Principle of Operation and Advantages of a Sensor for Fog Contamination Detection

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Abstract: *During out work in a project related to European security, we have created various devices. One of them is a sensor for control of contaminations in the composition of fogs, which is first of its kind in the world. The development of such a sensor is important because in this project, artificially generated fogs with special additives are used for decontamination, and it is crucial to control the quantity of impurities in these fogs. In this work, different aspects of the operation of this sensor, its advantages and design considerations are discussed.*
Keywords*: FOG, SENSOR, ELECTROMAGNETIC ECHO EFFECT, SECURITY*

1. Introduction

The project "Device for Large Scale Fog Decontamination" with acronym COUNTERFOG is a project funded by the European Commission under the FP7-Security Programme. Its main purpose is to build systems for quick and efficient counteraction against contaminations of the atmosphere of various nature. These can be any sort of dispersed CBRN (chemical, biological, radiological, nuclear) agents, that is why fog spraying was chosen as the decontamination method. Fog has the ability to collect any particles from the air and collapse them to the ground, thus minimizing the harmful impact on humans that may be present in the contaminated area. In order to control the presence of pollutants, both in the atmosphere and in the decontaminating fog, respectively the systems for decontamination, our team has created numerous devices for control of the presence of harmful substances [1]. One of them is a sensor with a liquid layer operating on the basis of the electromagnetic echo effect (EMEE). The former name of the effect is the "surface photo-charge effect" (SPCE) [2]. The method is contactless and quite fast, provides real-time analysis, and can be considered universal [3-5]. The EMEE generates signals that are highly sensitive even to imperceptible changes in the composition and properties of the object under study- gas, liquid, or solid. Some information about this sensor has already been published [6]. Here we will give more details about the principle of operation of the sensor, ways to optimize its performance and its main advantages.

2. Principle of operation of the sensor with a liquid layer

The EMEE sensor for detection of contaminations in the composition of fogs needs to have a layer of liquid inside of it. The liquid is of the same origin as the one used for generation of the decontamination fog (Fig. 1).

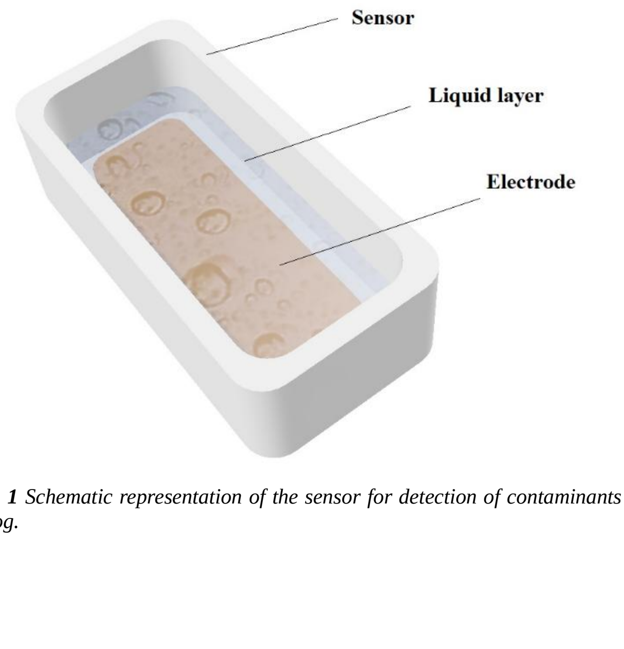

Fig. 1 *Schematic representation of the sensor for detection of contaminants in fog.*

When the fog droplets are in contact with the liquid layer, the EMEE signal is generated in the solid-liquid interface (between the electrode and the liquid). The signal does is not influenced by the main compound of the fog. However, when impurities are added, there will be a deviation in the amplitude of the signal.

The principle of operation of such a sensing structure and the measurement setup are shown in Fig. 2. The liquid is stored in a tank and fed by micro pumps (7) to the sensor (1), which is sprayed with fog by the fog generator (6). A power supply (3) powers a laser (2) and the beam is modulated by a frequency generator (4), which also feeds a reference signal to a lock-in nanovoltmeter (5) that measures the signal. The ready state of the sensing element is determined when a signal without liquid is received. On alert, a controlled filling of the sensor begins until the steady level is reached. After the liquid is present, the sensor is operational. The signal generated from uncontaminated fog is known. If a different signal is received, then the difference with the reference signal ΔV will inform us about the presence and the increase of any dangerous compound in the fog.

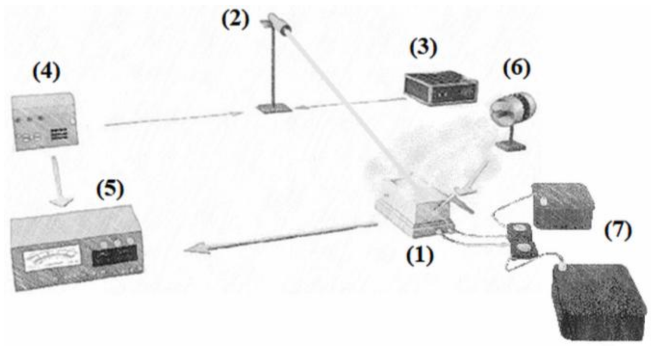

Fig. 2 *Measurement setup of fog contaminations by an EMEE sensor with a liquid layer.*

It has to be kept in mind that exact values about the increase/decrease of a certain compound in the vicinity of the sensing element can be obtained only for materials for which we have calibrated the system. Without calibration, we cannot know the increase of a random contaminant in absolute values. Yet, for our purposes, this is not so necessary. We can also work with relative values. The reasons for that are the following:

- In the initial hours (which are most essential for decontamination) the material of the attack can be unknown. And still, the neutralizing system has to react immediately. We cannot wait for the determination of the attacking agent.
- The purpose of the decontamination is the removal of the contaminating agent. Conducted experiments so far show that the sensor will react to it. It can be traced when the EMEE signal amplitude reaches its maximum deviation point from the initial condition, when there was no agent present. This way we can know when peak contamination

level is reached. Also by comparison, we can check when the signal returns to its initial state – without contaminant, which is actually the most valuable information for us. Between the two states, we will be able to make a relative assessment of the level of contamination. Even if we have calibrated the system and we measure the contamination in absolute values, the obtained results will also have relative accuracy. The reason is that fog is a dynamic constantly changing entity in every region of its volume. What we have measured at time t_1 for a given point, most certainly will not be the same at moment t_2 (for example, after a minute has passed).

It has to be noted that after each measurement, the liquid will be contaminated and it will have to be replaced. This means that the sensing element will have to be flushed with liquid from the tank by miniature pumps. There are be two exactly defined open-valve times for liquid flow – for flushing and filling of the sensor. The sensor is connected to a second tank for waste liquid. The operational sequence is the following: we pump liquid in and make a measurement. When the measurement is over, we flush with clean liquid. Next, the sequence is repeated – we load the sensor, measure and flush. And so on repeatedly. For better accuracy, we can control the liquid volume while measuring. The amount of liquid is about 5-10 millilitres.

We must note that the longer we wait, the more the signal from the sensor will increase. The admixture in the fog might decline, but in the liquid layer, it will be accumulated and the signal will grow. This is why, for example, we measure for 2 minutes, wash with clean liquid, load with fresh one, and measure for 2 minutes again, clean again and so on. In such a case, we will have a current measurement every 3 minutes (it takes about 1 minute to flush and fill). The period of this cycle has to be kept constant in order to avoid the error coming from admixture accumulation in the liquid.

Under real circumstances, we won't be able to calibrate the system for all types of contaminants. We will measure in relative values and we will monitor for the peak level of the harmful mixture. Next, we will monitor for its disappearance, at which point the signal will be zero (sensor reading will be zero, because only clean fog will have remained, which does not generate a signal). This will mean that the decontamination has finished. With the repetitive cycles of cleaning and filling, we will also solve the problem of raising the level of the liquid due to precipitation of fog in liquid form over the sensing element. A change in the level of the liquid can result in a measurement error.

We should also point out that when having a structure with a liquid layer, a better sensitivity is expected in contrast to a direct interaction fog–solid body. This is due to the fact that for the fog–solid interaction, the main signal comes from the predominant matter in the fog, based on which we have to capture small changes coming from the admixtures. In this case, we have the fog on one hand, generating a signal V_1, and an impurity on the other, creating another signal V_2. Since the quantity of the fog is much higher, in the general case V_1 will also be much stronger than V_2. The two signals will be combined. It is not easy to separate those signals since the fog changes constantly. Using the structure with a liquid layer, the predominant substance of the fog will not create a signal. Then V_1 will be zero and we will measure only V_2. Still, we have to keep in mind that with the liquid layer structure, the substance we are looking for is dissolving in the liquid and this may affect sensitivity.

The usage of a thin layer of liquid from the same kind as the one used for fog generation has different advantages. In this case, the sensing element does not react to the predominant fog compound. It only reacts to admixtures. Since the admixture is also present in the fog, we will still have fluctuations. The inconsistent volume of fog interacting with the sensor will also mean inconsistent amount of impurity interacting with the active surface of the sensor. Those fluctuations are averaged by the liquid layer for a period we define. This way the problem is solved to a satisfying extent.

If we use a structure with direct solid–fog contact, we will have to create a mechanism to prevent the condensation. In this case, we will probably also reject the admixtures absorbed in the fog to some extent, which will reduce the sensitivity.

3. Main advantages of a structure with a liquid layer

The main advantages of a structure with a liquid layer over the interface include:

- The problem with condensation on the sensor surface, which obstructs the measurements, is solved.
- The problem with surface pollution is solved, which is also an impediment to measurements.
- The sensitivity is increased by zeroing the signal from the predominant fog compound. It is taken into account that if the sensor is sensitive to the main composite of the fog, in the general case this compound will generate a much stronger signal. This is so because it is contained in greater amounts and on the base of that strong signal we will have to capture very small changes generated by the admixture.
- More realistic measurements can be taken. The density of fog varies constantly. The signal will be different depending on the quantity of fog that has interacted with the surface. We cannot be sure if the alteration of the signal is due to change in the mixture percentage or density of the fog. The liquid layer eliminates the influence of the main fog compound, so that only the impurity formed in the mist can influence the results. Naturally, if the density of the fog changes, the density of the impurity will also change. However, this is compensated greatly by the averaging, which the liquid provides.

A minor inconvenience is that during the measurements the sensor needs to be periodically filled in and out with small liquid volumes but this can easily be achieved by incorporating micro pumps in the setup.

4. Conclusion

In terms of the realization of the sensor, different structures have been developed and tested. Our aim is to create a stand-alone device, which can work automatically. The active surface should be integrated into a small vessel with an appropriate inclination where the contact with the liquid should be established. This vessel should be in a metal shield for protection against electromagnetic interferences because the generated EMEE signals are too weak. A balance needs to be found between requirements for electromagnetic shielding and the necessity for maximized sensor contact with the fog. Different technical requirements have to be followed. The protective shielding should have a cover that opens automatically. The working structure, the pumps, the laser module, the tanks and the electronic devices should all be placed in a suitable manner as one whole assembly.

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