Study on reducing pollutant gases and particulate content inside the passenger car

A M Vrana and C Bujoreanu
"Gheorghe Asachi” Technical University of Iasi, Department of Mechanical Engineering, Blvd Mangeron 43, 700050, Iasi, Romania

E-mail: carmen.bujoreanu@gmail.com

Abstract. The pollutant gases entering the car through the ventilation system are very harmful and the effect they have on the human body is often lethal. The European Environmental Agency is talking about over 45000 "premature deaths" that occur annually due to the particles in the atmosphere. A rigorous monitoring of pollutant content in the passenger compartment is absolutely necessary, therefore the appearance of the first pollen filter in 1940 by Nash Motors on the Weather Eye ventilation system. Studies conducted by researchers in Germany show that not all systems work the same way, and the degree of air filtration is only 40% for some cars, while other cars filter outdoor air up to 90%. The most car manufacturers recommend the filters replacing, and huge gaps exist between a classic particle filter (it captures and retains dust, pollen and soot) and one with active carbon that also captures unpleasant odours. In reducing the amount of pollutant gases entering the passenger compartment, the air quality sensor (AUC), mounted in the pollen filter housing, also controls the activation of the recirculation function when the car enters a polluted area. Our paper presents an overview in the field of pollution in the passenger compartment, the main types of passenger car filters launched on the market and the importance of their use according to the manufacturer's indications.

1. Introduction
Atmospheric air normally contains about 1 to 3% water vapour and traces of sulphur and nitrogen oxides, formaldehyde, ammonia, methane, carbon monoxide and solid suspensions (dust and pollen), in a word "pollutants". The pollutant is defined as a substance or mixture of substances that, in the air for a certain period of time, can endanger the health of humans, plants or animals [1].

Thermal engine which propels vehicles transforms chemical potential energy of fuel in mechanical energy through a thermodynamic cycle. The oxidation process in the combustion chamber uses as the working fluid the nitrogen gas and combustion gases and the oxygen in the air as oxidizer. In the ideal situation, water and carbon dioxide are the results of the oxidation reaction, but the real burning reaction of a fuel based on carbon and hydrogen takes place with formation of carbon monoxide, hydrocarbons and nitrogen oxides. The gases resulted from the burning reaction are evacuated through the exhaust and enters the cabin through the ventilation system [1].

In urban traffic, the highest degree of pollution inside the car is recorded when we stop at the traffic light, passing certain road sections in the column or running behind a car that pollutes excessively [2].

The air quality measurements in the passenger compartment are made to determine the mass of small particles (PM2.5 and PM10), because even with an efficient air filtration system, they enter...
inside the car. Suspended particles are a complex mixture of small particles and liquid droplets. They are derived from pollen dispersion, powders produced by machine tires and incomplete combustion.

The simplest solutions for the air in the car to be breathable is to move as much as possible with the glass and the closed air conditioning system, keeping a longer distance from the front car, avoiding smoking in the car, using the air recirculation function and replacing in-time filters of the passenger compartment [3].

2. The first air conditioning system
The pollutant gases entering the car through the ventilation system are very harmful, and the effect they have on the human body is often lethal. The European Environmental Agency considers over 45000 "premature deaths" produced each year as result of particulate matter.

A rigorous monitoring of pollutant content in the passenger compartment is absolutely necessary, therefore the appearance of the first pollen filter in 1940 by Nash Motors on the “Weather Eye” ventilation system. This “Conditioned Air System” is characterized by a cowl-mounted outside air receiver that passes fresh air through a heater core utilizing hot engine coolant for a heat source. The “Weather Eye” presented bellow in figure 1 was the first system mounted in a vehicle to use a disposable filter in the air-intake to clean the air flow [4]. The inlet air was first filtered, heated and dehumidified (to avoid steam fogging).

Between 1940 and 1942, 1500 Packard cars were equipped with the Nash “Weather Eye” air conditioning [5]. This has been a major breakthrough in car development for safe and comfortable transport.

![Figure 1. The first practical automotive air-conditioning system – 1939, [5].](image)

3. Pollution in Romania – IQ Air AirVisual
IQAir AirVisual is a global air quality information platform operated by the IQAir Group. By aggregating and validating air quality data from governments, private individuals and non-governmental organizations, IQAir AirVisual aims to provide global and hyper-local air quality information that allows individuals, organizations and governments to take steps that improve air quality in communities, cities and countries all over the world [6].

PM2.5 refers to particulate matter which measure up to 2.5 microns in size, and has a range of chemical makeups and sources. PM2.5 is widely regarded as the pollutant with the most health impact of all commonly measured air pollutants.
Common sources of particulate matter (PM) include combustion (from vehicle engines, wood and coal burning), as well as through other pollutants reacting in the atmosphere.

The World Health Organization (WHO) recommends an annual mean exposure threshold of 10µg/m³ [7]. The WHO target is shown in table 1.

| Pollutant | Averaging period | Objectives | Comments | Concentration | 99th percentile |
|-----------|------------------|------------|----------|---------------|----------------|
| PM<sub>2.5</sub> | One day | Target 25µg/m³ | Limit value since 1 Jan 2015 | 25µg/m³ | (3days/year) |
| PM<sub>2.5</sub> | Calendar year | Limit 50µg/m³ | Not to be exceeded on more than 35days/year | 10µg/m³ | |
| PM<sub>10</sub> | One day | Limit 40µg/m³ | | 50µg/m³ | |
| PM<sub>10</sub> | Calendar year | Limit 40µg/m³ | | 20µg/m³ | |
| O<sub>3</sub> | Maximum daily 8-hour | Target 120µg/m³ | Not to be exceeded on more than 25days/year, averaged over 3 years. | 100µg/m³ | |
| NO<sub>2</sub> | One hour | Limit 200µg/m³ | Not to be exceeded more than 18 times a calendar year. | 200µg/m³ | |
| NO<sub>2</sub> | Calendar year | Limit 40µg/m³ | | 40µg/m³ | |

Figure 2. PM 2.5 in Iasi/Constanta in 2018 [µg/m³] – IQ Air AirVisual, [5].

The most polluted city in Romania was Iaşi (in 2018) where the average particle concentration in suspension (PM 2.5) was 27 micrograms per cubic meter. At the opposite pole is Constanta, where in some months of last year the WHO target was reached, and the annual average was 12.4 micrograms per cubic meter (figure 2).
4. Cabin filters/pollen filters/microfilters

The pollen cabin filter is usually a foldable paper filter that is located in the air inlet that penetrates into the passenger compartment and acts as a barrier between the externally contaminated environment and occupants of the car [8].

The quality of indoor and outdoor air can be affected by two main types of substances: particles and gas. The types of air filters that people most commonly use in their homes are known as mechanical air filters. These are filters for use in heating and ventilating air conditioning (HVAC) system. Disposable filters need to be replaced and the systems must be cleaned at regular intervals.

Mechanical air filters work by trapping particles from the air onto the filter. High efficiency particulate air (HEPA) filters are a type of high efficiency mechanical filter. According to HEPA (High efficiency particulate air) standards, Tesla has the most advanced cabin filter system “Bioweapon Defense Mode” receiving the best rating [9]. To qualify as HEPA by industry standards, an air filter must remove (from the air that passes through) 99.97% of particles that have a size greater than or equal to 0.3 µm.

In Europe, 90% of cars are equipped with OEM (Original Equipment Manufacturers) passenger compartment filters. For example, the largest automotive platform equipped with pollen filters is VW (VW, Audi, Skoda, Seat), for which 500000 filters were needed in 2003, and after 2007 it reached 2.5 million filters per year [10].

With regard to aftermarket filters, after 1989, about 115 million cars were equipped with a pollen filter. The number of growing cars has led to the development of several after-sale products with different price and quality [10].

Although we tend to believe that all air conditioning systems work the same way, regardless of the car, a study in Germany showed that the differences between them are huge [11].

The air filtration system of a car managed to reduce the particle level by 90% from the outside air, while the filters in other cars retained only 40% of the dust. Tests were carried out using two air-analyzers, one mounted on the vehicle's rear, and another embedded in a manikin on the right-hand seat. In the case of longer journeys and with more people, the values increase considerably [11].

Preliminary tests carefully carried out by particle emission analyst specialists have shown that the level of filtration is independent of particle density in the air [11]. Consequently, we do not analyze the absolute number of particles, but their reduction as measured in percentages.

Figure 3 presents the analyzer used in tests mounted on the trunk of an Audi A5 car.

![Figure 3. Air analyser, [11].](image)

The graph (figure 4) analyzes the carbon dioxide concentration inside and outside an Audi A5 - initially the air conditioner operated only with an outside airflow, but after 27 minutes the gas recirculation function was activated [11].
5. Improvements for pollen cabin filters

As the number of machines has considerably increased, exhaust pollution also has increased. Pollutant gases penetrate inside the passenger compartment and are responsible for many lethal diseases. For this reason, a much greater capacity to block the particles and gases entering the cabin is needed.

There are two different types of cabin filter technology:

- Particle filters that capture and retain fine pollutants such as dust, pollen and soot, preventing them from entering the car compartment.

- Carbon filters that offer the same benefits as classic filters, but they also have the advantage of preventing odors and harmful gases such as exhaust gases, cigarette smoke and fuel vapor from entering the passenger compartment.

We also mention other examples: biofunctional polyphenol layer coating captures free allergens. The additional antimicrobial coating deprives food and bacteria of food [8, 12].

Filtration system developed by Tesla (Bioweapon Defense Mode) fulfils the most drastic HEPA (High efficiency particulate air) standards, blocking the entry of pollutants, pollen, or bacteria into the cabin while at the same time re-circulating and permanently reflecting air in the passenger compartment. The test was performed with a Tesla Model X model in a plastic ball, hermetically sealed.

Figure 4. Concentration of CO$_2$ - interior/exterior of Audi A5, [11].

Figure 5. New carbon filter photo NineX application – zoom ×400.

Figure 6. Used carbon filter photo NineX application – zoom ×400.
sealed and filled with contaminated air at a concentration above 1000\( \mu \text{g/m}^3 \). According to American standards, the air is breathable if the concentration of pollutants does not exceed 12\( \mu \text{g/m}^3 \) [9].

In the above pictures it is depicted a passenger compartment carbon filter before fitting on a car (figure 5) and after 10000 km (figure 6).

6. Air quality sensor
The air quality sensor (figure 7) is a metal oxide sensor. This sensor is highly sensitive to various smells and pollutants that are typical of traffic. The sensor for automatic air recirculation control (AUC sensor) is secured on the microfilter compartment. The automatic air recirculation control sensor evaluates the concentration of carbon monoxide and nitrogen oxides in the intake fresh air. The automatic air recirculation control sensor converts the detected air quality (air grade) into an electrical signal. The air quality is divided into 10 stages: clean to severely contaminated.

![Figure 7. Positioning of the AUC sensor 1 with connectors 2 and guide pins 3 in micro filter compartment, [13].](image)

If the automatic air recirculation sensor detects an increased level of pollutants in the environment from spark-ignition and diesel engines, the heating and air conditioning system control unit will automatically switch to air recirculation mode.

Because the lack of a fresh air supply, air recirculation mode is only available for limited period of time. When the engine is started and the AUC function activated, fresh air is always selected for approximate 40 seconds due to the warming phase of the AUC sensor [13].

The air quality sensor has reached its operating readiness after 30 seconds and responds to ambient air changes.

This sensor consists of two resistor elements and an electronic component.

Figure 8 presents a functional description of an AUC sensor which equips a BMW car. The automatic air recirculation control sensor transmits the corresponding stage as a pulse-width modulated signal (PWM) to the Body Domain Controller (BDC). The BDC transmits the digital signal as a message on the CAN bus (Controller Area Network) to the IHKA (integrated automatic heating/air conditioning system) control unit [13].

The advantage of using the recirculation function partially is to keep a low particle in the cabin. Using this function for a long time increases the carbon dioxide level in the passenger compartment.
7. Conclusions
Maintaining optimal air quality depends on vehicle speed, air recirculation function, ventilation rate, number of passengers and quality of cabin filter. In cabin air filtration, the car passenger is ultimately the customer. He must receive realistic information that can be used and understood. The benefit expected from the installation of a cabin air filter in a car needs to be communicated via development engineers and marketing people in the OEM and aftermarket organisations. It is important for the car user to understand the importance of maintaining the service interval for the microfilter, to choose a quality filter and to use the recirculation function when it is necessary. Future works propose air quality determination in various areas of the city of Iasi, Romania, inside the car with and without the active recirculation function. The weather is also important for the measurements. The measurements inside the car will be made with different cabin filters (classic, active pollen, with biofunction polyphenol layer). Upon completion of the tests, micrographs of the filters used for the measurements will be carried out.

8. References
[1] Golgotiu E 1995 *Genesis and combating environmental pollution* p 214
[2] Zhang K and Batterman S 2013 *Sci. Total Environ.* Apr 15 307–316
[3] Grady M L, Jung H, Kim Y and Park J 2013 *SAE Technical Paper* 2013-01-1494
[4] https://en.wikipedia.org/wiki/Weather_Eye, accessed at 10 august 2018
[5] Bhatti M S 2008 *ASHRAE Journal* 41 44-50
[6] www.airvisual.com 2018 *World most polluted cities*, accessed at 04 march 2019
[7] European Environment Agency 2016 *Air quality standards under the Air Quality Directive and WHO air quality guidelines*
[8] https://www.mann-filter.com/mann-filter/news/press-releases/newsdetail 2014 *Frescious Plus New cabin filter for increased protection against allergens, bacteria and mould*
[9] www.tesla.com/es_ES/blog/putting-tesla-hepa-filter-and-bioweapon-defense-mode-to-the-test 2016, accessed at 02 September 2018
[10] Reinhardt H 2005 *Filtration and Separation* 42(9) 18-23
[11] Auto Motor and Sport 2018 *Cabin air quality* September 74-79
[12] Daly S 2006 *Automotive Air-Conditioning and Climate Control* (Taylor & Francis) *Introduction: An overview of the automotive air-conditioning market, training and qualifications* p 382
[13] https://sgate.bmwgroup.com/eu/ BMW Group AIR (Aftersales Information Research) *Air Quality Sensor*, accessed at 16 January 2019