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ECOLOGICAL TRIBOTECHNOLOGY FOR RENOVATION OF AUTOMOTIVE AIR FILTERS

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Abstract. Automotive filters are basic elements of the air-fuel feeding systems and lubricating systems of the automobile, which have fundamental importance for its lifetime resource and for the functional characteristics. Their tribological aspects concern the role of the filters as contact elements in the construction of the automobile having impact on the environment. During the operation of automotive air filters there are complex contact processes occurring between the aerosol flow and the filtering matrix – adhesion, friction, cohesion, diffusion, etc. as result of which a contact layer is being formed on the filtering matrix, whose characteristics determine the functional parameters of the air filter and its exploitation resource. In case of specific values of the contact characteristics: conductivity and efficiency the automotive filters exhaust their resource. There are two approaches existing in the practice in regard to the spent air filters. The first approach, which is dominating all over the world, is discharging the air filters, i.e. the filters are treated as waste material and they cause many problems in the environment. The second approach is connected with the replacement of the filtering paper insert, without any precise control of the repaired filter. A peculiar feature of the contemporary use of automotive filters is their single utilisation. The applied so far approaches have deteriorated ecological-economical indices and they bring the shadow of the consumers spirit of the industrialised society. The solving of the ecological problems requires applying a new approach, new style and way of thinking to create ecologically sound and efficient economy. The present publication represents the tribotechnology and a complex of 5 devices for identification and renovation of automotive air filters, connected with input and output control, for rough and refined renovation, which have been elaborated in the Centre of Tribology. The tribological complex has already been introduced in exploitation in the practice of the ore-mining corporation 'Kazahmys' in the town of Zhezkazgan, Republic of Kazahstan and it is located on the territory of the enterprise TOO 'Rudservis K'.

Keywords: automotive filters, tribotechnology, ecology, renovation.

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AIMS AND BACKGROUND

The development of the automotive transport is a regular process during the industrial era of modern civilisation. It is the symbol of its rationalism and consumer culture. It is of special importance for the econoimic prosperity of the urbanised society and at the same time it has a substantial contribution in the energy, ecology crises and social tension. At the beginning of the 21st century the automobile entered a sharp contradiction in regard to the biosphere as a whole, but also with its separate components. Its presence is decisive with respect to the formation of the ecological situation on the Earth not only on a a local scale, but also on regional and planetary scale.

The automobile has direct connection with the substantial symptoms of the ecological crisis: mineral and raw material exhaustion of the Earth resources, heat contamination, atmospheric pollution, pollution of the hydrosphere and lithosphere with gases, liquids, powders, acoustic contamination of the urban ecosystem[1–5].

TRIBOLOGICAL ASPECTS OF AUTOMOBILE

The modern automobile is a compliated technical system having strictly defined functions. It represents a combination of sub-systems, mechanisms, components and details, which are bound by hundreds of contact conjunctions appearing on different structural levels and configuring the automobile as one whole functional entity. The contacts are forming the connecting tissue (the contact network) in the automobile realising energetic, material and informational connections in the automobile. Its complexity originates not so much from the large number of elements, but rather by the variety and metamorphosis of the contacts as separate functional bodies. The contact phenomena such as friction, wearing off, conductivity, lubrication, etc. are the sources and the mechanisms of all the arising problems in the automobile and in the environment – economical, technical, ecological and social. The complexity of the problems arises from their contacting character, in whose bases are the tribological phenomena and processes.

The friction is the main mechanism of the energetical contamination and it is expressed in intensive scattering of energy in the form of heat, noise and vibrations. In its contemporary interpretation the friction is a complex of structures, properties and processes in the contacting conjunctions, associated with the transformation of the external mechanical energy into internal energy of the bodies (thermal energy). All known kinds of friction are appearing in the automobile – dry friction, boundary, mixed and hydrodynamic friction, which do not exist in a pure form. The contact processes in the case of friction – physical, mechanical, chemical, electrical, etc. are occurring through a variety of factors acting as a combination: temperature, pressure, velocity, presence of lubricants, aggressive gasses, solid particles, water and water vapour and others. Due to the mechanisms of friction in the contacting conjunctions of the automobile a minimum of about 30% of the nominal consumed energy is being lost irreversibly in the automobile, while in the case of cargo automobiles/trucks under some unfavourable conditions the losses can become as high as 50%.

The wearing off is always accompanying the friction. All types of wearing off processes appear in the automobile – mechanical, abrasive, hydroabrasion, electric-erosion, fretting corrosion and others. Most often they occur in combination with the course of time and in the space, whereupon one type or another can be dominating, depending on the operational conditions of the contacts. The wearing off is a universal process and the mechanism of degradation, which in the process of exploitation deteriorates the technical state of the automobiles determining their resource. The complex functional parameters of the automobile, such as power and fuel expense, are changing in negative direction basically due to the wearing off in the contacts of piston-cylinder group and the gas-distribution mechanism. The wearing degree of the cogged gear transmission, the bearings and the other contacts of the transmission decrease the coefficient of efficiency, increase the loss of power and the fuel expense. As a result of the wearing off process in the engine the fuel expense can be increased by 5–15% (Refs 1 and 6).

The contemporary lubricating oils, used in the automobiles, contain toxic elements in the form of multifunctional additives, which are polluting the environment during the decomposition of the oils. The products of the automobile cosmetics are especially dangerous for water and the water pools. It has been established that 1 l of oil is able to poison hundreds of cubic meters of underground waters.

BASIC FUNCTIONS OF AUTOMOTIVE FILTERS AS TRIBOSYSTEMS

The automotive filters – air filters, fuel and oil filters are elements of the main systems of the automobile: air-fuel feeding system and lubricating system, and they have fundamental importance for their normal functioning. Their tribological aspects are expressed by their role as filters being the contact elements in the configuration of the automobile on a macro-level, i.e. the automobile taken as one whole entity interacting with the environment. The automotive filter represents a unique tribosystem. The functional triple unity of the filters as tribosystems is formed by the three main functions: two alternative functions – active (uniting) and defensive (separating) and a third one – the realising (compromise) function, which is the contact between the first two[8,9,14,15].

The first – active (*uniting*) *function* is expressed in the capability of the filters to transfer the necessary quantity of air, fuel and lubricant for the normal proceeding of the respective processes of combustion, friction and lubrication[10–13]. The integrated parameter of the active function of the filters is the complex index conductivity (transmittance), which characterises the interaction of the carrier medium (air, fuel, lubricant) with the filtering element, underlying its transmittance properties. The transmittance is measured by the mass flow rate m of the carrier medium, pertaining per unit of ressure drop ΔP between the inlet and the outlet of the filter:

$$G = m/\Delta P \tag{1}$$

The transmittance G, related per unit of working surface area S of the filter, is called specific transmittance ρ, or

$$\rho = G/S \tag{2}$$

The second one – protective function of the automotive filters has its purpose to protect the engine and the contacting conjunctions in the automobile from environmental components harmful for their functioning and from their own contaminating products – oxidation of the lubricating oil, heat evolved and wear. The air medium, the fuel and the oil media, passing through the filters, represent multiphase dispersed systems having different quantities of particles of different nature – liquid, solid, gaseous, organic, inorganic, metal oxides, water, lubricant oxidation products, products from the wearing off process and others. The integrated parameter of the protective function of the filters is the complex index effectiveness E, which characterises the interaction of the dispersed phase in the medium with the filtering element, underlying its retention ability. The effectiveness represents the ratio between the mass of dispersed particles n, 'trapped' by the filter and the total mass of the particles n_0, entering the filter:

$$E = n/n_0 \tag{3}$$

The effectiveness E, related to unit of working surface area (actual area) of the filtering element, is defined as specific effectiveness e, or

$$e = E/S \tag{4}$$

The functional parameters transmittance and effectiveness have been set by the companies-manufacturers of automotive filters, taking into account the technical and the constructional peculiarities of the different engines and automobiles. In the process of exploitation the filters are changing their functional parameters. The character of these changes is determined by the kinetics, structure and properties of the contacting powder layer, which is being formed all over the active working surface of the filtering element as a result of a complex of contact processes – adhesion, cohesion, friction, diffusion, adsorption, etc.

During the exploitation of the filters two contradicting tendencies are observed in the course of changing the functional indices of the filters: the transmittance is decreasing with the time, while their effectiveness is growing up. The optimum contact between the two alternative changes is realised by means of the *third function* of the filters, which is called *compromising* or *realising function*. The basic parameter of the compromising function is the index resource R of the filter. The resource R is such a state of the filter, in which the range of changes in the transmittance G and in the effectiveness E are guaranteeing its operational capacity as a functional element. Outside this range the filter is non-functional, i.e. it does not fulfil its basic functions, i.e. it is contaminated[10–13].

For the resource R of the filter one can write a system of the following two inequalities:

$$R\begin{cases} G_{\min} < G < G_{\max} \\ E_{\min} < E < E_{\max} \end{cases} \tag{5}$$

The ecological aspects of the automotive filters consist mainly in the significance of their functional parameters with respect to the quality and quantity of the automotive emissions discharged into the environment. The transmittance and the effectiveness are influencing the basic mechanisms of pollution – combustion, friction, wear, lubrication.

The transmittance of the fuel and air filters determines to a considerable extent the character of the combustion process in the engine. The decrease in the transmittance of the air filter leads to lower air flow rate, pressure drop in the combustion chamber, enrichment of the combustion mixture in fuel and therefore incomplete combustion. The latter fact in the gasoline engine enhances the emission of nitrogen oxides, carbon monoxide, heat, etc. In the diesel engines it is the reason for higher content of hydrocarbons and soot. The influence of the transmittance of the air and fuel filters on the combustion process is expressed directly by the two parameters α and λ. The parameter α represents the ratio between the actually incoming quantity of air and the theoretically needed quantity, while the second parameter λ is the ratio between the components of the combustion mixture: fuel-air. The reduced transmittance in case of contaminated air and fuel filters leads to 10–15% increases the expense of fuel, respectively increased quantity of toxic substances in the exhaust gases. The transmittance of the oil filters determines the state and the functionality of the lubricatinf system, and more specifically it concerns the processes in the lubricated contacting conjunctions. The lowering of the transmittance in case of contaminated oil filter, the pressure drop in the lubricating system, the deficiency of lubricant inside the contacts are the reasons for the transitional and boundary regimes of friction, which are accompanied by intensive evolution of heat, accelerated oxidation of the lubricating oil, intensive wearing off process, increased expenditure of fuel and oil, and enhanced autoemissions – gaseous, heat, acoustic emissions into the environment.

The effectiveness of the automotive filters is a decisive factor for the technical state of the automobile. On the basis of studies over the years and data from the practice, it has been established that more than 50% of the wearing degree in the engines are due to the abrasive wear, caused by solid particles and water as a result of poor filtering.

To summarise in brief: the transmittance and the effectiveness of the automotive filters exert influence both on the character of mixture formation and on the combustion process, as well as on the tribological processes – friction, wearing degree, lubrication, which are the main mechanisms of contamination. The contamination of the automotive filters results in poor combustion, intensive friction, wearing degree, deteriorated lubrication and hermeticity, which in their turn give rise to intensive heat, acoustic, gaseous, liquid and solid emissions, discharged into the environment.

In the world practice the companies-producers of filters do not engage themselves with any specific values concerning their exploitation resource. Some tentative values are reported as kilometers of runnning way. Expressed in the terms of tribology, it is so, because the resource of the filters is determined by the character of the contact interactions between the automobile, its eements and the environment, which are varying, dynamic and in many cases unpredictable (Fig. 1).

Fig. 1. Photographs of contaminated and renovated air filter

The commonly adopted practice in the world is that after exhausting the resource of the automotive filters these should be replaced by new ones, i.e. they pass over to the category of 'waste materials'. In Bulgaria – Technical University – Sofia there is a certain experience to renovate the polluted air filters by replacing the filtering element with a new one by dismantling and assembling again the filter. The paper filtering element is imported mainly from the countries of Western Europe and Turkey at high prices. Because of the absence of developed methodologies and devices the parameters of the renovated filter are not controlled.

Specific feature of the contemporary exploitation of automotive features is their single time utilisation (Fig. 2).

Fig. 2. Microstructure of the filtering matrix of contaminated and renovated air filter

The applied two approaches have poor ecological-economical indices, bearing the shadow of the consumers spirit of the industrialised society. The solving of the ecological problems in the industrial society requires a new approach, new style and way of thinking for creating an ecologically sound and efficient economy. From the viewpoint of the paradigm of tribology applying the contact approach, the outcome is to revise the values of the substantial (physical) space, due to depletion of the limited natural resources and the pollution. The raising of the values of the functional space in the world as a whole and its elements enables the option to use less energy, raw materials and wastes. In support of the above statement we can cite the report of the world-wide renowned experts of the Institute WorldWatch for the progress towards stable society: 'Economy based on traditional materials is to a great extent inefficient in all aspects' and 'the longer the lifetime of a product, the rarer will be the start of the cycle of its manufacturing and exploitation'. The preprocessing and multiple reutilisation of materials and articles is leading, on one side, to avoidance of the entire cycle starting from the creation of the product, i.e. economising materials, energy and less pollution, while on the other side – opening new jobs and positions and reducing its price.

In a specific case, if we follow all the stages in the lifetime of a filter since its manufacture, exploitation, until reaching a stage of waste product, we shall notice that in addition to yielding raw materials, whereupon large forest areas are being devastated, the production of filtering elements is connected with pollution of the environment with poisonous chemical compounds, including dioxine and respectively involving large expenses for ecological protection. After fulfilling its function the filters as waste materials are posing a great problem.

TRIBOTECHNOLOGY FOR PROMOTING THE RESOURCE OF AUTOMOTIVE AIR FILTERS

The Centre of Tribology at the Technical University – Sofia is developing a new functional approach (contact approach) towards the problem how to increase the resource of automotive filters. Its essence consists in multiple reutilisation of the filters by restoring the filtering element without dismounting the filter, whereupon the contact powder layer, formed in the process of exploitation of the filter, is destroyed. The topic ‘renovation and control of automotive filters’ became the object of systematic investigation in the Centre of Tribology in 1987 on the occasion of public order, referring to air filters of the greatest transport enterprise in Bulgaria SO MAT, which during this period was exploting about 5000 cargo trucks RENAULT, MERCEDESS, FIAT, VOLVO, MAN (Refs 16–19).

The main scientific-technological achievements of the Centre of Tribology in the field of identification and renovation without dismounting the automotive air filters in brief are the following:

– Stationary and non-stationary methods have been elaborated for the identification and control of air filters in regard to the indices transmittance and effectiveness, registered as inventions.

– Devices for identification and control of the state and resource of new and renovated air filters have been developed and manufactured and tested both in the laboratory and under real exploitation conditions considering the indices transmittance and effectiveness.

– A statistical methodology has been elaborated for evaluating the resource of air filters for cargo trucks.

– Ecological tribotechnologies and devices for renovating air filters have been elaborated and introduced in the practice, registered as a patent. The tribotechnologies are introduced in Bulgaria and also tested under the exploitational conditions in the mining industry in the Republic of Kazahstan, in the corporation ‘Kazahmys’ in the town of Zhezkazkan.

In its essence the regeneration is a process of destruction and changing the characteristics of the surface powder layer of the filtering element.

The tribological means for its destruction are complex: cavitation, vibration, ultrasound effects and processes, phenomena, caused by the action of streams and superficially-active substances and others (Figs 3 and 4). The principle of recycling includes a system of actions applying mechanical, physical and chemical agents, through which the parasitic contamination coating is being destroyed, and at the same time preserving the integrity and the qualities of the filtering matrix during the parallel realisation of the inlet and outlet control of the filter.

Fig. 3. Chamber for preliminary air-vibration regeneration of filters

Fig. 4. Chamber and cassette for fine regeneration of air filters

The technological process of regeneration of the filters comprises the following stages:

1. Control of the state and degree of contamination of the filter: the presence of rough mechanical damages by illuminating with rays of light; determining the air transmittance by the method of pneumatic extremum (using rotameter); measuring the degree of radioactivity of the filter; measuring the weight (the mass) of the filter.

2. Preliminary regeneration: rough renovation of the filter under vibration impact and impulse air purging, whereupon there occurs destruction of cohesion

bondings in the contact layer. During this stage about 50–60% degree of renovation of the air transmittance of the filter is achieved.

3. The basic (fine) regeneration, which is unique (patented) regeneration of the filter is realised in a special bath where the actions are occurring following a definite algorithm in aqueous solution using appropriate superficially active reagents (surfactants) at definite temperature of the multiphase operational medium; the processing of the active surfaces of the filter applying a system of biphase streams and high-frequency vibration.

4. Washing the filter by means of washing machine at high pressure.

5. Centrifuging, whereupon the main fraction of the water in the filter is being separated.

6. Drying of the air filters applying a definite temperature regime and specific time interval using a system of air stream-impact impulses.

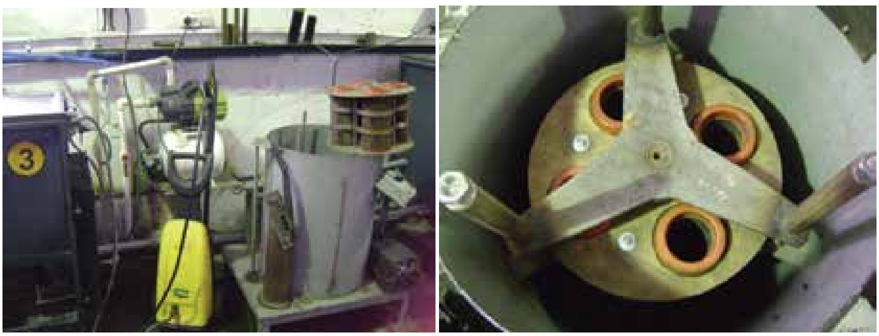

Fig. 5. System for centrifuging of filters

7. Control of the state and degree of renovation of the filter: measuring the air transmittance of the regenerated filter by the method of pneumatic extremum (using rotameter); measurement of the weight and control of the state of the filtering paper under microscope.

8. Marking, stamping and labelling of of the packing and storage in warehouse, from where the filter is directed to the consumers.

CONCLUSIONS

The use of renovated air filters under exploitation conditions of the mining corporation 'Kazahmyh' enables avoiding damages of propeller couples in the compressors. The practice shows that the working resource of the air filters in underground operation is 10–15 days, while after regeneration their resource is increased 2–3 times. The tests carried out with the regenerated air filters in the city buses in the town of Saptaevo gave also positive results – increasing the resource of the filters up to 3 times.

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