; this will enable the reduction of the size and weight of self-regenerating filters. The results of the development are applied also in personal protective devices.

Self-regenerating filters – a new type of filters that can be applied in vehicles.

The adsorption based gas and vapour filters, which can be called traditional, contain impregnated activated carbon. Their effects are basically catalytic, meaning that the metallic salts (silver, copper and zinc oxides) applied on the activated carbon catalyse the decomposition or hydrolysis of toxic substances. The adsorption and catalytic capacity of the impregnated activated carbons decreases during storage and use, therefore they should be replaced at certain intervals. This means that such filters provide sufficient protection only to a restricted period. It is also a problem that – depending on the impregnating agent – they provide reliable protection against certain substances only and this protection is not sufficient in case of the wide range of toxic industrial chemicals.

The advantage of the self-regenerating equipment is that it can be used for a long time (theoretically to an unrestricted period) because of the regeneration which significantly reduces the required logistics capacity. Another major advantage is that this filter provides protection also against toxic industrial chemicals. Self-regenerating equipment use physical adsorption (i.e. contain unimpregnated activated carbon) and operate on the principle of pressure swing adsorption (PSA). The selection of the adsorbent bed is one of the most important tasks.

The theoretical basis of the equipment is determined by the physics of adsorption. In gas-solid systems the surface coverage of adsorbers is generally influenced by pressure. This is due to the fact that the particles bound on the surface are in dynamic balance with the freely moving gas molecules surrounding the surface. Surface coverage is used to express the rate of adsorption. Relative coverage (θ) is the ratio of occupied adsorption spaces to all adsorption spaces. This indicator is often expressed in volumetric units, namely:

$$\theta = \frac{V}{V_\infty} \qquad (1)$$

where V_∞ is the volume corresponding to the full coverage of one layer. The rate of adsorption can be determined with this indicator which is the change of relative coverage over time. At constant temperature the pressure as a function of the surface coverage is expressed with adsorption isotherms. The shape of the isotherms defined for the gas-solid interaction depends on the solid surface and the characteristics of the gas. Several theories were created to model the graphs defined by practice. From these the Langmuir adsorption isotherms and the BET isotherms are the most widely used.

The shape of the Langmuir isotherm:

Let A be the molecule covering the N active parts of the solid surface. Let the adsorption velocity coefficient be k_a, and the desorption one k_d.

The adsorption velocity is proportional to the number of empty spaces and the pressure, i.e.

$$\frac{d\theta}{d\tau} = k_a p N(1-\theta) \qquad (2)$$

The velocity of the desorption process is proportional to the number of spaces occupied.

$$\frac{d\theta}{d\tau} = k_d N\theta \qquad (3)$$

This means that the binding of gases and vapours can be assisted by increasing the pressure, while regeneration can be assisted by decreasing it. In order to enable the adsorber to bind several different toxic substances the mixture of activated carbons with different pore size should be used. The following are typical pore types found on activated carbons:

- **Ultrapores:** They have a radius up to approx. 11 Å (1Å=10-7mm). The adsorption of gases, gaseous organic substances and low concentration vapours takes place in them, as well as the majority of gas catalysis and the adsorption of molecular size organic substances. Condensation is not considerable in them.
- **Micropores:** Radius approx. 11-20 Å. The reversible part of adsorption and the subsequent condensation takes part in these pores, as well as the majority of the eduction of organic and other dissolved substances of not colloidal size.
- **Macropores:** Radius approx. 20-100 Å. Adsorption and the irreversible, so-called capillary condensation takes place here, as well as the eduction of colouring and other substances of colloidal size.
- **Transitional pores:** Radius approx. 100-1000 Å. No significant adsorption takes place in them, and they become full of condensed substances only when the relative vapour pressure is close to be saturated; additionally they facilitate diffusion and play a role in removing colloidal size molecules from solutions.
- **Inactive pores:** Radius between 1000 Å and several microns. Their role in adsorption is negligible; they make the interior of activated carbon accessible for the substance to be adsorbed. They provide space for the solid substances that settle in case of adsorption from gases containing dust or substances educing in solid form.

By selecting the raw materials and the manufacturing technology the average pore size and the size distribution of the pores can be regulated. In case of self-regenerating filters the adsorber bed is assembled in a way that it is able to bind different size of molecules of harmful substances. The possibility of regeneration after the water vapour exposition is an extremely important design criterion.

The self-regenerating filtering device contains two adsorption beds. The operating adsorption bed works at a higher pressure, while the other bed, under regeneration operates at atmospheric pressure. The equipment is controlled by a continuously operating time-switch. The contaminated adsorber is relatively frequently scavenged with clean air of atmospheric pressure. The equipment is able to operate continuously for a long time. An important task of designing the equipment is the fastening of the adsorber bed in such a way that it withstands the often extreme military shaking and vibration circumstances on the one hand, and that no dusting out occurs during operation, on the other hand. The adsorber grains must be attached also to each other which can be carried out as with molecular sieves. The disadvantage of PSA equipment is that high-pressure air is required for the adsorption process and additional energy is required to produce it. This does not create a problem in case of newly developed vehicles but the equipment cannot always be installed into existing vehicles.

When the self-regenerating filters are installed as part of the Environmental Control System (ECS) the equipment only switches on if there is a real risk of a chemical attack, or if the chemical sensors detect the presence of toxic substances, respectively. The self-regenerating filter is not switched on under other circumstances and the air sucked in simply passes through the air, dust and HEPA filters. In this case the energy requirement can be reduced significantly. Fig. 3 shows the structure of the self-regenerating system [5].

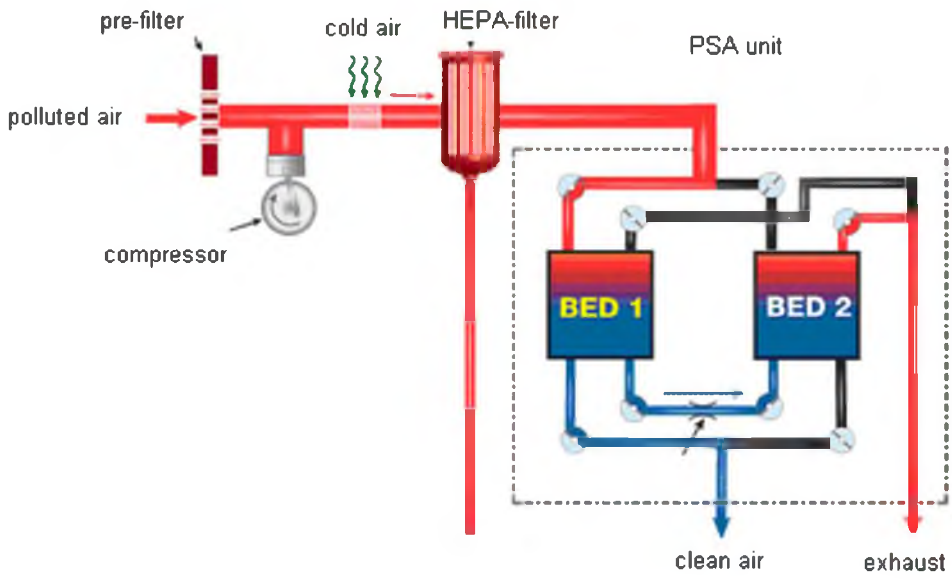

Fig. 3: Structure of the self-regenerating filters

The development of the air-conditioning equipment needed to cope with the climate change is also in progress. The one-way chemical defence system requires high pressure air while the air-conditioning system requires low pressure air. Separate chemical defence filtration systems and air-conditioners are used in armoured vehicles. The air supplied by the latter is passed to the fighting chamber but through pipes it can also be passed into the cooling vests of the crew.

Fig. 4: Self-regenerating CBRN-filter using Pressure Swing Adsorption
http://www.pall.com/main/aerospace-defense-marine/product.page?id=53202, download: 29.05.2013.

Low risk operations

The deployment of CBRN weapons is highly improbable in case of certain operations (e.g. in Afghanistan). Climatic circumstances necessitate the air-conditioning of the vehicles. Under such circumstances the positive pressure protection of the fighting chamber and the personal protection of the crew provide sufficient defence. Air-conditioners have been installed in smaller vehicles by removing the CBRN defence system therefore there is not enough room for the protective devices. The significant efforts to develop integrated systems are continued. There are solutions to control the two independent systems from a common panel. The new self-regenerating filters also provide satisfactory protection against toxic industrial substances.

4. Conclusions

The impact of climate change makes its influence felt also in the design of military equipment thus in case of combat vehicles. There is high emphasis on the thermal design of combat vehicles. Besides, the necessity of conventional tasks, thus CBRN defence remained. In case of CBRN defence the necessity of protection against industrial toxic substances has come to the forefront. To solve this problem and for a long service life self-regenerating filters are the adequate devices. In case of new vehicles the CBRN defence equipment, the air conditioner and other necessary cooling units are built into an integrated environment control system equipped with appropriate sensors. This system is able to operate automatically based on the assessment of environmental circumstances.

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