Experimental analysis of the influence of clogging on the filtration process for internal combustion engines

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Abstract. This article presents the analysis of the laboratory tests results carried out to investigate the effects of the clogging phenomenon developed at internal combustion engine filters. A classical filter module from an aspirated engine was used to carry out the tests, composed of air ducts, filter housing and a standard panel filter element made of paper, mounted on the test stand designed by the authors, for analysis of flow state parameters in dynamic mode.

1. Introduction

Based on the specialty literature data [1-4], in practice filtration mechanisms present filter processes that can be classified in two states, stable and unstable state. In the stable state the filtration efficiency and the pressure drop are fixed over time solely depending on the intrinsic characteristics of the filter materials, the nature of the solid particles and the flow of air. The stable state of filtration through fiber-containing elements can also be classified by five filtration mechanisms, as follows: Interception, inertial deposition, diffusion, electrostatic effects or gravity effects (Figure 1).

![Figure 1](image-url)  
(A) main filter mechanisms of fibrous material; (B) filter efficiency for particles of different diameters; (C) primary filter effect based on particle size [1]
Unstable state with changes in filtration capacity and pressure drop due to accumulation of particles over time on the surface of the filter element. Due to the complexity of the filtering process in an unstable state, currently no data are available on theories for accurate predictions of the actual filtering process [1], [4].

Unstable filtration is also found at internal combustion engines where the filter modules are primarily intended to prevent abrasive particles from entering the cylinder in order to avoid mechanical wear and oil contamination.

In most cases where fuel intake is by injection, folded panel type filter elements are used, which are placed in the plastic housing connected to the throttle valve by means of working pipes. Exception to this constructive solution being some older engines, which may be equipped with various types of filter elements made of polyurethane foam, textile fiber, stainless steel or even filter elements into oil bath [2], [3].

2. Case of study and test methodology
The study proposes for analysis the influence of clogging of the filter element used under normal operating conditions on the flow state parameters following the filtration process. The study object used in the experimental analysis is the filter module (Figure 2) from a Fiat brand car model Stilo, manufactured in the period 2001-2007, this model has a 4-cylinder aspirated engine with a cylinder capacity of 1600cm³. The filter module contains the filter housing (1) inside which is the panel type filter element made of paper, air ducts (2), also the module is equipped with a series of Helmhotz resonators (3) in order to attenuate the noise level produced by the engine during operation. The analysis is based on the results obtained from laboratory tests performed using the stand designed by the authors to analyze the flow state parameters (Figure 3). The experimental stand has an electric motor with a power of 1kW (1), air turbine (2), control panel which facilitates the variation of the rotation speed (3), and a flow uniformization tube equipped with a static pressure measuring socket (4). In order to highlight the influence of clogging on the filtration process, two constructively identical filter elements were used, a new one and a used one, under normal conditions for 13000 km.
Figure 3. Experimental stand for analysis of flow state parameters

During the test process, the air flow velocity at the inlet of the intake system was measured in real time with a Testo 410-1 anemometer (Figure 4) and the static pressure drop at the outlet of the system, on the pressure port of the uniformity tube with the help of a differential manometer model Testo 510 (Figure 5).

Test conditions:
- Temperature (T): 25 ° C (298.15 K)
- Area of entry into system (S1): 0.0035 m²
- Area exit from system (S2): 0.0028 m²
- System inlet pressure (p1): 98400 Pa

Figure 4. Anemometer model Testo 410-1

Figure 5. Digital manometer model Testo 510
During the test, the mass flow varied linearly from 0.004 kg/s up to a maximum of 0.068 kg/s (Figure 6).

![The variation in flow rate over the test duration](image)

**Figure 6.** Variation of the mass flow introduced into the system during the test

3. Results and discussions

Prior to the test, the filter elements have been subjected to an analysis to identify and establish the condition of the surfaces and the cause of the clogging shown in Figure 7 and Figure 8.

![New filter](image)

**Figure 7.** New filter

![Polluted filter](image)

**Figure 8.** Polluted filter

Following the analysis, it was found that the clogging of the used filter element is due to the agglomeration of abrasive particles between the fibers of the filter material, not identifying technical causes, which leads to the following conclusion: operating conditions were normal.
Analyzing the values of the pressure drop measured at the exit of the system during the test presented in Figure 9 we can observe the difference between the two situations, this being due exclusively to the clogging.

![Pressure drop obtained during testing](image)

Figure 9. Pressure drop obtained during testing

As the air flow rate (v1) measured at different points on the cross-section of the intake system inlet pipe does not vary considerably, a stationary flow assumption can be taken.

Thus, in the case of stationary flow, the mass flow is constant according to the mass conservation equation (1):

$$Q_M = \rho \cdot S \cdot v = \text{const}$$  \hfill (1)

Hence (2):

$$\rho_1 \cdot S_1 \cdot v_1 = \rho_2 \cdot S_2 \cdot v_2$$  \hfill (2)

Considering the working fluid an ideal gas, the density can be determined using the thermal equation of state (3):

$$\rho = \frac{p}{\rho \cdot T}$$  \hfill (3)

Knowing the pressure drop we determine the pressure at the exit of the system with the following relation (4):

$$p_2 = p_1 - \Delta p$$  \hfill (4)

By replacing the known values in the mass conservation equation (2) the flow rate of the fluid at the outlet of the system (5) can be determined:

$$v_2 = \frac{p_2 \cdot S_2 \cdot v_2}{p_2 \cdot S_2}$$  \hfill (5)

Using the flow rate at the exit of the system determined by the relation [5] it is possible to calculate the volume flow at the exit of the system with the relation (6):

$$Q_v = S_2 \cdot v_2$$  \hfill (6)
Thus, knowing the volume flow at the exit of the system and the pressure drop can determine the loss of power due to the filtration process (7):

\[ P = \frac{dU}{d\tau} = \frac{Fdx}{d\tau} = \Delta pQ \nu \]  \( \text{where } F \text{ is the pressure force.} \) (7)

![Figure 10. Graph of power loss due to the filtering process](image)

Following the calculations, the graph of the power loss due to the filtration process was drawn (Figure 3, Figure 4), from which it can be observed that, at the value of flow velocities of 13 m / s, the maximum difference of the power loss of 9.5 W is registered [5], [6].

4. Conclusions

Following the analysis of the obtained results we can conclude that, at high flow rates, in the case of clogged filter the power loss is higher compared to the new filter element, this difference being due to clogging. The level of clogging of the filter element is not only influenced by the service life of the system, but especially by the environment in which it operates. Thus, under heavy operating conditions, a filter element can have a high level of clogging in a short period of operation, then the filtration process will require a higher amount of energy. Therefore, due to the unstable filtration state and the lack of a theory that can present a prediction of the filtration parameters evolution, the existence of a control system to indicate the need of the filter replacement based on the value of the pressure drop generated by it, would be an advantage.

References
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