Filtration Material for Capturing Dangerous Substances and Its Use in Area of Population Protection

Lucie Jurikova, Jakub Rak, Milan Adamek and David Sevcik

Abstract— *This article is focused on the use of filtration material, namely on dangerous substances and capturing of their particles. It provides an overview of possible principles of capturing dangerous substances using filters (membranes). At the same time it introduces the types and sizes of the particles of the dangerous substances closely related to this subject. This contribution also outlines the problem that is being solved in the research, namely the use of filters (membranes) in an improvised shelter in such a way so that they create protective elements for sheltered persons. The article deals with the testing of filters for the various types of dangerous substances in cooperation with chosen companies and the university in order to ensure credible data and information.*

Keywords— *Filtration material, Dangerous substances, Nanofibers, Particles of substances, Improvised shelter, Membranes*

INTRODUCTION

The article responds to the current events in various countries, such as Japan; The human body encounters dangerous substances on a daily basis. Whether it is on the way to work or just while staying around the house, a person comes across particles, such as pollens, tobacco smoke, smog, etc. Some particles are reliably captured in the nasal cavity but many of them can penetrate deeper into the respiratory system and thus into the lungs. In the event of penetration of particles of dangerous substances (DS) into the lungs in a certain concentration one's health can be affected. Such a situation occurs in the case of extraordinary situation (ES) or crisis events (CE). In these cases a protective mask with a filter for the given type of event is used – especially for the transfer of an exposed person to a safe place. By transfer is meant the relocation of persons to the area for evacuees – out of the exposure to these DS. In the event of an extensive accident it is appropriate to use improvised shelters (IS) in order to avoid exposure to these substances. These shelters should provide a safe place for the sheltered persons until the effects of the DS disperse. The IS must have most fundamental safety features, for instance, the ventilation system with a protective filter. The design of the ventilation system together with the choice of filters for different types of DS is dealt within the framework of the research.

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PROBLEM FORMULATION

The selection of filters is one of the key components for the provision of safe sheltering. In order for the design of the self-built IS to be efficient, it must be affordable and materials used must be available for purchase.

The particles appearing during the ES or CS are of various nature and size. A large number of particles are invisible to the human eye; their size is smaller than 20 microns. These very small particles are not captured in the upper parts of the human body and they can penetrate into the lungs and alveoli. The sizes of some dangerous substances are shown in the following table.

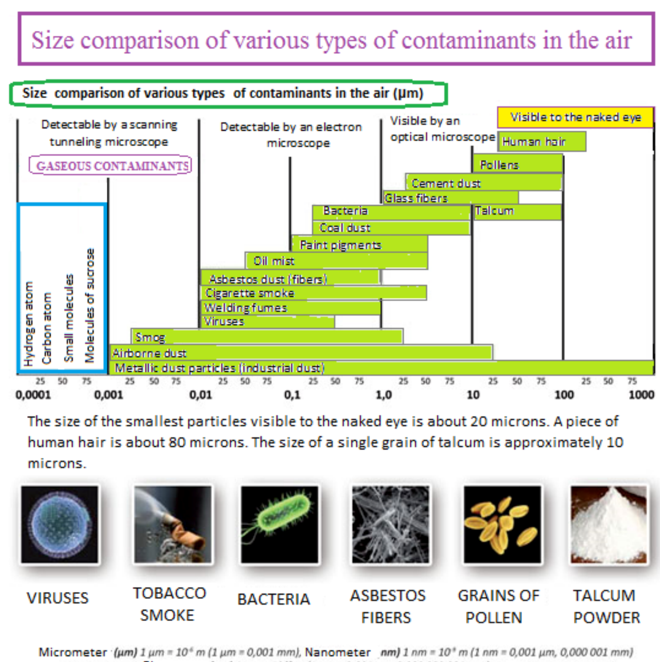

Figure 1: A comparison of the size of various types of contaminants in the air [14]

Particles smaller than 10 microns penetrate into the respiratory tract. The smaller the particle the deeper the DS penetrates. In such cases, there is a high risk of disease, permanent damage due to the impact of substances, or even death. The following figure depicts the respiratory tract of a human, inclusive of various sizes of DS. Particles of such sizes may penetrate into the human body and damage the health.

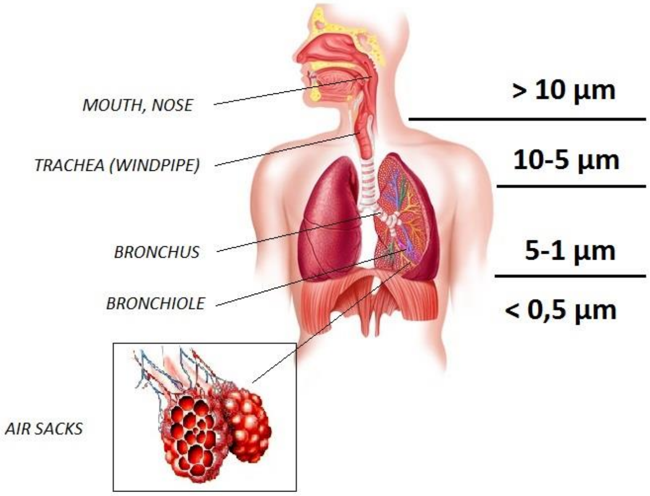

Figure 2: Sizes of particles capable of entering into the human body (the respiratory tract) [14]

1. Dangerous substances and their size

DS are substances, which have toxic, explosive, flammable, corrosive and caustic effects on the human body. In certain quantities they can endanger human health but also the life.

1.2 Definition of the dangerous substance

Dangerous leakage of these substances can be caused by accident (EE, CS) or a targeted attack – terrorism. For instance, it is of great importance for a tank transferring DS to be properly marked by a code. It is the so-called Kemler Code – the UN number that displays numeric codes in the fraction in an orange table. The figures indicate type, nature and characteristics of the transported substance in the event of an accident and the subsequent actions of the Integrated Rescue System (IRS).

The Kemler Code displays the following figures:
2 - pressurized gas, explosion hazards;
3 - flammable gas or liquid;
4 - flammable solid;
5 -substance of oxidizing (fire-intensifying) effects;
6 - toxic substance;
7 - radioactive substance;
8 - substance with caustic (corrosive) effects;
9 - spontaneous reaction (risk of violent, vigorous reaction);
0 - without meaning.
If marked with the letter X – the substance reacts dangerously with water. [12]

1.3 Types of DS

The most frequent chemicals occurring in emergencies and accidents are, for instance.
Chlorine;
Ammonia;
Acetylene;
Hydrogen chloride;
Hydrogen cyanide;
Phosgene;
Formaldehyde;
Carbon disulfide;
Propane-butane;
Gasoline;
Natural gas;
Carbon monoxide.
In the event that biological weapons are employed, these are, in particular, aerosols (bacteria, viruses and toxins). Some dangerous substances cause infections with a short period of incubation, such as plague, cholera, splenic fever, smallpox, spotted fever, etc. For example, one of the dangerous toxins is a bacterial toxin called Clostridium botulinum.
A great disadvantage of biological weapons is the fact that contamination of the area is undetectable by human senses. It is detected by special equipment and sampling. In addition, the contamination is often detected at the time when the infection is widely spread. For persons who are not infected by DS the improvised protection is possible by means of protective masks or sheltering in the IS. [19]

1.4 Particle of chemical substances

The most frequently transported DS and substances exploitable for a terrorist attack or substances with increased risk of accidents are predominantly: CHLORINE and AMMONIA.

CHLORINE (Cl_2):
Chlorine is yellow-green gas, heavier than air, highly toxic and caustic; in contact with humid air it forms vapors; inhalation of chlorine leads to severe chemical burns of the respiratory tract and lungs, pulmonary edema may occur even with a delay of two days; in gas form it causes severe eye burns and skin irritation up to blister formation, the liquid form may cause chilblains.
The first time Chlorine was used as a warfare agent was in World War II. It also serves as a base for the production of other warfare agents - phosgene and mustard gas.

AMMONIA (NH_3):
Ammonia is achromous gas, lighter than air, with sharp acrid odor during the evaporation; in liquid condition it forms cold mists which are heavier than air; in contact with air it forms caustic explosive mixtures; it is moderately flammable; in liquid and gaseous forms it severely irritates eyes, respiratory tract, lungs and skin, it causes irritating cough and dyspnea, breathing spasms can lead to suffocation, in a liquid condition it causes severe chilblains, inhalation of higher concentrations can cause death. [19]

1.5 Particle of biological substances

In particular, these are bacteria, viruses and toxins. Biological substances can be spread through the air or water and their use is possible in the following form:

a) the release of aerosols into the atmosphere or to a confined space;
b) the launch of the insect;
c) by infecting food, water, air and objects.

The most common form of the terrorist attack is the aerosol spread into the atmosphere; it is a silent method of infection, which spreads rapidly.

BACTERIA

The size of bacteria ranges from 0.1 to 10 μm. For instance, *Escherichia coli* reaches a length of 2 to 3 μm and a width of 0.6 μm. [2]

The basic shapes of bacteria:

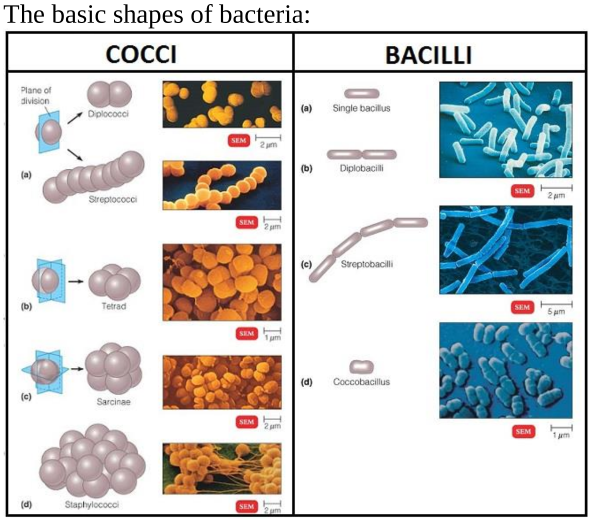

Figure 3: The basic shapes of bacteria – cocci and bacilli (the size of the bacteria ranges from 1 to 2 μm)

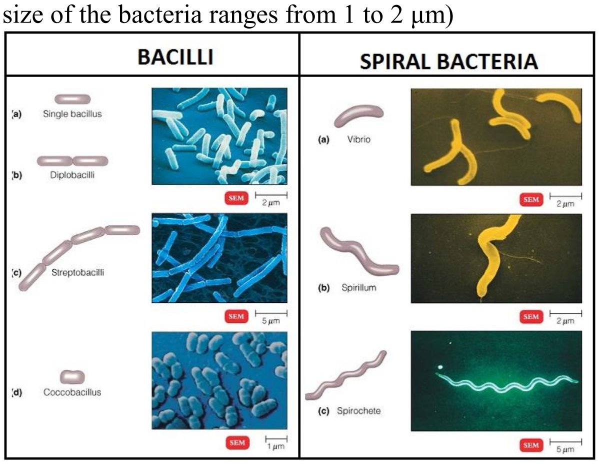

Figure 4: The basic shapes of bacteria – Bacilli and Spiral Bacteria (the size of the bacteria ranges from 1 to 5 μm)

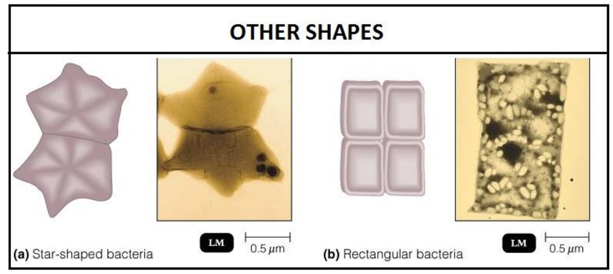

Figure 5: The basic shapes of bacteria – Other shapes (the size of bacteria is 0.5 μm) [6]

VIRUSES

Belong to the group of the so-called acellular re are a great variety of viruses depending on their size; the average of a viral particle in clinically significant viruses ranges from just 16 to 18 nm (parvoviruses, circoviruses) to 300 nm for poxviruses.

Even greater viral particles have been described lately: for example, Mimivirus reaches the size up to 750 nm. This means that while the smallest virions resemble ribosomes by their size, the greatest are fully comparable with the smallest bacteria.

The viral particle consists of a protein shell (the so-called capsid) and nucleic acid (the viral genome). Some viral particles also contain an outer membrane shell. [21]

2. Types of Filters

Particle filters capture solid and liquid aerosols (dust, smoke, fume, vapors, bacteria, viruses and radioactive particles). They contain filter fibers against particles.

Gas filters protect from dangerous gases and fumes. They operate on the principle of activated carbon.

Combined filters protect from gaseous substances as well as harmful particles. They consist both of a layer of activated carbon and filter fibers against particles.

Air filters = atmospheric air filters used for filtering solid aerosols from the air. The filters are classified as follows:

2.1 gross (G);
2.2 fine (F);
2.3 HEPA (H);
2.4 ULPA (U).

Absorbing capacity of a filter corresponds to the amount of dust captured during testing until the final pressure loss is reached. The absorbing capacity is given in g/m^2.

*2.1 HEPA filters ((**H**igh **E**fficiency **P**enetration **A**ir)*

They were developed during World War II to reduce the effects of radioactive dust. Originally, they were intended for astronauts to protect them from dangerous microparticles. The filtration material is microfiber glass fanfold paper capturing bacteria and viruses. From a layman's perspective, one can imagine a bed sheet folded to the size of a matchbox. Such a large cleaning area is condensed in a small and hardly permeable space of the size of the box. HEPA filters are also used in vacuum cleaners as final filters (they clean the air that the vacuum cleaner lets out). They are classified according to their efficiency – class 10 to 17 – where the best vacuum cleaners are of the class 13. The efficiency of air filtration is 99.97% (out of 10.000 particles >0.01 μm it lets only 3 particles out). The filter is placed at the front-end of the air-conditioned space.

*2.2 ULPA filters (**U**ltra **L**ow **P**enetration **A**ir)*

These filters are of better quality than the HEPA filters.

2.3 FINE filters (F)

They are predominantly used at the outlet of the air conditioner.

2.4 GROSS filters (G)

They are used as inlet filters of the air conditioning system for capturing coarse impurities and for reducing the clogging of the other filters. [23]

3. The principles of capturing particles of dangerous substances in particle filters

Successful capturing the particles of dangerous substances (DS) is provided by the composition of the filter and its principle. The principles of DS collecting are as follows:

3.1 The principle of filtration of gases and fumes:

The main component is **ACTIVATED CARBON** (either in a raw form or impregnated with various chemicals). The carbon is activated by the disruption of the carbon structure by hot steam or chemicals. This leads to the creation of a number of little paths – the micropores in the carbon structure. These pores are rough inside, so that pollutant molecules can penetrate inside where they merge with the surface. [15]

3.2 The principle of particle filtration

The **PARTICLE FILTER** is an active component created by layers of randomly arranged glass microfibers within the range of 1 to10μm:

3.2.1 INTERCEPTION:

Interception it is possible to capture light and small particles according to the type of fiber. If the particle gets close to the fiber and touches it, it is captured.

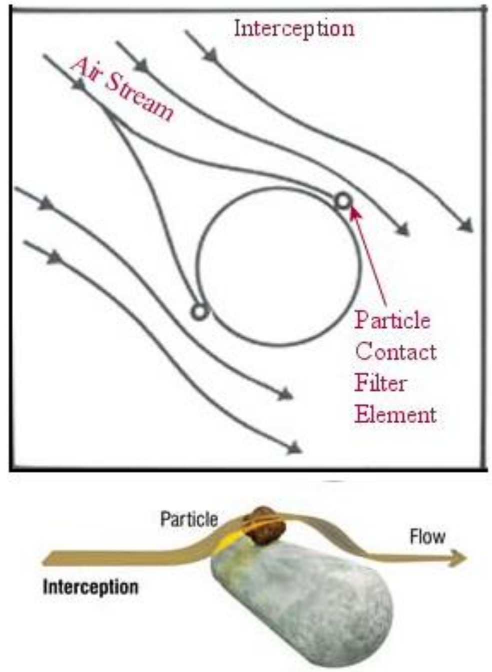

Figure 6: Representation of the principle of capturing particles in the fiber – The interception [3]

3.2.2. INERTIAL IMPACTION

Inertial impaction is caused by the inertia. The heavy particles do not follow the same path as the air stream but continue in their own direction, which leads to impaction in the fiber. High efficiency is obtained by greater air velocity, larger size of particle and smaller diameter of the filter's fiber.

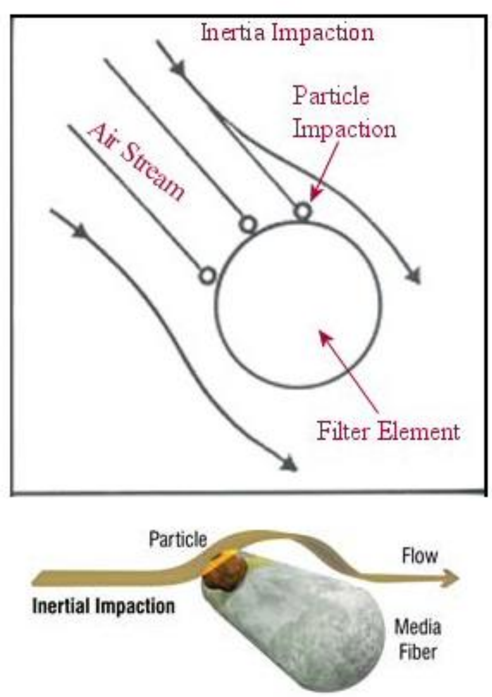

Figure 7: Representation of the principle of capturing particles in the fiber – The inertial impaction [3]

3.2.3 DIFFUSION

Particles smaller than 1 μm are captured owing to the so-called Brownian motion (oscillating random movement of microscopic particles). This random movement causes the particles to be captured in the fiber.

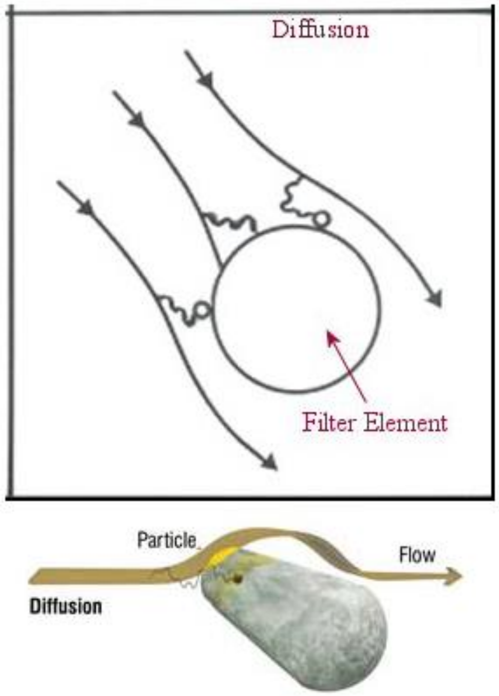

Figure 8: Representation of the principle of capturing particles in the fiber – The diffusion [3]

3.2.4 ELECTROSTATIC ATTRACTION

The particles are captured owing to electrostatic forces in the fiber.

4. Parameters influencing the filtration performance

The main parameters influencing the filtration performance are as follows:
parameters of the filtration material;
parameters of the particles;
parameters of a filtration process.

a) Parameters of the filtration material
the filter surface;
the thickness of the filter;
surface and volumetric weights of the filter;
the regularity of the material;
the material and its parameters;
parameters of fibers (diameter, shape, softness).

b) Parameters of the particles
the particle size of the dispersion difference;
distribution of the size of particles of the dispersion difference;
the concentration of particles;
the shape and surface of the particles;
volumetric weight of particles;
electrical characteristics;

c) Parameters of a filtration process
the speed of deposit of particles in the filter;
the viscosity of the flowing medium;
temperature, pressure, humidity.

5. The main filtration characteristics

5.1 Efficiency = separability

a) the formula: E = 1 – [G1/G2] (%);
b) [G1/G2] = P: is penetration;
c) G1: is the quantity of dispersed phase behind the filter;
d) G2: is the total quantity of dispersed phase (sometimes the quantity of the dispersed phase in front of the filter is given).
e) In some cases the efficiency is determined indirectly.

5.2 The pressure gradient

a) the formula: Δp = p1- p2 (Pa);

5.3 Lifespan of the filer

a) states when the filter should be replaced;
b) For disposable filters the amount of dust which it is able to absorb until the moment the pressure loss is too high, is given.
c) For the filters with a cleaning system it is given by intervals between cleaning and by their number.
d) It is possible to express e.g. the absorbing capacity of the filter (EN 779). The absorbing capacity = Es . m

5.4 Resistance to external factors:

a) chemical;
b) mechanical;
c) temperature;
d) combination.

5.5 Other characteristics related to the filtration

a) the permeability: how much fluid penetrates through 1 m^2 of the filter per minute at a defined pressure gradient of 196 Pa, the units: (l/m^2/min)
b) the porosity: the pore size is usually determined by a medium or maximum value, or size distribution.[7]

Problem Solution

The increased protective properties of the shelter lead to the increased protection of sheltered people. This is done by means of the appropriate design of the ventilation system and the right choice of the filter. The main objective of the filter choice is to design such a filter that is not only efficient but also affordable. The term “affordable” plays an important role as it allows an ordinary citizen to design and build his/her own IS.

Material composition of filters (fabrics), fibre composition as well as the size of DS particles against which the filter is to be effective are significant for the selection of filtration material.

1. Filtration material

Among the most broadly used filtration materials are glass and synthetic fibers. There is a large number of such filters on the market but the choice is dependent mainly on the technical data, such as:
filtration class;
thickness of material;
retentiveness;
air flow ($m^3/h/m^2$);
initial pressure loss;
final pressure loss;
maximum thermal resistance (°C), etc.

Glass fibers can be used in various sectors. They are of excellent technical characteristics (high firmness, tensile strength, fire resistance, good chemical resistance, etc.) The most common types of synthetic fibres are polyamide, polyester, nylon, etc. [4]

1.1 Nanofibers

Nanofibers are referred to as the material of the third millennium, which is supposed to induce a revolution in medicine, electronics, car industry, as well as in filtration, environmental protection, nanocomposites, energy, IT, protective devices and barriers.
Nanofibers are fibers of submicron proportions the diameter of which is 50 to 500 nanometers. Often, their thickness is of a few atoms. Nanofibers are not visible by conventional microscopes as their diameter is smaller than the wavelength of light. Such extremely small fibers can only be seen and photographed by an electron microscope. For illustration: the ratio of the diameter of the nanofiber and a soccer ball is comparable to the ratio of the size of the soccer ball and the globe.

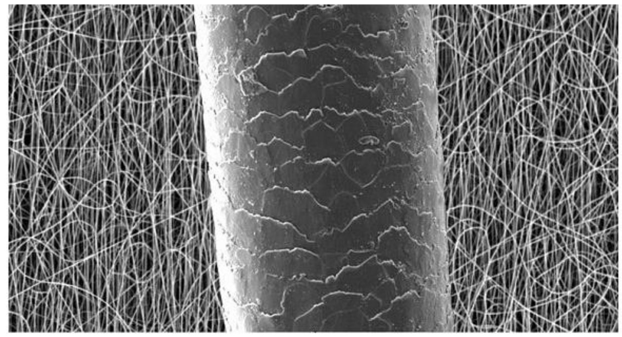

Figure 9: For illustration – a comparison of a piece of human hair and nanofibers [18]

Characteristics: large specific surface; high porosity; small pore size.
Material: polymer solutions or melts; more than 50 polymers.

2. The use of contemporary materials in the ventilation unit

The basic element for the protection of sheltered persons is the design of the shelter ventilation system. In the event of a leakage of dangerous substances it is necessary to design the ventilation system with a suitable filter for capturing these substances in order to provide a comprehensive protection for persons in the shelter. This requires cooperation with companies engaged in the distribution of filters or with the university that deals with this issue within the framework of its research. Materials specified in Chapter 3.1 can possibly be used within the research.

3. Filter testing

For the use in the ventilation unit of the IS it is possible to buy currently available filters designated for a variety of chemical or biological substances. From the perspective of financial costs it is necessary to design filters affordable for ordinary citizens. The designed IS should comply with the protective characteristics of the shelter; this will be achieved primarily by testing the chosen filters. These filters can be tested by all companies approached and universities which have facilities suitable for testing filtration material for various types of dangerous substances. Another possibility is the use of testing simulation software for spreading such substances through simulated membranes.

3.1 Cooperation with companies

In order to obtain reliable information for the purposes of the research cooperation with selected companies has been initiated. Not only do these companies contribute with their expertise but they also offer the possibility to test the chosen types of filters for the given type of substance and they provide testing results of their research.

3.2 Cooperation with the university in Liberec

The issue of filtration material is being dealt with at the Faculty of Textile Engineering of the Technical University in

Liberec. A wide range of methods and standards is available for testing the filters. At the university it is possible to test the air filtration. The great advantages are their own testing facilities. This university was also approached for possible cooperation in testing the chosen filters.

4. Laboratory for filtration testing

Communication with the Department of Nonwoven Textiles has been established where the following test facilities for testing air and partially liquid filtration are available:
1. Facilities for testing by means of the Dust Filter Tester (DFT-2, DFT-3) - air filtration;
2. Facilities for testing by means of NaCl aerosol (Bench Mounting Rig Type 1100 P) - air filtration;
3. Facility for measuring the permeability of fabrics (Metefem FF-12/A) - air filtration;
4. Facility for testing the pore size by means of the bubble method (Macropulos 5) - air and liquid filtration;
5. Facility for testing dynamic permeability of water (WPT-1) - liquid filtration. [20]

For the purposes of the research the type 1 and 3 can be used. The type 1 **facility DFT-2** can be used for testing the separability of synthetic dust, pressure gradient, velocity of the air entering the filter, the total amount of dust captured by the filter during the test (related to a life span of the filter) and changes to the said characteristics during the filtration process. Polydisperse synthetic dust complies with the ISO 12103-1 Standard; particle size varies from 0.3 to 80 mm, the velocity is within the range of 0.6 to 1.5 m/s. The DFT device – 2 has been developed and constructed by the Department of Nonwoven Textiles. In comparison to standardized devices it enables testing of samples of smaller surface. Especially, it is intended for testing filters of lower and medium separability.

Figure 10: Facility no. 1 for testing by means of synthetic dust Name: DFT-2 (Dust Filter Tester), DFT-3 [20]

Another facility utilizable in the research is **Type 3 Metefem FF – 12/A** for measuring the permeability of fabrics. The objective of the test is to measure the amount of air that passes between the opposed surfaces of fabrics, related to time and the tested surface, measured at a standardized pressure gradient (usually 20 mm H2O). The size of the tested surface is 20 - 50 cm^2 (or smaller), the pressure gradient is in the range of 0 to 200 mm H2O and the flow rate is in the range of 4 to 8000 l/hour.

Figure 11: Facility Metefem FF-12/A for measuring the permeability of fabrics [20]

The aim of the cooperation with the University is the use of the previously described facilities for testing of the chosen materials within this research. The chosen filtration materials are to be tested for effectiveness of the specified matters. The consequent results of testing are to be fully used for the design of a ventilation unit for the IS. Tested filtration material should provide the following information and data: e.g. effectiveness of the material at a particular concentration of the chosen DS, pressure gradient, velocity of the medium flow though the material, flow rate, etc.

5. The use of software for filter testing

There is a great number of modelling and simulation software designated for the field of risks and modelling. The following software packages were considered for use within the research:
Airpak;
Contam;
Simprocess;
Simul8;
Anylogic;
Aloha;
Solidworks Flow Simulation;
Urban Sim, COMIS;
Ansys;
AutoCad Simulation atd.;

From the above software the AutoCad Simulation and the Ansys were chosen as they fulfill all requirements for the simulation. This software could be used for the simulation of dangerous substances spreading through the filters (membranes) for the chosen types of substances that cannot be tested in manufactured devices. These software packages shall assist in the design of the IS model, including its protective elements, together with the ventilation unit and a database of the tested filtration materials.

Conclusion

The objective of this article was to outline a possible way of constructing the shelters, mainly in the case of a self-build. The purchase of manufactured and tested filters from companies is too expensive for many citizens if one considers the design of the filtered ventilation in the shelter as a whole. The research should provide a cheaper version for the filtered ventilation that would be suitable for self-construction of the IS. In this way, the research could benefit a large number of citizens in the event of an extraordinary or crisis situation in the Czech Republic. Not only are the designed shelters cheaper but they also meet the requirements on the protective elements for sheltered persons. A further benefit of this research is the creation of a database of the tested filters for various types of substances, including the tests results. The aim is to contribute to the field of population protection by sheltering and encourage the citizens to build their own shelters and thus increase the preparedness of the population in the country.

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