Emissions of hydrocarbons from evaporation of fuel. Regulation and test methods. Ways to ensure future requirements

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Abstract. Stricter requirements for hydrocarbon emissions both from the vehicle as a whole and from the fuel system are a necessary measure to preserve the environment. Hydrocarbon emissions from fuel vapors from vehicles equipped with spark ignition engines are determined and regulated in accordance with «Uniform provisions concerning the approval of vehicles with regard to the emission of pollutants according to engine fuel requirements» in Europe and the California evaporative emission standards and test procedures for 2001 and subsequent model motor vehicles (Amended: September 2, 2015) in the United States. To meet the promising standards for fuel vapor emissions from the fuel system, vehicle manufacturers use special designs and manufacturing technologies for fuel systems. The automotive industry as a whole is committed to minimizing emissions and making driving environmentally sound, both in the short and long term.

1. Introduction
When discussing the emissions of harmful substances from a vehicle, they mainly mean the substances contained in the exhaust gases (the emissions that vehicles produce when fuel is burned). However, there is another type of emissions that deserve special attention - evaporative emissions.

Before the introduction of the carbon canister into the fuel system, the contribution of emissions from fuel vapors to total emissions was about 20%. Since the installation of the first EVAP (Evaporative Emission Control) gasoline vapor recovery systems in a car, emissions of non-methane volatile organic compounds (VOC) road transport have been dramatically reduced. Table 1 shows the percentage contribution for various European countries [1].

Gasoline consists of hundreds of different hydrocarbons. Since gasoline or other fuels undergo a natural evaporation process, they release vapors into the air. Fuel vapors are pollutants that can harm air quality and therefore human health.

With an understanding of the harmful effects of evaporative emissions, more efficient fuel vapor emission controls and less harmful gasolines have been developed. There are the following types of emissions of fuel vapors (Fig. 1).
- **Resting loss**: Diurnal emissions result from the evaporation of gasoline due to temperature fluctuation during the day and night.
- **Running loss**: Running loss emissions represent gasoline that is vaporized from the engine and fuel system while in operation.
- **Hot soak**: Hot Soak emissions occur during the first hour that the vehicle is parked after normal operation.
- **Refueling**: Refueling emissions occur as gasoline is pumped into the tank displacing the gasoline rich vapor [1].

**Table 1.** Figures of total emissions in the form of vapor, represented as a percentage of the national totals of VOC from road transport emissions.

| Country            | %  | Country    | %  |
|--------------------|----|------------|----|
| Austria            | 2,9| Hungary    | 4,4|
| Belgium            | 6,8| Ireland    | 12,7|
| Switzerland        | 11,2| Italy     | 8,5|
| Czech Republic     | 5,0| Luxembourg | 6,6|
| Germany            | 11,5| Netherlands| 4,9|
| Denmark            | 6,1| Norway     | 16,7|
| Spain              | 9,0| Poland     | 9,4|
| Finland            | 5,1| Portugal   | 3,5|
| France             | 10,5| Sweden    | 10,2|
| Greece             | 8,8| Slovenia   | 3,6|
| Great Britain      | 15,2|           |    |

**Figure 1.** Fuel Vapor Emission Types.

2. **Results**
In the world, hard requirements are imposed on hydrocarbon emissions from evaporation. Developing countries are limiting these rates, each time reducing the amount of hydrocarbon emissions from evaporation (Table 2).

Fig. 2 shows the downward trend in emissions from fuel vapors. The most stringent requirements are imposed on vehicles imported and manufactured in the USA [2, 3].
Table 2. Allowable amount of hydrocarbons as a result of evaporation for different regions.

| Region | Year | Normative base           | Standards | g / test duration | Fuel |
|--------|------|--------------------------|-----------|------------------|------|
| Europe | 1999 | Regulation №83 (UN/ECE) | EURO 3    | 2.0/24 hour      | E0   |
|        | 2005 | Regulation №83 (UN/ECE) | EURO 4    | 2.0/24 hour      | E0   |
|        | 2009 | Regulation №83 (UN/ECE) | EURO 5    | 2.0/24 hour      | E0   |
|        | 2015 | Regulation №83 (UN/ECE) | EURO 6    | 2.0/24 hour      | E0   |
|        | 2020 | Regulation №83 (UN/ECE) | EURO 6d   | 2.0/48 hour      | E10  |
| USA    | 1996 | EPA¹                     | Tier I    | 2.0/24 hour      | E0   |
|        | 2000 | EPA                      | Tier II   | 0.95/48 hour     | E0   |
|        | 2005 | EPA                      | Tier III  | 0.95/72 hour     | E0   |
|        | 2014 | EPA                      | Tier IV   | 0.5/72 hour      | E10  |
|        | 2015 | CARB²                    | LEV I³    | 2.0/72 hour      | E0   |
|        | 2020 | CARB³                    | LEV II    | 0.5/72 hour      | E10  |
|        |      | CARB                      | PZEV⁴     | 0.35/72 hour     | E15  |
|        |      |                          | LEV III   |                  |      |
| China  | 2020 | CARB                      | China 6b  | 1.2/48 hour      | E0   |
| India  | 2000 | Regulation №83 (UN/ECE) | Bharat VI | 2.0/24 hour      | E0   |
| Brazil | 2020 | Evaporative requirement  | PROCONVE  | 1.5/24 hour      | E22  |
|        |      | (E22/E61/E100)           | L6        |                  |      |
|        | 2022 | Evaporative requirement  | PROCONVE  | 0.5/48 hour      | E22  |
|        |      | (E22/E61/E100)           | L6        |                  |      |

¹ EPA – Environmental Protection Agency;  
² CARB – California Air Resources Board;  
³ LEV – Low-Emission Vehicle;  
⁴ PZEV – Zero-Emission Vehicle.

Testing of vehicles on Regulation №83 UN type 4 are in accordance with Figure 3. In 2020, the day test has increased to 48 hours instead of 24 hours. The emission limit value did not change and remained at the level of 2 grams per test cycle. Also, the reference fuel that is used during testing contains 10% ethanol. This, in turn, increases the diffusion permeability of the fuel by ≈50%.

In some countries (USA, China, etc.), in addition to the evaporative emission test, a fuel emission test is carried out during refueling. [4]. With a traditional fuel system, when refueling, fuel entering the tank displaces the vapors that are in the tank. These vapors enter the atmosphere thereby polluting the environment. The ORVR (Onboard refueling vapor recovery) system counteracts this phenomenon. Such a system does not allow vapors to get into the atmosphere during refueling, it directs them to the adsorber. Fuel tank filler neck seals the fueling nozzle, which prevents fuel vapors from penetration into the atmosphere. For such a system to work, it should not exceed 38 l/min. [4]. Such a vehicle refueling rate is much lower than in European countries (about 60 l/min).
**Figure 2.** Fuel vapor emission decrease trend per daily test.

**Figure 3.** Vehicle Test Algorithm.
3. Ways to ensure future requirements
To meet future requirements, the body of the fuel tank must be made of a multilayer material (Fig. 4). Plastic fuel tanks are made of HDPE High-Density Polyethylene. The main disadvantage of HDPE is the high permeability of hydrocarbons due to the low degree of polarization of polymer macromolecules and weak bonds between the chains of macromolecules.

To prevent diffusion of hydrocarbons through the tank wall, an EVOH (Ethylene-Vinyl Alcohol) barrier layer is used. The EVOH layer is suitable in all its parameters to polypropylene, has a similar melting point, is neutral and does not emit harmful substances when heated.

![Figure 4. Layers of the body of a modern plastic fuel tank.](image)

Currently, the vast majority of plastic fuel tanks are of a 6-layer design with an EVOH barrier layer (Figure 4).

The high barrier characteristics of the wall of a multilayer tank with a barrier layer are explained by the three orders of magnitude lower permeability of EVOH compared to HDPE.

Plastic tanks are made by extrusion blow molding of separate tank halves with their subsequent welding. In this case, the weld seam accounts for up to 60% of the total diffusion of hydrocarbons due to the fact that the thickness of the barrier layer in the seam area is noticeably reduced. In order to meet modern requirements to vapors from the fuel tank, it is necessary to provide in the weld seam area of a continuous barrier layer of sufficient thickness.

Attempts are known to connect the barrier layers of the two halves of the tank in the area of the seam edge by means of a “bridge” (Fig. 5). This technique includes the following steps: chamfering the seam, treating the seam end (for example, corona discharge or plasma to increase adhesion) and applying a barrier material to the seam end that is compatible with the barrier materials in both halves of the tank.

[5]

The main trend in the development of the design of automobile fuel tanks, determined by the need to reduce fuel vapors, is the placement of the components of the low-pressure fuel system and the elements of the ventilation system inside the fuel tank and the reduction in the number of detachable connections of the fuel tank. First, this trend affected the fuel pump and fuel filter, which moved into the tank. Nowadays, technologies that provide for the placement of elements of the fuel system and the ventilation system before welding of parts of the fuel tank, in which the number of holes cut in the tank is minimized, are becoming more widespread (Fig. 6, 7).
Figure 5. Tank seam with a barrier bridge: 1, 2 - tank walls; 3 - EVOH barrier layer; 4 - barrier bridge EVOH.

Figure 6. Examples of traditional and BFS placement of fuel tank elements: a - traditional technology; b - BFS technology.

Figure 7. Examples of BFS fuel tanks (Honda Civic, Ford Focus).
Such technologies are called BFS (Built-in Fuel tank System) - Yachiyo Industry Co (Japan) and SIB (Ship-in-a-Bottle) - TI Fluid Systems (USA) [6, 7].

Fuel tanks contain elements that are used to monitor the internal pressure of the tank or determine the total filling volume. In the traditional manufacturing method, these elements are welded into holes cut in the tank. In this case, the required impermeability of the tank wall for hydrocarbon vapors cannot be ensured.

In BFS technology, system elements are placed inside the tank without creating holes. These elements are attached to additional brackets or partitions that increase the rigidity of the tank and reduce the level of fuel splashing noise (Fig. 8).

![Figure 8. Fuel tanks with integrated struts and brackets.](image)

The filling pipes have integrated elements such as a fuel vapor separator, a safety valve (fig. 9).

![Figure 9. Fuel pipes with an integrated vapor separator.](image)

For vehicles of LEV and PZEV standards, tanks are used, consisting of two walls separated by an air gap, each wall being an identical multi-layer structure. (fig. 10).
The tightness of the tank is ensured by welding the walls together. TI Fluid Systems (USA) was one of the first to produce 2-wall tanks, calling the TAPT technology (Tank Advanced Process Technology), which combines two-wall components integrated inside the tank. A similar technology called TSBM (Twin Sheet Blow-Molding) uses firm Plastic Omnium (France) [8].

TAPT and TSBM technologies allow, in comparison with traditional approaches, to significantly reduce permeability, increase mechanical and thermal insulation properties. Placing and securing the elements inside the tank provides additional freedom of positioning and increases the usable tank capacity for the available space in the vehicle.

The number of holes in the tank body is reduced. As a rule, there is only one hole for the fuel module, all components of the ventilation system are located inside the tank (Fig. 11). In a Ford GT fuel tank, even the fuel module is mounted inside the tank before welding the halves (Fig. 12).
Figure 11. Mercedes S-Class fuel tanks: a - traditional technology; b - TAPT technology.

Figure 12. Ford GT fuel tank (TSBM technology).
4. Conclusions
To meet modern requirements for emissions of fuel vapors into the atmosphere, it is necessary to use modern materials, have additional subsystems (fuel vapor recovery system, ORVR, leak diagnostics system, etc.). In the initial step of the way carbon canister of a small size was enough. Now the size of the adsorber has been increased by 2-3 times. Also it is necessary to simulate the formation of fuel vapor on the basis of the temperature inside and outside the fuel tank, its volume, etc., for selecting the characteristics and scope of the subsystems carbon adsorber in the initial design phase of fuel storage and delivery system. Otherwise, this can lead to a change in the design of the car's fuel system at the final stages of its development, which in turn can lead to a change in other vehicle systems.

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