

Research on criteria selection for replacing air filters and consequences emphasis

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Abstract. Automotive engine air filters have numerous shapes best suited for each engine. Most used filter materials are paper fibres (cellulose fibres) and felt (non-woven fibres). Current maintenance practice for replacement of air filters is indicated by certain distance travelled, by certain number of hours in use, or less common by a specialized transducer indication. The current paper is about experimental research done on Renault K9K 612 engine air filters. Experimental tests were done on a specially built testing stand based that includes the original air intake system from the said engine. This air intake system has a special transducer that measures the air restriction and gives indication for when to be replaced. We measured air restriction produced by new and used OEM air filters, and two types of aftermarket filters and came to the conclusion that the filters were changed prematurely. Also, while the specialized OEM transducer showed a higher value of restriction as a mark to change the filter, the actual air restriction of the used filters shown by our test stand is much lower.

1. Introduction

There are multiple particles in the air that reaches engines intake. Depending of environment and running conditions those particles are either organic or mineral. These particles are hard, with irregular forms and sharp, so the intake of such particles into the engine cylinders and then into fuel line and oil system, they contribute to accelerated wear thus reducing greatly the life expectancy of the engine, by [1], [2].

Air filtering system includes the air filter, its housing and the air ducts that are used for internal combustion engines should satisfy the following conditions:

- Great filter efficiency
- Low air restriction in the majority of air filters duration of use.
- Big storage capacity of particles
- Great duration of efficient use to reduce service intervals

The following terms are defined as [3]:

- “restriction” meaning the static pressure measure immediately downstream of the single air cleaner element (or the complete air cleaner assembly) as per standards.
- “efficiency” meaning the ability of the air cleaner or the unit to remove contaminant under specified test conditions
- “capacity” - quantity of contaminant removed by the unit under test in producing specified terminal conditions



- “absolute filter” - filter downstream of the unit under test to retain the contaminant passed by the unit under test

2. Results and conclusions from specialty literature

In [4] we find that we may define service life as the useful functional life of an engine air induction filter, in order to protect the engine without any appreciable performance degradation. And in [5] we find that the service life of an air filter is commonly defined as a level of restriction which results in a pressure drop across the filter of about 2.5 kPa.

The service life of an air filter for automotive engines is usually expressed by distance travelled (in thousands of kilometres) or by duration of use (in months and years). These intervals are set in engineering terms by destination of use of the vehicle.

Usually for identifying the moment the air filter should be changed, we refer to the total restriction of the filter (to prevent clogging) and the increase of restriction from the initial restriction of a new filter. Total restriction values are set by the engine manufacturer depending on engine type [6].

In [6] and [7] it is stated that the total restriction limit for diesel engines is between 3.7-7.5kPa, and for gasoline engines 3.8-5kPa.

In [8] it is mentioned that the filter for light and medium vehicles should be changed if the restriction increases by 2.5kPa over the initial restriction of a new filter.

Few engines are equipped with an air filter indicator, which represents a device that indicates when to change the filter based on the actual restriction. It also indicates by colours the state of the air filter including the recommended change moment. These types of sensors are usually found on trucks and heavy vehicles. We have done measurements of the actual air restriction on two vehicles equipped with an air filter indicator, in order to verify the actual value for a clogged air filter that was indicated to be replaced. The limit values of air restriction are 3.6kPa for a 6.7L diesel engine [5] and 5.7kPa for a 5.3L gasoline engine [9].

For light and medium duty engines, paper media filters and synthetic felt media filters have a restriction between 125Pa-750Pa, and the dust storage capacity is between 50g-500g [4]. Under normal driving conditions a 100g dust capacity is generally recommended for a 30000miles service.

A new air filter, depending on its media, has an initial efficiency between 96%-99.6%, and at the end of life of the filter (corresponding to a relative restriction value of 2.5kPa) reaches an efficiency of 99.99% [10].

Observing in several studies, there is a correlation that there is a linear relation between the dust concentration and the wear rate of the engine and the particle dimension that reaches past the air filter have a major implication for increasing cylinder-segment-piston wear. Particles larger than 4-5 μ m represent a significant wear factor, while particles smaller than 2 μ m (that usually gets past the air filter) poses insignificant wear. Particles larger than 5 μ m can get past common air filters but in very low percentage, and for high efficiency filters such particles can't get past the filter [10].

Similar conclusions are to be found in [2].

The state of wear of engine components is depended on the particle size and the thickness of the dynamic oil film between the moving parts, such as particles with a similar size to the oil film thickness produce the most amount of wear. The oil film thickness is generally greater than 1 μ m.

Observing in several studies and in [2], particles smaller than 10 μ m have produced four times the wear than larger 10-20 μ m particles.

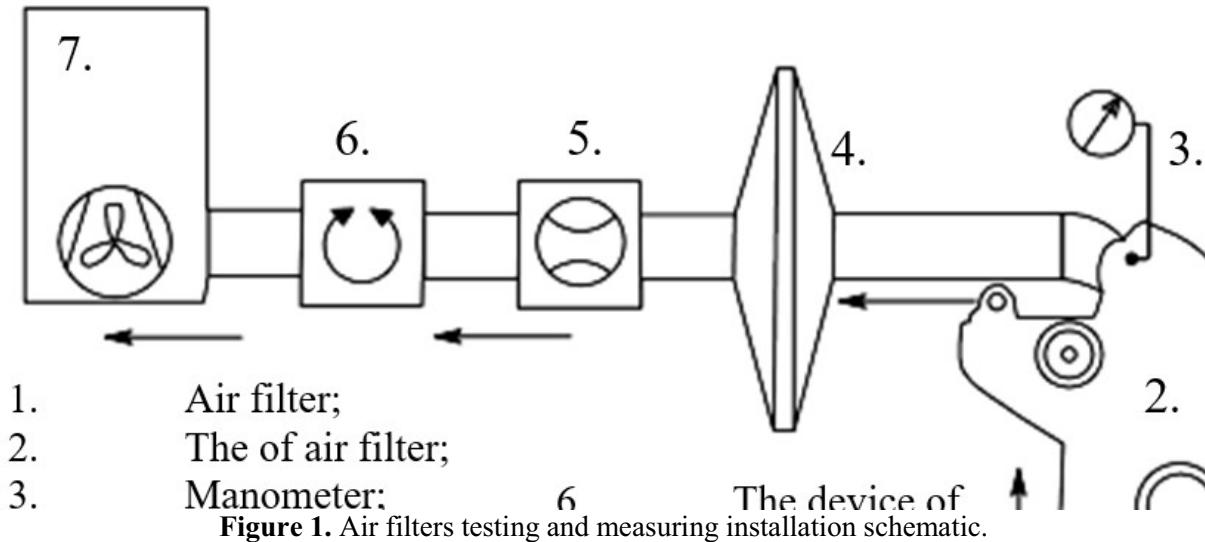
3. Experimental Research

The study object is to measure the actual restriction produced by new and used filters. Also by measuring we can observe the actual air restriction value when the air cleaner indicator is recommending the replacement of the filter.

In order to do such a measurement a new filter will be gradually and controlled filled with dust and with dedicated laboratory equipment, will raise the air restriction characteristic relative to the mass of dust collected. This is done in order to determine if the used air filters replaced as per manufacturer

indications were changed at the correct moment when the air restriction reached the limit value, and the consequences of such action.

The dedicated stand for testing air filters was made in according to ISO 5011 standard.



The air filter system used for testing is found on the Renault K9K 612, 902 diesel engines which are equipped by Dacia between 2011 and 2012 for several models such as Logan and Duster.

For these vehicles, the manufacturer recommends in the operation manual that the air filters should be changed after 20000km or one year of use (whichever condition is reached first). The air filter housing is equipped with an air restriction indicator presented in figure 2. It is recommended in [11] to replace the air filter immediately when indicated, regardless of number of kilometres travelled or duration in use.



Figure 2. (a) Air filter housing equipped with air restriction indicator. (b) air filter “OK”
(c) air filter replace

Filters used in testing are original OEM. The used filters were collected from vehicles in use at service shops in the normal periodic maintenance program. After the filters were removed from the

housing, they were placed inside plastic bags to prevent absorbing moisture or losing any dust or gathering other contaminants not gathered in normal use. New filters are noted with NF1, NF2 and NF3, while the used filters are noted with UF1 to UF10.

The testing was conducted in several stages. First the new and used filters were weighted. Then the air restriction was measured with the dedicated stand (first for three new filters then for three used filters). Then it was at which restriction value the indication shown on the air filter indicator on the housing recommended to replace the filter. Then the new filter was gradually filled with dust and it was determined the initial and final efficiency of filtration. From the absolute filters there were prevailed samples to be analysed at microscope.

3.1. Weighting of the filters

The air filters were weighted using a scale with 0.01g resolution. In order to measure the dust stored in the filter we first measure the filter in the new state and then we measure the filter after it was used.

Only OEM filters were used.

In order to measure the dust already stored in the used filters, three new filters were dried in order to remove any moisture and weighted with the mass noted with (m_n) with the following results: $m_{n1}=131.82\text{g}$, $m_{n2}=131.68\text{g}$, $m_{n3}=131.78\text{g}$. And then we measured the used filter mass noted with (m_U). The dust mass (m_D) was calculated as the difference between the used filter mass (m_U) and the new filter mass (m_D) (we used the m_{n2} value as a reference being the lightest new filter, and to account for the highest values of stored dust)

3.2. Measuring the air restriction

The conditions for air filter testing are recommended in ISO 5011 standard and are at maximum airflow for that particular engine equipped. For the K9K 612 engine the maximum air flow is of 321kg/h specified in [12].

Measuring the restriction was done at several loads for partial loads of the engine at half of the maximum airflow noted with $Q_{50\%}$. Such load is relevant because engines are rarely used at full load and in the majority of time it is used at partial loads, and such the air filter is used with mostly partial load airflow.

To measure the restriction value when the indicator on the housing is recommending to be changed, the restriction was gradually increased by adding paper towels as mentioned in [5] until the indicator reached the replace mark as in figure 2.

3.3. Controlled dust fill

The dust used for the fill was collected in brute form from the Bucharest city environment near the road surface. Then the dust was sifted for particles under 100 μm and under 40 μm .

To be as close to the ISO 12103-1 standard, the dust used has 90% particles under 40 μm and 10% particles between 40-100 μm .

We used the NF1 filter for this test. The absolute filter has a progressive structure of unwoven fibres. The media of the filter is category M5 F7 as in [13] and shown in figure 3. The particle collection mechanism is through inertial impact and direct interception as shown in [16].

The controlled dust fill of the air filter was done as stated in ISO5011 standard. The airflow value used for the fill was 321kg/h, the maximum airflow for the K9K 612 engine. After injecting 20g of dust, we measured the filtering efficiency as in ISO 5011 standard. This represents the initial efficiency. After measuring the initial efficiency, the absolute filter was replaced. Then the dust injecting continued until the air restriction indicator on the housing reached the replace mark. At this stage was measured the final efficiency.

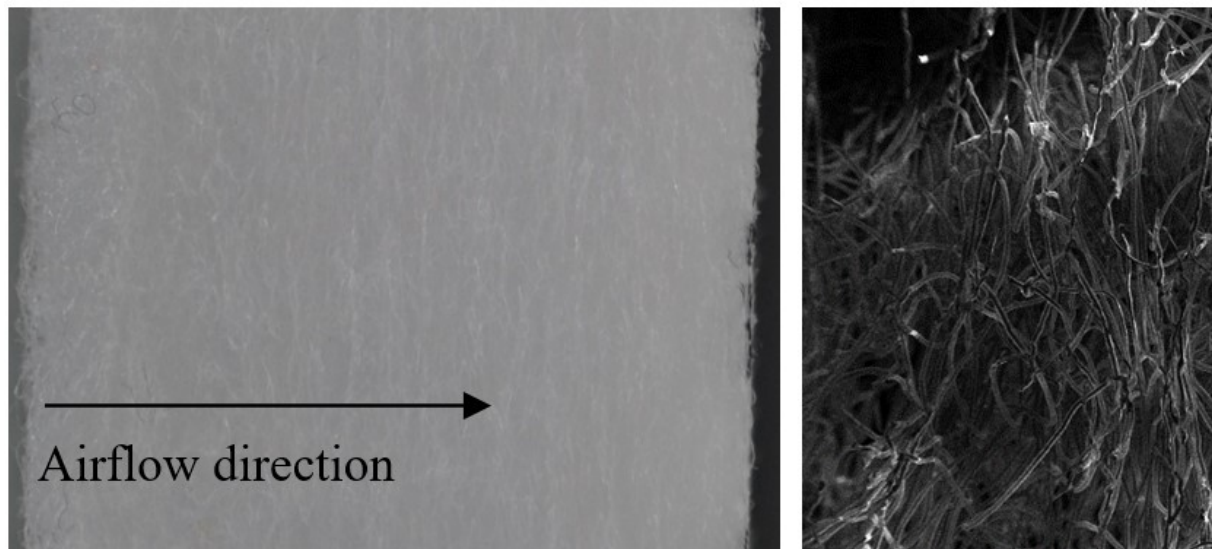


Figure 3. (a) Photo of absolute filter (b) Electron microscope view of absolute filter fibers

3.4. Microscope analysis of the samples from the absolute filter

From the two absolute filters used we relieved three samples of filter media from the centre area of each filter.

Trough microscope analysis of the absolute filter the object is to identify the size of the particles that passed by the air filter in the two stages while measuring the initial efficiency at 20g of dust injected and final efficiency at 200g of dust injected.

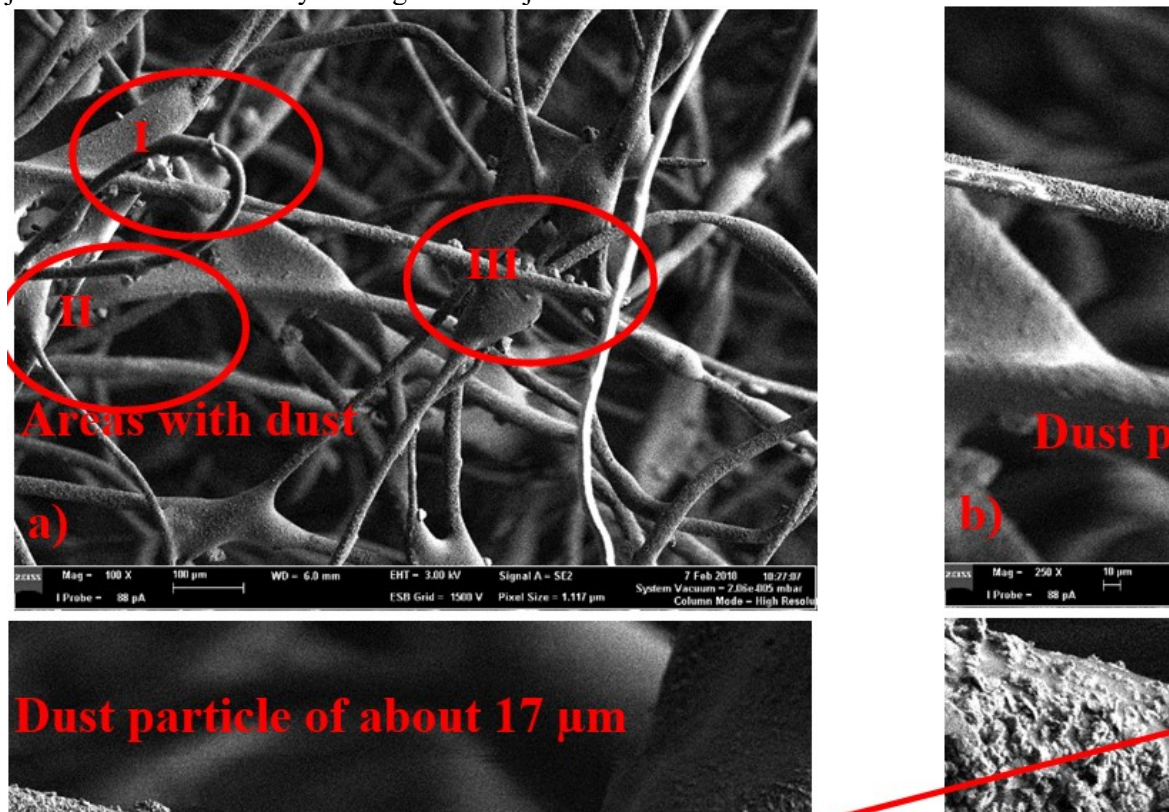


Figure 4. Electron microscope photos from the first absolute filter.

The electron microscope imagery was conducted by a qualified operator. The images produced by the electron microscope for each sample are done at x100, x250, x500, and x2500 zoom at the scale of 100 μ m, 10 μ m and 1 μ m and are shown in figure 4 and figure 5.

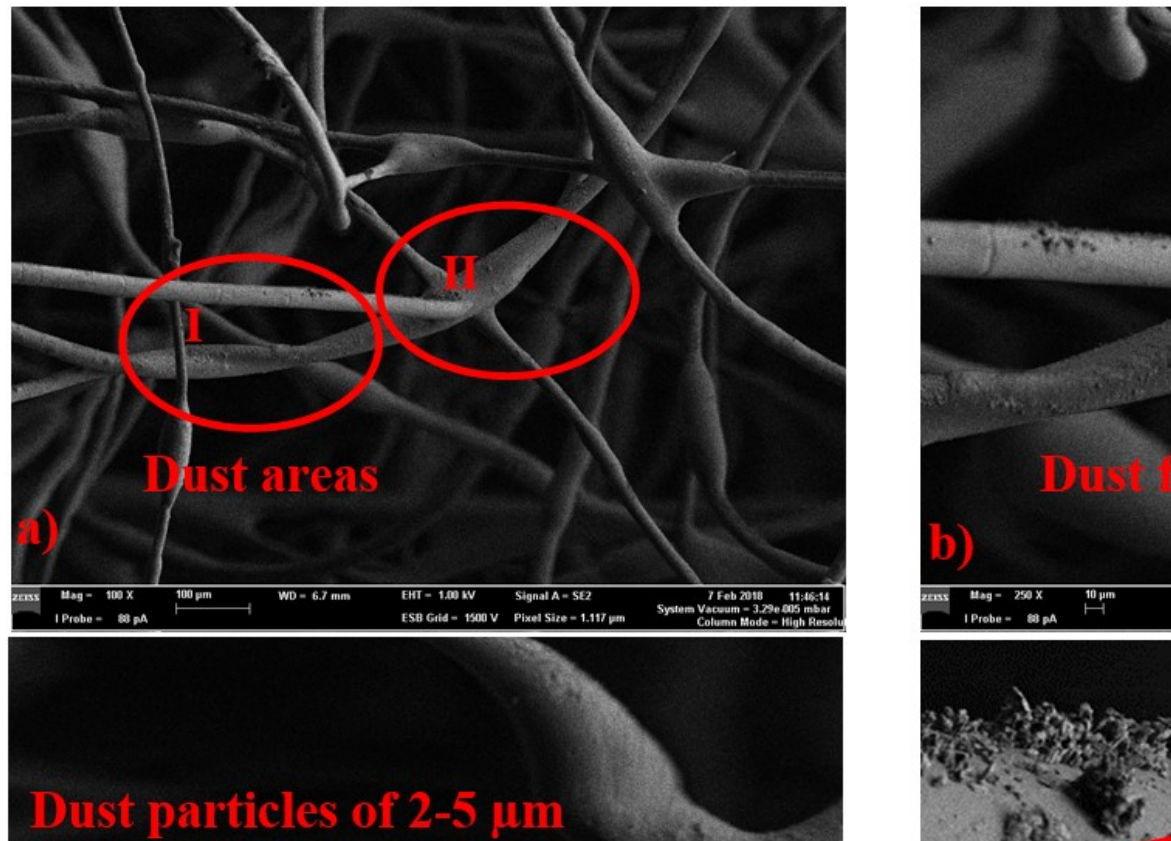


Figure 5. Electron microscope photos from the second absolute filter.

4. Research results and interpretation

4.1. Weighting of the filters

Before weighting, the filters were dried to remove any moisture. The dust mass found in the used OEM filters is approximated in table 1.

Table 1. Dust mass found in filters.

Air filter	Mass of air filter [g]	Mass of dust [g]	Surface density of dust [g/m ²]	Air filter	Mass of air filter [g]	Mass of dust [g]	Surface density of dust [g/m ²]
UF1	132.94	1.26	4.41	FU6	134.82	3.14	10.99
UF2	141.88	10.2	35.69	FU7	137.75	6.07	21.24
UF3	136.45	4.77	16.69	FU8	134.97	3.29	11.51
UF4	142.84	11.16	39.05	FU9	135.25	3.57	12.49
UF5	145.11	13.43	46.99	FU10	134.87	3.19	11.16

Analysed filters have a filtering surface area of 0.258m². It is observed that the maximum mass of dust found in used filters was of 13.43g as resulted from table 1. From [4], for a 20000km distance

travelled, an engine air filter on a car in normal conditions can collect between 8.7g-25.4g of dust. Also, in [4] is noted that the dust capacity for a filter is up to 100g of dust.

In [10] is noted that a dust load of up to 10.8g/m^2 for an air filter is almost new. As such from table 1 is observed that air filter UF1 was almost new at replacement time, and filters UF6, UF8, and UF10 have very close load to 10.8g/m^2 noting they were still at the beginning of the use cycle.

Based on the dust storage capacity and the surface density of the dust on the filter we concluded the filters were replaced prematurely before reaching its full capacity.

4.2. Air restriction caused by air filters

Air restriction values for the $Q_{50\%}$ airflow testing condition are represented in Figure 6. In figure 7 are represented the restriction values of the filters for Q_{\max} at the maximum airflow of the engine, including the restriction at which the air restriction indicator was indicating to replace the filter noted with RR (Replace Restriction).

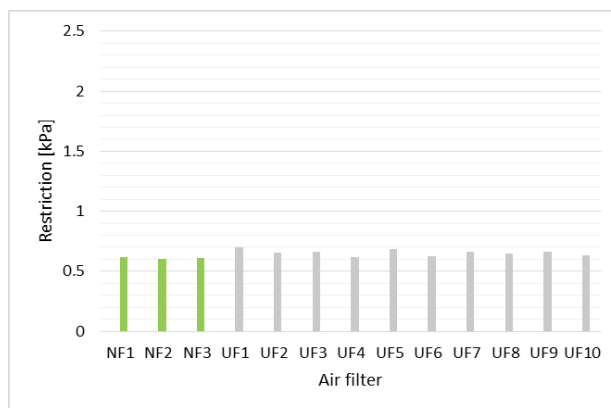


Figure 6. Restriction for $Q_{50\%}$.

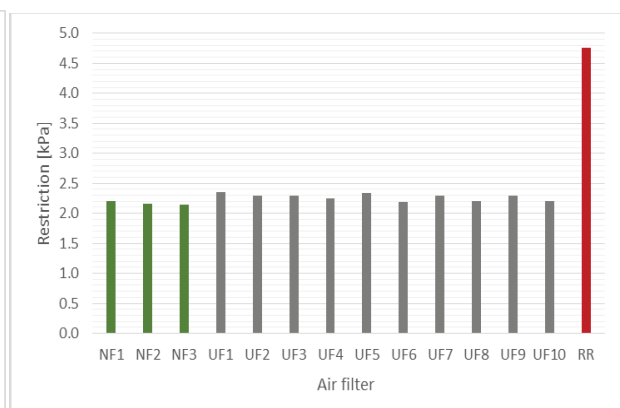


Figure 7. Restriction at Q_{\max} .

It is shown that the new filters produce a restriction close to the used filters at both states of the test. This is showing that the filters have an almost identical construction. Restrictions measured at Q_{\max} are greater than the restrictions measured at $Q_{50\%}$ in average by 71.8%.

It is noticed that all used filters show a greater restriction than new filters at both states. The increase of the restriction for used filters is ranging from 0.028kPa for UF6 air filter and 0.183kPa for UF1 air filter. This increase is insignificant comparing to engineering recommendations aforementioned of 2.5kPa. As we expected, filters with lowest quantity of dust produced the lowest restriction out of the used filters. The greatest restrictions were produced by UF1 and UF5, but the dust load is different. While UF5 has the most dust mass in it, the dust mass in UF1 is significantly lower and still produce similar restriction. This is accounted by the fact that dust particle size influences the air restriction, such as finer dust particles has low mass and produce greater restriction. So, it may differ the environment and origin of the dust for the used filters, thus having different structure, size and composition of the dust.

The restriction shown by the indicator at moment of replace is of 4.68kPa and is within normal range of 3.7-7.5kPa as mentioned in [6] and [7]. The increase of restriction between a new and a used filter is of 2.51kPa. This shows that the indicator is respecting normal recommendations found in engineering literature as [5, 8].

So it is observed that all the filters that were changed by manufacturer specification, were changed prematurely by ignoring the air filter indicator. One explanation can be the fact that the air filter indicator moves at a high value of restriction, and also the driver is not informed of the current state of the filter. The indication can be seen by lifting the hood and observing the indicator on the housing.

Service shops are changing filters as manufacturer specifications or if the client asks for it. In [14] it is shown that common drivers have bad decisions with regard of air filter maintenance.

4.3. Controlled dust fill

Increase of restriction from a new filter is dependant of mass of dust stored and is shown in figure 8.

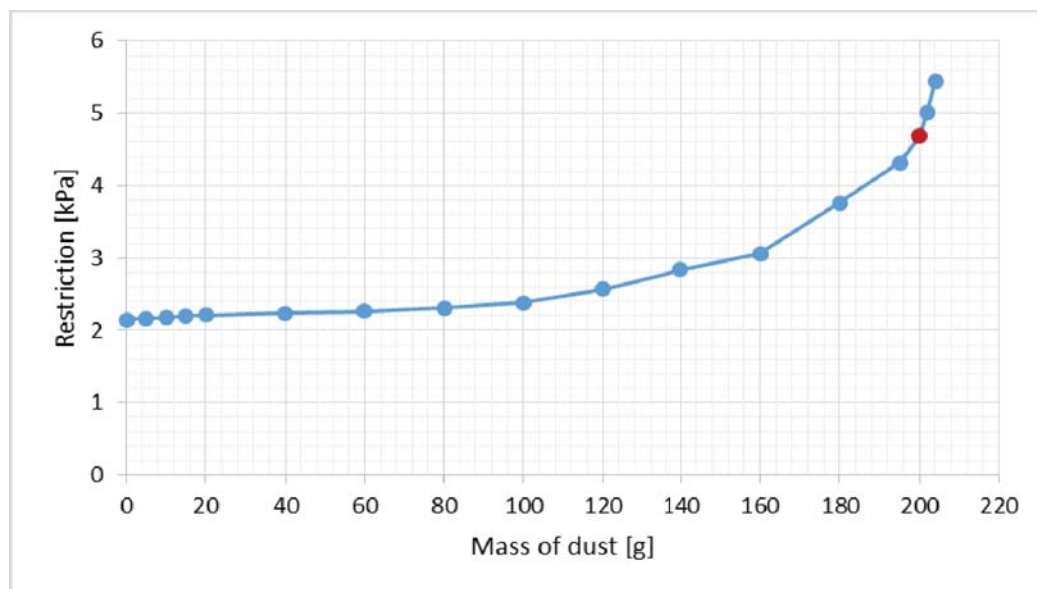


Figure 8. Relation between mass of dust accumulated and restriction

The shape of the curves in figure 8 is typical, as presented in literature in papers [15], [1], [7]

For the same amount of restriction produced by an air filter, the mass of dust is greater in the laboratory controlled filled than the real life used filters, due to difference of conditions like vibrations, variations of the airflow, variation of atmospheric conditions, and other factors.

We can see that the restriction value is still low even after 40g of dust are injected at 0.084kPa. An increase of restriction is shown at 0.231kPa after 100g of dust injected. And after 160g of dust stored the restriction value is just 0.902kPa. The rate of increase of restriction is accentuated by injecting more dust. After 200g of dust stored in the air filter the restriction value is 2.512kPa and the air restriction indicator shows the replace mark.

The graph shows the great storage capacity of air filters. For this engine, the air filter can be made smaller and reducing the capacity but it will be changed more often. By comparing the values from table 1 and the graph in figure 8 it is shown that the used filters had much more storage capacity left and were changed prematurely.

After the initial injection of 20g of dust, the absolute filter gathered 0.12g of dust that went past the air filter. After injecting another 184g of dust it was found 0.27g of dust gathered on the second absolute filter. Thus, the calculated initial efficiency is 99.399% and the final efficiency is 99.865%.

As observed in [10] and [2] the efficiency of air filters increases continuously as they are used reaching up to 99.99% at the replace moment.

Because the initial efficiency of new air filters is lower than the final efficiency, replacing a filter prematurely will cause an increase of particles that reach past the filter, thus increasing wear in the engine components.

4.4. Analysis of the absolute filters samples photos.

After analyzing the microscope images there was revealed the dust particles that went past the air filter and collected by the absolute filter. On the first absolute filters fibers we found dust particles up to

17 μ m. In figure 4a) are indicated regions with agglomerations of particles. In figure 4c) the dust particle shown is about 19 μ m in length and 10 μ m in height averaged as 11 μ m. So we conclude that dust particles up to 11 μ m can pass by the new air filter at its first use. This is confirmed by the fact that the new air filter has lower initial efficiency than the same filter in used state with higher final efficiency. In [2, 10] it is shown that particles of 5-10 μ m can get past an air filter especially when is in new state. The particles most encountered in the absolute filter have sizes up to 2 μ m as shown in figure 4d).

In the second absolute filter samples in figure 5 it is shown that the largest particles found are up to 7 μ m. The majority of dust particles found have sizes lower than 5 μ m so we confirmed the increase of efficiency as the filter is used.

Replacing air filters prematurely will let more and bigger particles enter the engine increasing wear, as well as increased maintenance costs.

5. Conclusions

By observing the dust quantity collected by air filters and the surface density of dust we conclude that the air filters were replaced prematurely way before reaching their full use cycle.

It was observed that the restrictions measured at Q_{max} are in average higher with 71.8% than the air restrictions measured at $Q_{50\%}$.

All used filters have higher restriction values than new filters, but the increase of restriction from the used filter is insignificant at the replacement moment by comparing with the speciality literature recommended values.

Air filter with lowest surface density of dust have produced the lowest restrictions.

The air restriction value where the air indicator is showing replacement moment is of 4.86kPa with an increase from the new filter to the used state of 2.51kPa.

The restriction value remains low after injecting 40g of dust, the increase being of only 0.084kPa. The increase of restriction from a new filter is of 0.231kPa after injecting 100g of dust and after 160g of dust injected the increase of restriction reaches 0.902kPa. The rate of increase of restriction is exponentially as dust is injected. After 200g of dust injected the air indicator shows the replacement moment.

Air filters used in automotive engines have high dust storage capacity in the order of hundreds of grams.

Because of the lower initial efficiency, the premature replacement of an air filter will lead to larger and more dust particles entering the engine which increases engine wear for engine components. Even if the vehicle is equipped with an air restriction indicator, this is often ignored.

6. References

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Acknowledgments

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