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Možnosti regeneracije filtra trdnih delcev v izpuhu dizelskega motorja

Some Possibilities for the Regeneration of Diesel Exhaust Particle Filters

JOSIP ZAVADA - IVAN MAVRIN - ERNEST BAZIJANAC

V članku so obravnavane možnosti regeneracije filtra trdnih delcev v izpuhu dizelskega motorja kakor tudi spremljajoči problemi.

Filter trdnih delcev v izpušnih plinih se vse več uporablja predvsem zaradi znižanja dovoljene emisije v vozilih z dizelskim motorjem, kar je posebej očitno pri tovornjakih in avtobusih. Trdni delci, nakopičeni v filtru, povečujejo tlak izpušnih plinov in negativno vplivajo na delovanje motorja. Regeneracijo najlaže izvedemo s sežiganjem nakopičenih trdnih delcev.

Temperatura izpušnih plinov dizelskih motorjev na omenjenih vozilih ni dovolj visoka, da bi se trdni delci vžgali. Zato je treba temperaturo dvigniti nad potrebno temperaturo za vžig trdnih delcev (550 °C). Da bi to učinkovito dosegli, uporabimo spremembe zunaj motorja, ali pa kombinacije sprememb v motorju in zunaj njega.

V članku so obravnavane predvsem spremembe zunaj motorja, to so gretje filtra z gorilnikom, električnim grelnikom in mikrovalovno energijo, uporaba dodatkov v gorivu in uporaba katalizatorja.

(Ključne besede: motorji dieselski, filtri trdnih delcev, regeneriranje filtrov, energija mikrovalovna)

The paper studies the regeneration possibilities of Diesel exhaust particle filters, as well as the resulting problems.

The application of exhaust particle filters is increasingly required, because of the severe limitations imposed on the exhaust emissions of Diesel engine vehicles, particularly on trucks and buses. The particles trapped in filters increase the backpressure in the exhaust gases and reduce the engine performance. The most suitable method for performing regeneration is to burn the combustible particles trapped in the filter.

The temperature of the Diesel engine exhaust gases in the mentioned vehicles is not high enough to ignite the particles. In order to reach the temperatures higher than 550°C, certain measures have to be undertaken. There are efficient measures outside the engine or their combination with measures within the engine.

The paper deals especially with measures undertaken outside the engine, such as heating the filter using a burner, electric heater or microwave energy, use of fuel additives or application of a catalyst.

(Keywords: Diesel motors, exhaust particle filters, regenerations of filters, microwave energy)

0 UVOD

Emisija škodljivih snovi pri motornih vozilih je v vseh deželah vprašljiva zaradi onesnaževanja okolja. Izpušni plini dizelskih motorjev vsebujejo okolju škodljive komponente NO_x, CO, HC in trdne delce. Pri tem je, zaradi vse strožjih zakonskih omejitev, posebej pomemben problem dušikovih oksidov in trdnih delcev. Z uporabo filtrov pa lahko učinkovito zmanjšamo emisijo trdnih delcev. Filtri se razlikujejo po vrsti materiala in po konstrukciji. Uporabljena materiala sta najpogosteje jeklo in keramika, konstrukcije pa so lahko izvedene s poroznimi stenami, s penastimi stenami, z nitmi, pletene, sintetizirane in elektrostatične. Med uporabo se v filtrih odlagajo trdni delci, kar povečuje pretočni upor oziroma tlak. Ker to negativno vpliva na delovanje motorja, je treba filter redno obnavljati, se pravi čistiti toliko pogosto, kolikor je potrebno. Zaradi visoke cene in večjih zahtev pri vzdrževanju vozila periodična zamenjava filtra ni primerna.

0 INTRODUCTION

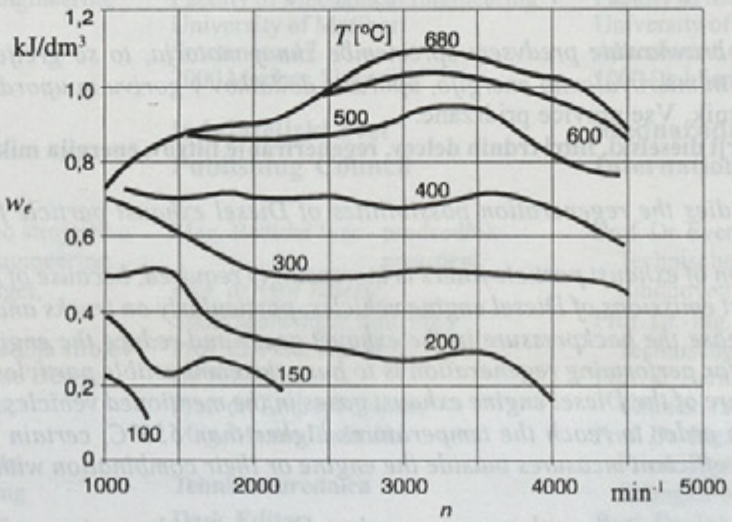
The emission of harmful components in motor vehicles presents a significant problem in all countries because of environmental pollution. Diesel engine exhaust emissions contain harmful NO_x, CO, HC components and particles. The problem is how to reduce nitrogen oxides and particles, because legislation is increasingly severe in their limitation. The emission of exhaust particles is efficiently reduced by the use of filters. Filters vary according to the material and design. The most common materials are ceramics and steel, and designs include porous wall, foam wall, and fibres - plaited, synthetized and electrostatic. During service, particles start to deposit in the filters, which causes a greater resistance to the flow of exhaust gases, i.e. it increases the backpressure. Since this has an adverse effect on the engine performance, the filter needs to be regenerated in a controlled manner, i.e. cleaned as often as necessary. Regular filter replacement is not acceptable because of the high costs and increased requirements of vehicle maintenance.

1 POGOJI IN UKREPI, POTREBNI ZA OBNOVO FILTRA

Za obnovo filtra z zažiganjem gorljivih trdnih delcev, oziroma saj, je treba zagotoviti temperaturo nad 550 °C. Izpušni plini dizelskih motorjev težko dosegajo tako visoke temperature, ker je njihova temperatura v večjem delu delovnega režima pod to mejo. Primer odvisnosti temperature izpušnih plinov od delovnega režima dizelskega motorja z vrtinčno komoro in predkompresijo je prikazan na sliki 1 [1]. Temperatura izpušnih plinov dosega potrebno vrednost za vžig saj samo pri polni obremenitvi in višjih vrtilnih frekvencah motorja.

1 CONDITIONS AND MEASURES FOR FILTER REGENERATION

For the filter regeneration by burning combustible particles, i.e. soot, a temperature higher than 550 °C has to be provided. It is difficult to reach such a high temperature using Diesel engine exhaust - gas, since the exhaust gases temperatures tend to be lower during most of the working regime. An example showing the dependence of exhaust gases temperature on the working regime of a Diesel engine with a swirl chamber and turbocharging is given in Figure 1 [1]. It is clear that only with full load, and at higher engine speeds, the exhaust gases temperature will reach the degree necessary for soot combustion.



Sl. 1. *Odvisnost temperature izpušnih plinov od obremenitve in hitrosti vrtenja dizelskega motorja*
Fig. 1. *Dependence of exhaust gases temperature on load and Diesel engine speed*

Ker je potem, ko se v filtru nabere določena količina trdnih delcev, potrebna obnova, dizelski motorji pa le redko delujejo pod polno obremenitvijo, moramo obvezno z dodatnimi ukrepi zagotoviti čiščenje filtra.

Ukrepi za obnovo filtra so:
- ukrepi v motorju,
- ukrepi zunaj motorja.

1.1 Ukrepi v motorju za obnovo filtra

Ukrepi v motorju, ki lahko povzročijo povečanje temperature izpušnih plinov, so:
- vračanje izpušnih plinov v sesalni sklop,
- dušenje na sesalnem sklopu,
- predgrevanje zraka na sesalnem sklopu.

Vsi ti ukrepi posamično in njihove kombinacije povečujejo temperaturo izpušnih plinov, vendar pri nobeni kombinaciji to povečanje ne dosega temperature 550 °C, ki bi povzročila vžig nakopičenih gorljivih trdnih delcev. Zato ti ukrepi ne zadoščajo za obnovo filtra.

Since regeneration has to be carried out after a certain amount of particles have been deposited - and Diesel engines in vehicles seldom work fully loaded - it is necessary to provide regeneration through additional measures.

The filter regeneration measures are:
- measures undertaken in the engine, and
- measures undertaken outside the engine.

1.1 Filter regeneration measures within the engine

Measures undertaken within the engine that can cause an increase in exhaust gases temperature involve the following:
- return of exhaust gases back into the intake system,
- damping in the intake system, and
- pre-heating of intake air.

Each of these measures and their combinations increase the temperature of exhaust gases but none of them increases the temperature to the necessary degree (above 550 °C) that would ignite the trapped combustible particles. Therefore, these measures alone do not suffice for the filter regeneration.

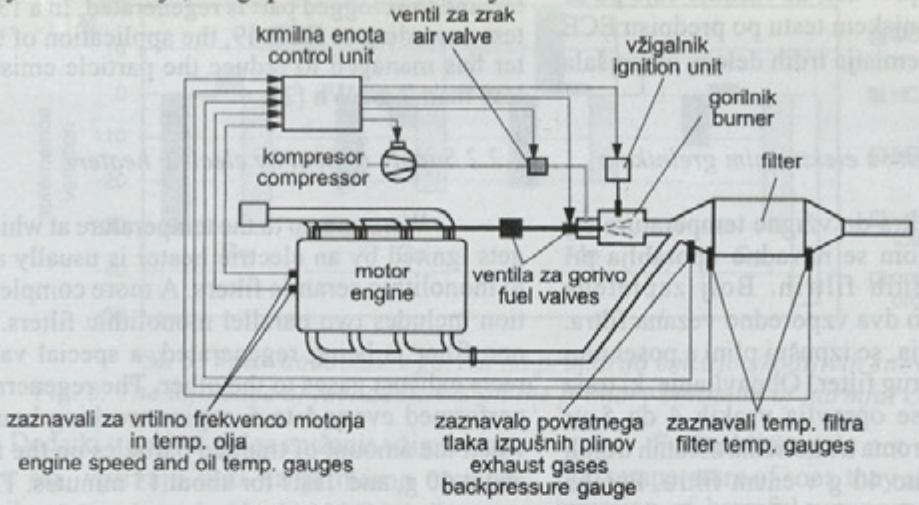
1.2 Ukrepi zunaj motorja za obnovo filtra

Ukrepi zunaj motorja, ki omogočajo regeneracijo filtra, so:
- dovod toplote z gorilnikom,
- dovod toplote z električnim grelnikom,
- uporaba dodatkov gorivu,
- uporaba katalizatorja in
- uporaba mikrovalovne energije.

1.2.1 Dovod toplote z gorilnikom

Povečanje temperature filtra trdnih delcev na vžigno temperaturo saj z uporabo posebnega gorilnika je obetavna rešitev, ki jo preskušajo v različnih konstrukcijskih izvedbah. Preskusi se izvajajo večinoma na tovornih vozilih in avtobusih, ker izločajo večje količine trdnih delcev in imajo na voljo več vgradnega prostora. Pri tem se uporabljajo pretežno filtri iz monolitne keramike, z navitji keramičnih vlaken in iz sintetičnega materiala.

Običajno se izvedba z enim filtrom obnavlja, ko vozilo ni v uporabi, izvedba z dvema filtroma pa med uporabo vozila. Izvedba z dvema filtroma omogoča, da se pri delujočem motorju en filter uporablja za filtriranje, drugi pa se hkrati obnavlja.



Sl. 2. *Shema naprave za obnovo filtra z gorilnikom*
Fig. 2. *Scheme of a filter regeneration device with a burner*

Na sliki 2 je prikazana izvedba naprave za obnovo podjetja KHD. Enodelni filter iz drobno porozne keramike se obnavlja med delovanejm motorja, ko njegova temperatura z uporabo gorilnika doseže temperaturo 600 °C. Gorilnik porabi 0,5 l dizelskega goriva na deset ur delovanja motorja in ni občutljiv za protitlak izpušnih plinov med obnovo. Zrak za delovanje gorilnika zagotavlja posebna kompresorska naprava. Celotno napravo krmili elektronska enota na podlagi podatkov o temperaturi filtra, protitlaka izpušnih plinov in režima delovanja motorja. Ta naprava učinkovito obnavlja filter, neodvisno od režima delovanja motorja.

1.2 Filter regeneration measures outside the engine

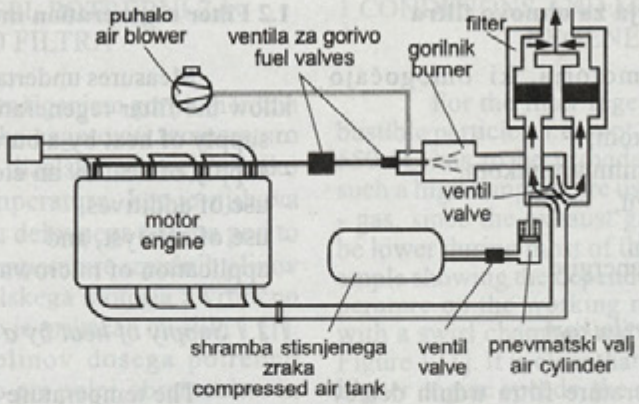
Measures undertaken outside the engine that allow the filter regeneration include:
- supply of heat by a burner,
- supply of heat by an electric heater,
- use of additives,
- use of catalyst, and
- application of microwave energy.

1.2.1 Supply of heat by a burner

The temperature increase in the particle filter up to the degree needed to ignite the trapped soot using a special burner is a promising solution, tested in various designs. The testing is carried out primarily on trucks and buses, which emit greater amounts of particles, as well as because of the necessary space for fitting in the device. These are mainly filters made of monolithic ceramics, wind up ceramic knitting and synthetized material.

The one-filter design is often meant for operation when the vehicle is not used, and the two-filter design during exploitation. Two filters allow one of the filters to carry out the filtering, with the engine running, while the other is being regenerated, and vice versa.

An example of a one - filter regeneration device designed by KHD is shown in Figure 2. The regeneration of a single part filter made of fine porous monolithic ceramics is carried out while the engine is running, when the filter temperature reaches 600°C due to a burner. The burner uses 0.5 l of diesel fuel every ten engine operating hours and is insensitive to exhaust gases backpressure during regeneration. The burner operates with air supplied by a special compressor. The device is controlled by an electronic unit using the data on filter temperature, exhaust gases backpressure, and engine operating regime. The device regenerates the filter efficiently, regardless of the engine operating regime.



Sl. 3. *Shema filtra dupleks za obnovo z gorilnikom*
Fig. 3. *Scheme of the Duplex-filter for the regeneration with a burner*

Slika 3 prikazuje shemo filtra duplex, ki ga je razvilo podjetje MAN. Filter je iz monolitne keramike. Naprava je popolnoma avtomatizirana in deluje med delovanjem motorja. S pnevmatsko napravo se krmili ventil, ki usmerja izpušne pline iz motorja v del filtra za filtriranje, vroče pline iz gorilnika pa v del filtra za obnovo. Gorilnik se vključuje samo med obnovo filtra. Ko se v drugem delu naberejo saje, ventil preusmeri izpušne pline v obnovljeni del filtra, prvi del, ki vsebuje saje pa se obnavlja. Po 13-stopenjskem testu po predpisu ECE 49 se je pri tem filtru emisija trdih delcev zmanjšala pod 7g/kWh [2].

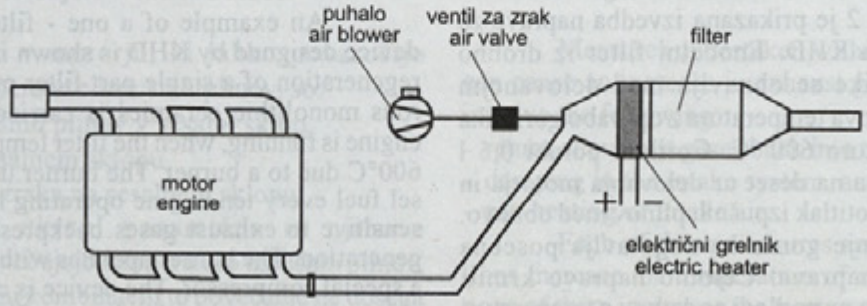
The principle scheme of the so-called Duplex-filter, developed by MAN is shown in Figure 3. The filter is made of monolithic ceramics. The device is fully automated and operates while the engine is running. The pneumatic device is controlled by a valve directing the exhaust gases from the engine to the part of the filter for filtering, and the hot gases from the burner to the part of the filter for regeneration. The burner is switched on only during the filter regeneration. When the other part, the valve redirects the gases to the regenerated part of the filter, and the clogged part is regenerated. In a 13-phase test according to ECE 49, the application of this filter has managed to reduce the particle emission to less than 7 g/kWh [2].

1.2.2 Dovajanje toplote z električnim grelnikom

Segrevanje filtra do vžigne temperature saj z električnim grelnikom se navadno uporablja pri monolitnih keramičnih filtrih. Bolj zapletene konstrukcije vsebujejo dva vzporedno vezana filtra. Ko se en filter obnavlja, se izpušni plini s posebnim ventilom usmerijo v drug filter. Obnavljanje, ki traja približno 15 minut, se opravlja vsakih 4 do 5 ur delovanja motorja, oziroma ko količina zbranih trdnih delcev doseže približno 40 g v enem filtru. Poraba goriva se pri tem poveča za 1 do 2 odstotka.

1.2.2 Supply of heat by electric heater

Warming up to the temperature at which soot gets ignited by an electric heater is usually applied to monolithic ceramic filters. A more complex solution includes two parallel monolithic filters. While one filter is being regenerated, a special valve directs exhaust gases to the other. The regeneration is performed every 4 to 5 engine working hours, i.e. when the amount of trapped particles on the filter is about 40 g, and lasts for about 15 minutes. The fuel consumption increases by about 1 to 2 %.



Sl. 4. *Shema filtra za obnavljanje z električnim grelnikom*
Fig. 4. *A scheme of a regeneration filter with an electric heater*

Na sliki 4 je prikazana načelna shema naprave (Volvo) za izločanje trdnih delcev iz izpušnih plinov z vgrajenim električnim grelnikom. Filter uporablja monolitno keramično telo. Po vsakih 300 km vožnje je treba obnoviti filter. Zato se vključi električni grelnik pred filtrom in poseben dovod svežega zraka, potrebnega za gorenje zbranih gorljivih delcev. Emisija škodljivih elementov pri obnavljanju je približno enaka emisiji pri nekaj sekund trajajočem delovanju motorja v prostem teku. Filter zmanjša emisijo trdih delcev za najmanj 80, emisijo HC za približno 60, emisijo CO pa za približno 50 odstotkov [2].

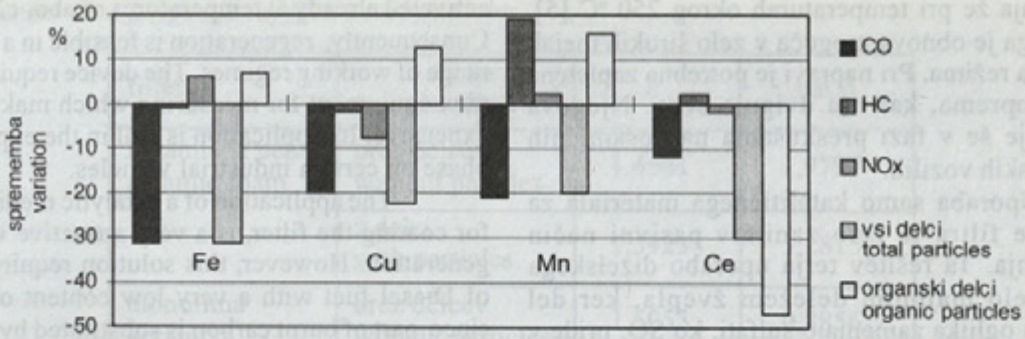
1.2.3 Uporaba dodatkov

Uporaba dodatkov omogoča znižanje vžigne temperature trdnih delcev za približno 150 do 200 °C [3]. Dodatki so najpogosteje snovi na temelju bakra, železa, mangana in v zadnjem času cera. Dodajajo se gorivu ali pa neposredno pred filter. Pomanjkljivost tega načina je izločanje kovinske komponente v okolico. Ker še ni podatkov o delovanju te snovi na okolje, so te naprave še v fazi preskušanja.

A principle scheme of a device for filtering exhaust gases particles with a built-in electric heater, designed by Volvo is shown in Figure 4. The filter is made of monolithic ceramics. After about every 300 clocked-up kilometers the filter needs to be regenerated. In order to do this, an electric heater fitted before the filter is switched on, with the necessary supply of air for combustion of the trapped combustible particles. The resulting emission of harmful components during the regeneration is comparable to the emission of the engine idling for only a couple of seconds. The filter reduces the emission of particles by at least 80%, the emission of HC by about 60% and CO by about 50% [2].

1.2.3 Use of additives

The use of additives reduces the ignition temperature of particles by about 150 to 200 °C [3]. Additives are most often on the basis of copper, iron, manganese and more recently cerium, and they are added to the fuel or supplied directly before the filter. The deficiency of this solution is that it results in polluting the environment by the metals from the additives. Since there are still no results regarding the effects that these elements have on the environment, this device is still in its experimental phase.



Sl. 5. *Vpliv dodatkov v gorivu na primarno emisijo škodljivih snovi*
Fig. 5. *The influence of fuel additives on the primary emission of harmful components*

Dodatki v gorivu, poleg znižanja vžigne temperature saj, vplivajo tudi na primarno emisijo škodljivih snovi iz motorja. Na sliki 5 [4] je prikazano relativno razmerje, v katerem posamični dodatki vplivajo na primarno emisijo škodljivih snovi. Opazimo lahko, da ima cer največji vpliv na znižanje emisije vseh škodljivih snovi in posebej organskih delcev, poleg tega pa je cer malo strupen material z veliko inertnostjo.

Z uporabo cera kot dodatka gorivu se zniža vžigna temperatura saj v filtru na približno 400 °C. Torej mora temperatura izpušnih plinov občasno doseči 400 °C ali več, če želimo, da se obnavljanje odvija samodejno (pasivno), brez dodatnih ukrepov. Zaradi tega je potrebno pri tem načinu obnavljanja poznati režime delovanja motorja na določenem vozilu.

Fuel additives do not only reduce the ignition temperature of soot, they also affect the primary emission of harmful components from the engine. The influence of certain additives in the fuel on the primary emission of some harmful components is shown comparatively in Figure 5 [4], which clearly shows that the emission of total and organic particles is best reduced by cerium. At the same time cerium is only slightly toxic and highly inert.

With the use of cerium as a fuel additive, the ignition temperature of soot in the filter is reduced to about 400°C. For the regeneration to be carried out automatically without any special measures - i.e. so that the system is completely passive - the exhaust gases temperature should from time to time reach 400°C or more. Therefore, in order to apply this regeneration method, it is necessary to know the engine operating regimes for a particular vehicle.

Nekatera vozila, npr. mestni avtobus večinoma delujejo pri tako majhnih obremenitvah, da izpušni plini skoraj nikoli ne dosegajo temperature 400 °C. Potrebno povečanje bi lahko dosegli z uporabo kake aktivne naprave, npr.: gorilnik ali električni grelnik. To pa bi konstrukcijo zapletlo in podražilo in ji znižalo zanesljivost. Preprostejši način za doseganje ustrezne temperature bi bil v tem primeru uporaba ukrepov v motorju, kakor je bilo že omenjeno.

Ukrepi v motorju za povečanje temperature izpušnih plinov znižujejo izkoristek motorja, oziroma povečujejo porabo goriva. Ker pa obnavljanje filtra traja le kratek čas, je to povečanje minimalno. Vpliv je še manjši, če upoštevamo, da cer, kot aktivna sestavina pri procesu zgorevanja, vpliva na zmanjšanje porabe goriva in na zmanjšanje emisije saj in drugih trdnih delcev.

1.2.4 Uporaba katalizatorja

Uporaba katalizatorja pomeni, da je filter obložen s katalitičnim materialom (z bakrenim oksidom ali z vanadijem). Z dodatkom sredstva za aktiviranje katalize tik pred filter se začne proces obnavljanja že pri temperaturah okrog 250 °C [5]. Zaradi tega je obnova mogoča v zelo širokih mejah delovnega režima. Pri napravi je potrebna zapletena merilna oprema, kar mu dviguje ceno. Njegova uporaba je še v fazi preskušanja na posamičnih gospodarskih vozilih.

Uporaba samo katalitičnega materiala za oblaganje filtra je zelo zanimiv pasivni način obnavljanja. Ta rešitev terja uporabo dizelskega goriva zelo majhnim deležem žvepla, ker del zgorelega ogljika zamenjajo sulfati, ko SO_2 pride v stik s katalitičnim materialom v navzočnosti kisika. Ker v široki uporabi še ni dizelskih goriv s tako majhnim deležem žvepla, se ta rešitev še ni širše uveljavila.

1.2.5 Uporaba mikrovalovne energije

Uporaba mikrovalovne energije je novejša metoda obnavljanja filtra trdnih delcev. Ta metoda je zelo učinkovita, energetsko skromna, ne potrebuje zelo drage opreme in je primerna za uporabo, zaradi tega ima možnosti, da odpravi napake, ki izhajajo iz prej opisanih metod.

Gretje z mikrovalovno energijo je drugačno kakor običajno gretje s prehodom toplote ali toplotnim sevanjem. Mikrovalovna energija se spreminja v toploto v samem telesu, zato je učinkovitost pretvorbe znatno večja. Absorbirana mikrovalovna moč P ogrevanega telesa v mikrovalovnem polju se izračuna po obrazcu:

Some vehicles, e.g. city buses, operate mostly under such small loads that they almost never reach the exhaust gases temperature of 400°C. The necessary temperature increase could be achieved by application of some active system, such as a burner or an electric heater. This, however, makes the design more complex, more expensive and less reliable. A more simple approach for obtaining the necessary temperature of exhaust gases involves the already mentioned measures undertaken within the engine.

The measures within the engine to increase the exhaust gases temperature also reduce the engine efficiency, i.e. increase the fuel consumption. However, the filter regeneration is a very short operation, and the fuel consumption is only slightly increased. The influence is even less when one takes into consideration that cerium affects the reduction in fuel consumption as an active factor in the combustion process, as well as the reduction of soot and all particle emissions.

1.2.4 The use of a catalyst

The use of a catalyst means coating the filter with catalytic material, e.g. copper oxide or vanadium. By adding a catalysis-activating medium directly before the filter, the regeneration process is activated already at temperatures of about 250°C [5]. Consequently, regeneration is feasible in a very wide range of working regimes. The device requires a complex equipment for measuring which makes it more expensive. Its application is still in the experimental phase on certain industrial vehicles.

The application of a catalytic medium alone, for coating the filter, is a very attractive way of regeneration. However, this solution requires the use of Diesel fuel with a very low content of sulphur, since part of burnt carbon is substituted by sulphates when SO_2 comes into contact with the catalytic medium in the presence of oxygen. Since Diesel fuel with such a low content of sulphur is not yet being used, this solution is not widely used.

1.2.5 Application of microwave energy

The application of microwave energy is a new regeneration method for particle filters: it is efficient, saves energy, the equipment is not very expensive and it is suitable for use. This method helps to eliminate the deficiencies resulting from the other methods.

Heating by microwave energy differs from common heating by conducting the heat or heat radiation. Microwave energy converts into heat in the body itself, and therefore the energy conversion efficiency is much greater. The absorbed microwave power P of the heated material in the microwave field is calculated using the following formula:

$$P = \frac{10^{-10}}{1{,}8} \cdot f \cdot E^2 \cdot \varepsilon \cdot \tan\delta \quad \text{W/m}^3 \qquad (1),$$

kjer so: f v Hz - mikrovalovna frekvenca,
E v V/m - jakost električnega polja,
ε - dielektričnost materiala,
tan δ - koeficient izgub v materialu.

with: f in Hz - microwave frequency,
E in V/m - strength of electric field,
ε - dielectric constant of the material,
tan δ - loss coefficient of material.

Ogrevanje telesa, izraženo s spremembo temperature v enoti časa, je:

The heating of the body expressed by the change in temperature per time unit is:

$$\frac{\Delta T}{\Delta t} = \frac{10^{-10} \cdot f \cdot E^2 \cdot \varepsilon \cdot \tan\delta}{1{,}8 \cdot \rho \cdot c_p} \quad \text{°C/s} \qquad (2)$$

kjer pomenita: ρ v kg/m^3 - gostoto materiala,
c_p v J/kg°C - specifično toploto materiala.

with: ρ in kg/m^3 - density of the material,
c_p in J/kg°C - specific heat of the material.

Iz zgornjih enačb je razvidno, da absorbirana energija in dvig temperature nista odvisna le od električnega polja in frekvence, ampak tudi od električnih in fizikalnih lastnosti materiala. Prav to pa omogoča selektivno ogrevanje posamičnih materialov z mikrovalovno energijo, kar se v praksi lahko izkoristi za obnavljanje filtra.

The given equations show that the absorbed energy and the temperature increase do not depend only on the power of the electric field and the frequency, but also on electric and physical properties of the materials. This is precisely what enables the selective heating of certain materials by microwave energy, which can be practically used for regenerating the filters.

Preglednica 1. *Mikrovalovne lastnosti filtra in trdnih delcev*
Table 1. *Microwave properties of filters and particles*

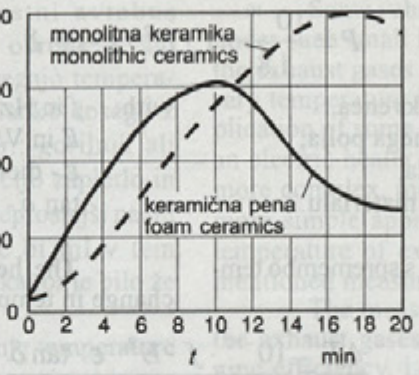
filter	stanje condition	ε	tan δ
keramična pena ceramic foam	brez delcev without partcles	1,4661	1,9797
	z delci with particles	1,5923	5,2815
monolitna keramika monolithic ceramic	brez delcev without particles	1,5053	0,8856
	z delci with particles	1,5187	5,2890
	samo delci only particles	1,5186	161,2193

Mikrovalovne lastnosti keramičnih filtrov z monolitno in penasto keramiko so prikazane v preglednici 1 [6]. Pri meritvah je bila uporabljena frekvenca 9,37 GHz. Pri trdnih delcih so opazne veliko večje vrednosti dielektrične konstante in izgub v materialu kakor pri keramiki. Zato delci absorbirajo več mikrovalovne energije od keramike. Z uporabo te lastnosti se segrevajo delci z mikrovalovno energijo na temperaturo, višjo od temperature keramičnega filtra. Tako dosežemo gorenje delcev in obnavljanje filtra z manjšo porabo energije.

Z napravo za ustvarjanje mikrovalovnega polja frekvence 2,45 GHz in moči 1 kW povzroči

The microwave properties of ceramic filters in a foam and monolithic design, and of particles themselves are shown in Table 1 [6]. The measuring was done with a frequency at 9.37 GHz. The values of the dielectric constant and loss coefficient are much greater for particles than for the ceramic filter. Therefore, the particles absorb more microwave energy than the ceramics. Using this property, the particles are selectively heated by the microwave energy to a higher temperature than the ceramic filter, thus causing the combustion of particles and the regeneration of the filter, thus consuming less energy.

The filter regeneration performed by using the device for creating a microwave field of 2.45 GHz frequency and of 1 kW power with exhaust gas



Sl. 6. *Sprememba temperature na površini filtra med obnavljanjem*
Fig. 6. *The change of temperature on the surface of the filter during regeneration*

regeneracija, izvedena pri protitlaku izpušnih plinov 20 kPa, spremembo temperature na površini filtra, kakor je prikazano na sliki 6 [6].

Preskusi kažejo, da je prenovo z mikrovalovno energijo mogoče v celoti izpeljati. Paziti je treba le na količino absorbirane energije, ker se lahko zgodi, da se osrednji deli filtra začnejo taliti zaradi previsoke temperature.

Ker je za zgorevanje trdnih delcev treba zagotoviti temperaturo nad 550 °C, keramika pa se začne taliti nad 1500 °C, je treba zagotoviti, da je temperatura filtra med regeneracijo med 600 °C in 1200 °C. Približno tako območje temperatur dobimo s preračunom filtra po delih od sten proti sredini. Za to temperaturno območje je potrebna mikrovalovna moč med 580 W in 600 W. Za eno regeneracijo je potrebno 5 do 10 minut [6]. Največja moč ne sme biti večja od 1000 W.

2 SKLEP

Prenova filtra se izvaja z gorenjem nabranih trdnih delcev. Za vžig delcev je potrebna temperatura nad 550 °C. Ker so režimi delovanja dizelskih motorjev na tovornih vozilih in avtobusih, pri katerih se v prvi vrsti načrtuje uporaba filtrov, takšni, da se ta temperatura večinoma ne dosega, so potrebni dodatni ukrepi. Za učinkovite so se izkazali le ukrepi zunaj motorja, sami, ali pa v kombinaciji z ukrepi v motorju.

Ukrepi zunaj motorja so ogrevanje filtra z gorilnikom, električnim grelnikom ali pa z mikrovalovno energijo, uporaba dodatkov v gorivu in uporaba katalizatorja.

Ogrevanje filtra z gorilnikom je učinkovito sredstvo za prenovo, vendar je potrebna oprema draga, zapletena in zahteva več prostora za vgradnjo. Ta metoda minimalno povečuje porabo goriva (približno 0,5 l dieselskega goriva na vsakih deset ur delovanja motorja).

backpressure of 20 kPa causes a change in temperature on the surface of the filter as shown in Figure 6 [6].

The experiments show that regeneration by microwave energy can be fully performed. However, attention should be paid to the amount of absorbed energy since central parts of the filter might begin to melt due to the exceeding temperature.

Since a temperature of more than 550 °C should be provided for the combustion of particles - and the ceramics begin to melt at temperatures higher than 1500 °C - the filter temperature during regeneration should be maintained between 600 and 1200°C. An approximately likely range of temperatures is obtained by the calculation in parts from the periphery towards the center of the filter. For this temperature, a range microwave power of 580 to 600 W lasting from 5 to 10 minutes per regeneration is required [6]. The power should not exceed 1000 W.

2 CONCLUSION

Filter regeneration is performed by combustion of the trapped particles. In order to ignite the particles, a temperature higher than 550°C has to be provided. Since the Diesel engine operating regimes in trucks and buses - at which the application of filters is primarily aimed - do not allow the exhaust temperatures to reach that value, some additional measures are required. Only the measures undertaken outside the engine, or their combination with the measures within the engine, have proven efficient.

Measures undertaken outside the engine include the heating of the filter by a burner, electric heater or microwave energy, use of fuel additives and application of a catalyst.

Heating the filter with a burner is an efficient means for the realization of the regeneration, but the equipment is complex and expensive and requires more space for fitting-in. It slightly increases the fuel consumption (about 0.5 l of diesel fuel to every ten engine running hours).

Ogrevanje z električnim grelnikom je preprosta rešitev, povzroča pa veliko obremenitev akumulatorja na vozilu. Zaradi intenzivnejšega polnjenja akumulatorja se poraba goriva poveča za en do dva odstotka.

Uporaba dodatkov v gorivu znižuje vžigno temperaturo delcev za 150 do 200 °C. Dodatki so najpogosteje na podlagi bakra, železa, mangana in cera. Pomanjkljivost te metode je izločanje kovin iz dodatkov v okolje. Večina dodatkov tudi zmanjšuje primarno emisijo škodljivih snovi v izpušnih plinih. Cer je pri tem najbolj učinkovit. Če želimo doseči vžigno temperaturo delcev približno 400°C, je primerno to metodo kombinirati z ukrepi v motorju. Za to je potrebna elektronska naprava za krmiljenje motorja. Ukrepi v motorju za povečanje temperature izpušnih plinov povečujejo porabo goriva, vendar je povečanje majhno, ker traja prenova le kratek čas. Če se za dodatek uporablja cer, ki zmanjšuje porabo goriva s pospeševanjem procesa zgorevanja v valju motorja, je povečanje porabe pri prenovi še manjše.

Uporaba katalitičnega materiala za oblaganje filtra je zelo zanimiv pasivni način prenove. Ta rešitev pa zahteva uporabo dizelskega goriva z zelo majhnim deležem žvepla. Ker v široki uporabi še ni dizelskih goriv s tako majhnim deležem žvepla, se ta rešitev še ni širše uveljavila.

Uporaba mikrovalovne energije je učinkovita in preprosta metoda za prenovo filtra. Trdni delci absorbirajo več energije kakor keramični filter. Ta lastnost omogoča selektivno segrevanje delcev na višjo temperaturo kakor filter, za kar je potrebno manj energije za vžig delcev. Male mikrovalovne naprave na vozilih avtomatsko vključuje elektronska naprava, ko je dosežen ustrezni protitlak izpušnih plinov. Za prenovo potrebuje naprava 580 do 600 W moči.

Vsaka od navedenih naprav za prenovo filtrov ima določene prednosti in pomanjkljivosti; izkušnje iz uporabe in razvoja pa bodo privedle do najbolj sprejemljive rešitve.

Heating by an electric heater is a simple solution, but a great load on the vehicle battery. Because of the greater battery charging, the fuel consumption rises by about 1 to 2%.

The use of fuel additives reduces the ignition temperature of the particles by about 150 to 200 °C. Additives are mostly based on copper, iron, manganese and cerium. The deficiency of this solution lies in the pollution of the environment by metals from the additives. Most of the additives also reduce the primary emission of harmful components in exhaust gases. The primary particle emission is best reduced by cerium. To achieve an ignition temperature of gases of about 400°C, this measure should be combined with measures within the engine. Also an electronic device for controlling the engine is needed. Measures undertaken within the engine to increase the temperature of exhaust gases also increase fuel consumption. However, this increase is only slight, due to the short time needed for regeneration. If cerium - which reduces the fuel consumption, is used as an additive because it improves the combustion process in the engine cylinder - then the total fuel consumption is only slightly increased.

The use of a catalytic medium for coating the filter is a very attractive passive way of regeneration. However, such a solution requires the use of very low sulphur content Diesel fuel. Since Diesel fuels with such low level of sulphur are not yet widely used, this solution has not yet achieved wider application.

The application of microwave energy is an efficient and relatively simple solution for filter regeneration. The particles absorb more microwave energy than does ceramic filter. This property allows the trapped particles to be selectively heated to a higher temperature than the filter itself which requires less energy to ignite the particles. A small built-in microwave device on a vehicle is switched on automatically by an electronic device, when certain backpressure values are reached in the exhaust gases. In order to activate the regeneration, the device should emit a power of 580 to 600 W.

Each of the mentioned ways for regenerating the filters has certain advantages and disadvantages, and experience from exploitation and development will point to the most suitable solution.

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