Ivan Filipović, Boran Pikula, Dževad Bibić, Mirsad Trobradović

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PRIMJENA ALTERNATIVNIH GORIVA U CILJU SMANJENJA EMISIJE ZAGAĐIVAČA KOD CESTOVNIH VOZILA

Sažetak

Jedan od najutjecajnijih činilaca u procesu onečišćenja čovjekovog okoliša je cestovni prijevoz, tj. emisija zagađivača u ispušnim plinovima kod vozila. Posebno izražen problem visokih koncentracija zagađivača od cestovnih vozila je u urbanim sredinama gdje je prisutna velika koncentracija vozila, s vrlo različitim režimima vožnje. Na emisije zagađivača od vozila najveći utjecaj imaju:

- *tehničko-tehnološka rješenja koja se koriste na motorima s unutarnjim izgaranjem, što je direktno povezano s godinom proizvodnje motora i vozila,*
- *tip motora,*
- *vrsta i kvaliteta goriva,*
- *koncentracija i prohodnost vozila u pojedinim zonama,*
- *uvjeti (režimi) vožnje i drugo.*

U cilju dobivanja slike o utjecaju cestovnih vozila na emisiju zagađivača u radu je napravljena analiza emisije zagađivača na primjeru urbane sredine sa cca 100000 registriranih vozila, gdje je oko 60 % vozila s dizelovim motorom, te dosta nepovoljne starosne strukture. Dobiveni rezultati su uspoređeni sa sličnim rezultatima u zemljama Zapadne Europe.

U radu je dat i prikaz suvremenih tehničkih dostignuća koja se koriste na vozilima koja koriste konvencionalna goriva u cilju zadovoljavanja europskih regulativa o emisiji zagađivača. Posebno su obrađena alternativna goriva, s naglaskom na ona goriva koja se danas uglavnom koriste. Prikazana su tehnička rješenja uporabe prirodnog plina, kao perspektivnog alternativnog goriva i njegov utjecaj na emisiju zagađivača.

1. Uvod

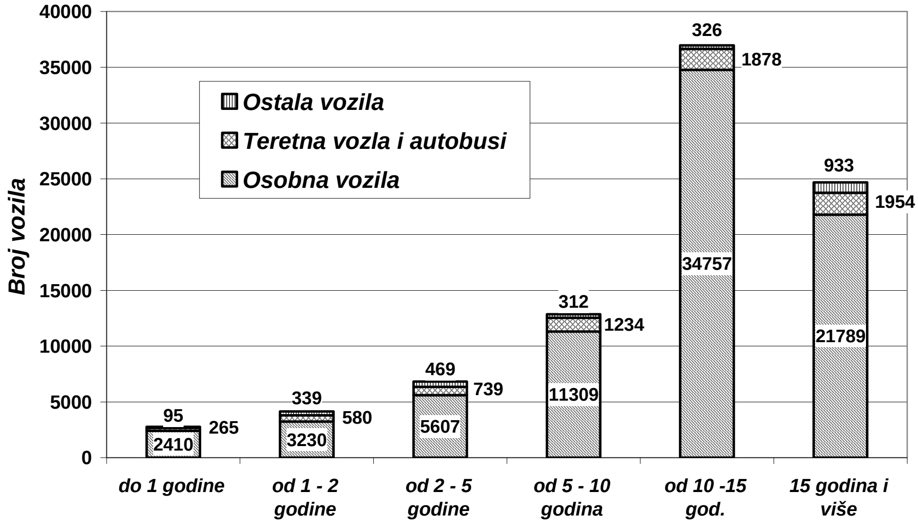
Doba širokog industrijskog razvoja društva, s naglim razvojem tehnike i tehnologije, predstavlja razdoblje kada počinje masovna eksploatacija prirodnih resursa, što ima posljedicu narušavanja kvalitete međusobnog odnosa čovjek - okoliš. Razvoj automobilske industrije dovodi u drugoj polovini XX. stoljeća do enormnog razvoja sektora cestovnog prijevoza ljudi i dobara. Cestovna vozila, odnosno štetne komponente u ispušnim plinovima cestovnih vozila postaju prepoznatljivi kao jedan od najutjecajnijih činilaca u onečišćenju okoliša. Posebno je ovaj problem izražen u urbanim sredinama, gdje je na relativno malom prostoru prisutna velika koncentracija cestovnih vozila. Urbane sredine postaju prezagađene, što ima velike posljedice za zdravlje ljudi. Ovakvo stanje utjecalo je na buđenje ekološke svijesti kod ljudi – čist zrak postaje imperativ. U tom svjetlu je posljednje desetljeće proteklog stoljeća obilježeno nizom zakonskih mjera, koje su popraćene odgovarajućim tehničkim rješenjima, kojima se nastoji smanjiti zagađenje zraka. Pred cestovna vozila se postavljaju sve stroži zahtjevi u pogledu emisije zagađivača, prije svega CO, C_xH_y, NO_x i čestica. Pravilnicima Ekonomske komisije Ujedinjenih naroda za Europu (ECE Pravilnici) propisane su norme u pogledu emisije ispušnih plinova koje cestovna vozila moraju zadovoljiti (Euro 1, Euro 2, Euro 3, Euro 4). Trenutačno su važeće Euro 3 norme, dok Euro 4 norme stupaju na snagu od 2005. godine za osobna vozila, odnosno 2006. godine za teretna vozila. Sve prisutniji trend globalnog zagrijavanja planeta u posljednje vrijeme u fokus stavlja emisiju plinova koji doprinose efektu staklenika, prije svega CO_2.

2. Analiza ekološke slike tipične urbane zone

U cilju dobivanja što potpunije slike o utjecaju cestovnih vozila na emisiju zagađivača analizirana je urbana sredina s oko 100000 registriranih vozila, tipična za europske tranzicijske zemlje. Od navedenog broja vozila 90 % čine osobna vozila, dok ostatak otpada na teretna vozila, autobuse i ostala vozila. Sa stajališta pogonskog agregata oko 60 % vozila je pokretano dizelovim motorom. Starosna struktura razmatranog voznog parka je dosta nepovoljna. Samo 14 % vozila je mlađe od 5 godina, dok je 70 % vozila starije od 10 godina. Od ukupnog broja promatranih vozila gotovo 30 % su starosti 15 i više godina. Prosječna starost razmatranog voznog parka iznosi 13 godina. Starosna struktura voznog parka, s brojem vozila po pojedinačnim kategorijama, prikazana je na slici 1.

Na osnovi izvršene analize strukture voznog parka učinjen je proračun karakterističnih emisija zagađivača pomoću računarskog programa Copert III (*Computer program to calculation emissions from road transport*) koji se uspješno koristi na području cijele Europe. Verificiranje rezultata učinjeno je usporedbom proračunate i stvarno utrošene količine pojedinih pogonskih goriva. Odstupanja su se kretala u rasponu od -1,1 % do +3,7 %, pa se proračun može smatrati valjanim. Rezultati proračuna po pojedinim zagađivačima i kategorijama vozila prikazani su u tablici 1.

Slika 1: Starosna struktura voznog parka za analiziranu urbanu sredinu
Figure 1: Fleet age structure for the analyzed urban area



N° of vehicles, Other vehicles, Commercial vehicles and buses, Passenger vehicles/
Up to 1 year from (…) to (…) year 15 years and more

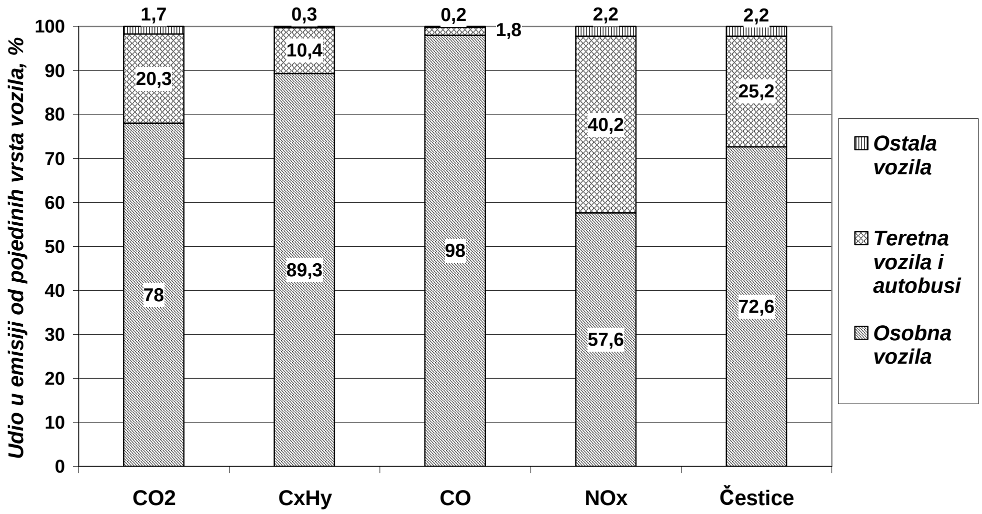
Tablica 1: Emisije zagađivača u ispušnim plinovima cestovnih vozila za analiziranu urbanu sredinu
Table 1: Road vehicles exhaust gas pollutant emission for the analyzed urban area

Emisija zagađivača		Osobna vozila	Teretna vozila	Autobusi	Ostala vozila	Ukupno
CO_2	tona	276.193	61.924	9.878	6.072	354.067
C_xH_y	tona	1.635	146	8	4	1.793
CO	tona	13.636	229	21	24	13.910
NO_x	tona	1.148	716	84	44	1.992
Čestice	tona	164	54	3	5	226

Postotni udio pojedinih kategorija vozila u ukupnoj emisiji različitih zagađivača prikazan je na slici 2. Sa slike 2 se može uočiti da najveća količina ukupno emitiranih zagađivača potječe od osobnih vozila. Međutim, da bi analiza bila sveobuhvatna, mora se u obzir uzeti i udio pojedinih kategorija vozila u ukupnom broju vozila. Na osnovi navedenih činjenica može se doći do sljedećih zaključaka: Najveću odgovornost za emisiju CO imaju osobna vozila. Emisija C_xH_y je proporcionalna udjelu pojedinih kategorija u ukupnom broju vozila, ali su zbog brojnosti glavni nosioci emisije C_xH_y osobna vozila. Teretna vozila i autobusi proizvode značajnu količinu NO_x i čestica, što posebno dobiva na značaju ako se zna da ova vozila čine manje od 10 % voznog parka. U okviru kategorije osobnih vozila najveća količina proizvedenih NO_x i čestica dolazi od osobnih vozila sa dizelskim pogonskim agregatima, tako da se uopće vozila s dizelovim motorom mogu označiti kao glavni nosioci emisije čestica i velikim dijelom NO_x. Emisija CO_2 je uzrokovana potrošnjom goriva i tu su osobna vozila označena kao glavni nosioci zagađenja. Ipak zbog velikih snaga pogonskih dizelovih motora, kao i većeg broja prijeđenih kilometara i teretna vozila imaju značajan utjecaj na emisiju CO_2.

Slika 2: Postotni udio u ukupnoj emisiji različitih zagađivača prema kategorijama vozila

Figure 2: Percentage ratio of pollutant emission of different category of vehicle in total pollutant emission



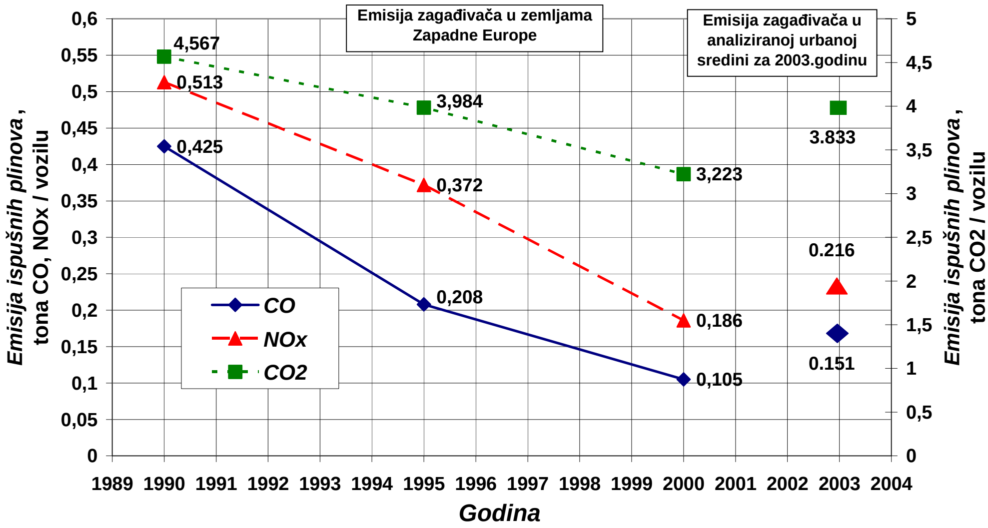
Emission share per individual vehicle types
Other vehicles Commercial vehicles and buses Passenger vehicles
Particulates

Da bi se mogla izvršiti realna valorizacija prije prikazanih rezultata, potrebno je dobivenu ekološku sliku usporediti s ekološkom slikom drugih gradova u Europi, prije svega u razvijenim zemljama. Studijom OECD [1] analizirani su rezultati emisije zagađivača u zemljama Zapadne Europe i predviđanja emisije zagađivača do 2030. godine. Na slici 3 su prikazani rezultati emisije zagađivača u analiziranoj urbanoj sredini za 2003. godinu u usporedbi s trendom emisije zagađivača u zemljama Zapadne Europe za razdoblje 1990. do 2000. godine.

Analizirajući vrijednosti prikazane na slici 3 može se zaključiti da je ekološka slika za 2003. godinu u analiziranom području na razini ekološke slike u zemljama Zapadne

Europe iz 1997. i 1998. godine. Razlog zašto se trenutna ekološka slika u analiziranom području razlikuje od ekološke slike u razvijenim europskim zemljama leži prije svega u starosti voznog parka. U cilju smanjenja onečišćenja okoliša i hvatanja koraka s Europom neophodno je poduzeti određene mjere na smanjenju emisija zagađivača od cestovnih vozila. Načini i mogućnosti koje stoje na raspolaganju razmotrene su u nastavku.

Slika 3: Emisije zagađivača u zemljama Zapadne Europe i u analiziranom primjeru
Figure 3: Pollutant emission in Western European countries and in analyzed area



Emission of exhaust gases, tons of CO, NOx per vehicle
Pollutant emission in Western European countries
Pollutant emission in analyzed urban area for 2003 / Year

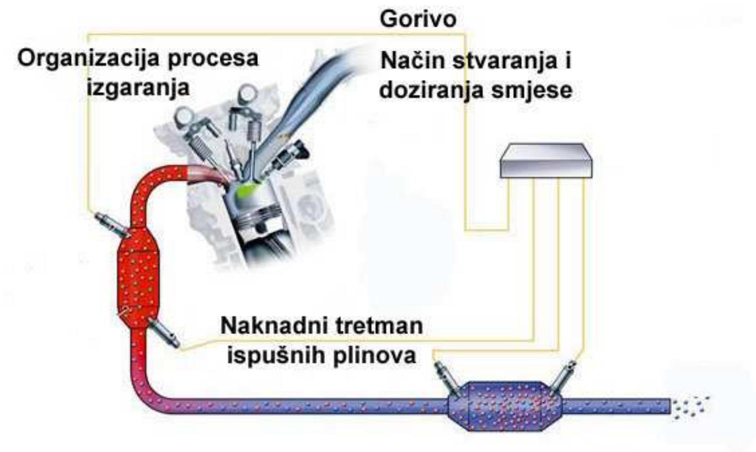
3. Mogućnosti smanjenja emisije zagađivača od cestovnih vozila

Sa stajališta cestovnih motornih vozila, na emisije zagađivača najveći utjecaj imaju: tehničko-tehnološka rješenja koja se koriste na motorima s unutarnjim izgaranjem, radni ciklus motora, vrsta i kvaliteta goriva, koncentracija i prohodnost vozila u pojedinim zonama, uvjeti (režimi) vožnje.

Promatrajući motor s unutarnjim izgaranjem kao zasebnu cjelinu smanjenje emisije zagađivača u cestovnom vozilu moguće je postići na tri načina: povećanjem kvalitete korištenih goriva, optimizacijom radnih procesa u motoru i naknadnim tretmanom ispušnih plinova, što je shematski prikazano na slici 4.

Smanjenje sadržaja sumpora, te ukidanje pojedinih štetnih aditiva u konvencionalnim gorivima omogućava postizanje niže emisije zagađivača, prije svega sumpornih oksida i drugih nereguliranih komponenti (zakonski netretiranih zagađivača). Primjenom suvremenih konstruktivnih rješenja i naprednih elektronskih regulacijskih sustava optimiziraju se procesi u motoru, prije svega dobava goriva i proces izgaranja, i na taj način se dobivaju povoljnije karakteristike ispušnih plinova. Kao karakteristični primjeri mogu se navesti: *common rail* sustav za visokotlačno direktno ubrizgavanje goriva kod dizelovih motora, direktno ubrizgavanje goriva kod Otto motora, recirkulacija ispušnih plinova, varijabilno upravljanje ventilima, itd. Neizbježan dio suvremenih vozila su i sustavi za naknadni tretman ispušnih plinova (tzv. katalizatori) kojima se postiže dodatno smanjenje emisije zagađivača. Kombinacijom navedenih rješenja mogu se postići niske emisije štetnih komponenti, koje mogu zadovoljiti zahtjeve definirane ECE pravilnicima. Navedena tehnička rješenja direktno su vezana s godinom proizvodnje vozila, pa se pomlađivanje voznog parka može navesti kao jedan od načina za smanjenje emisije zagađivača od cestovnih vozila i poboljšanje ekološke slike.

Slika 4: Načini na koje se može utjecati na smanjenje emisije zagađivača kod motora s unutarnjim izgaranjem
Figure 4: Ways for reduction of pollutant emission in internal combustion engines



Fuel
Combustion process organization Mixture generation and dosage manner
Exhaust gases after treatment/

Organizacija prometa u urbanim sredinama i korištenje alternativnih vidova prijevoza je drugi način na koji se može utjecati na smanjenje emisije zagađivača.

Treći način na koji je moguće utjecati na smanjenje emisije zagađivača od cestovnih vozila, naročito u urbanim sredinama, jest uporaba alternativnih goriva. Ovdje treba istaći da tehničko-tehnološka rješenja na motorima, u cilju postizanja zadovoljavajuće ekološke slike, postaju preskupa, pa alternativna goriva predstavljaju rješenja koja zadržavaju i razumnu razinu cijene vozila.

4. Primjena alternativnih goriva s ciljem redukcije zagađivača

Uporaba alternativnih goriva za pogon cestovnih vozila predstavlja jedan od realno mogućih načina za smanjenje štetne emisije ispušnih plinova iz vozila. Pored toga, primjena alternativnih goriva vodi ka smanjenju ovisnosti o konvencionalnim pogonskim gorivima, dobivenim iz nafte, čije su rezerve ograničene. Stoga se pitanje izbora adekvatnog alternativnog goriva može promatrati i u mnogo širem kontekstu. Općenito se izvori energije mogu podijeliti na obnovljive i neobnovljive, a njihova podjela i moguća primjena u domeni cestovnih vozila je prikazana na slici 5.

Kako se sa slike 5 može uočiti motor s unutarnjim izgaranjem u lancu transformacije energije predstavlja gotovo nezaobilaznu kariku, budući da se pokazalo da on svoje pozitivne osobine, uz odgovarajuću optimizaciju zadržava bez obzira koje se pogonsko gorivo koristi.

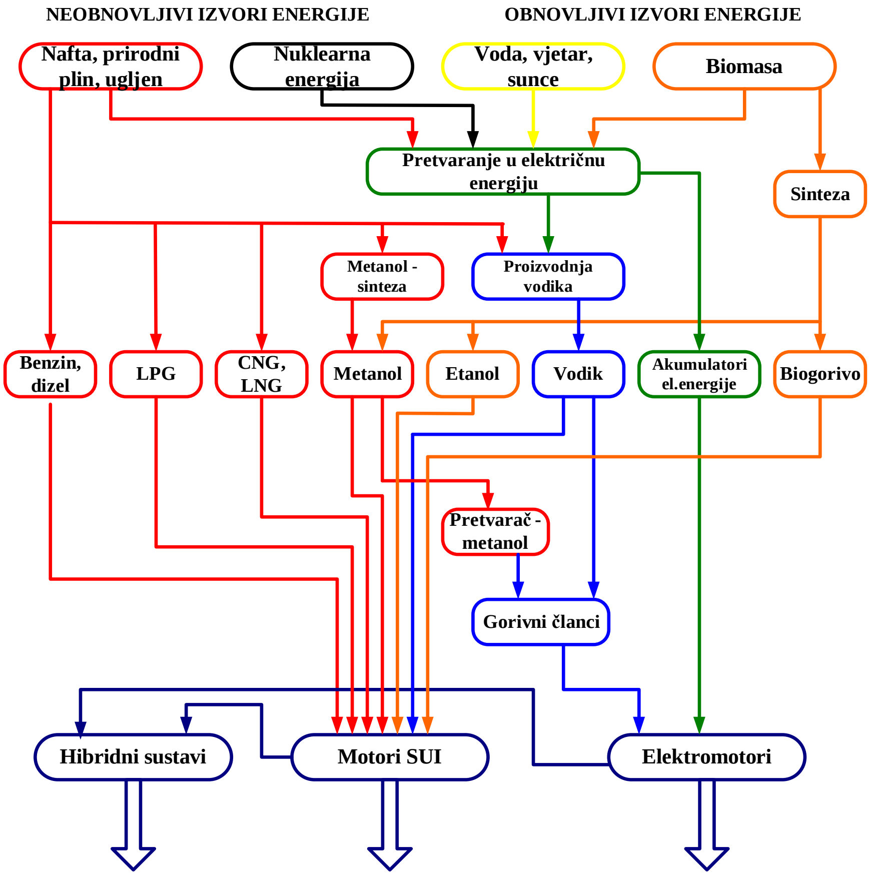
Za potpuno razumijevanje razmatrane problematike potrebno je definirati pojam alternativnog goriva. U alternativna goriva za pogon motora SUI spadaju sva goriva, osim benzina i dizelskih goriva, koja mogu efikasno izgarati u motoru SUI i koja imaju mogućnost masovne proizvodnje (npr. prirodni plin, metanol, vodik, biogorivo).

Da bi se neko alternativno gorivo uspješno primijenilo za pogon cestovnog vozila, moraju biti ispunjeni brojni zahtjevi. Osnovni kriteriji bitni za ocjenu primjenjivosti alternativnih goriva za pogon motora SUI su:

- emisija ispušnih plinova,
- potrošnja goriva,
- cijena alternativnog goriva,
- performance vozila s pogonom na alternativna goriva,
- nalazišta, način dobivanja i rezerve alternativnog goriva,
- troškovi konverzije ili proizvodnje vozila,
- načini i mogućnosti uskladištenja goriva na vozilu,
- mogućnost punjenja gorivom i potrebna infrastruktura,
- opća sigurnost vozila.

U alternativna goriva koja se danas nalaze u primjeni za pogon motora SUI spadaju: alkoholna goriva (metanol i etanol), ukapljeni naftni plin (LPG), prirodni plin, biljna ulja, vodik. Sva navedena alternativna goriva, zbog jednostavnije kemijske strukture u odnosu na benzinsko ili dizelsko gorivo, imaju potencijal za smanjenje emisije štetnih ispušnih plinova. Zbog manjeg sadržaja atoma ugljika, alternativna goriva pri izgaranju proizvode manju količinu CO_2, a u slučaju uporabe vodika emisija CO_2 potječe isključivo od izgaranja ulja za podmazivanje. Bitno je napomenuti da se uporabom alternativnih goriva ne može u potpunosti postići tzv. „nulta“ emisija štetnih ispušnih plinova, i zbog kemijske strukture ugljikovodičnog goriva (i pri idealnim uvjetima izgaranja prisutan je CO_2), i zbog same konstrukcije motornog mehanizma koja zahtijeva određen stupanj podmazivanja (u ispuhu su prisutni produkti izgorjelog ulja čak i pri uporabi vodika kao pogonskog goriva).

Slika 5: Izvori energije za pogon cestovnih vozila
Figure 5: Energy sources for road vehicle propulsion



non renewable – renewable
oil, natural gas, coal; nuclear power / water, wind, sun; biomass
conversion into electrical power
synthesis
methanol synthesis; hydrogen generation
gasoline, diesel; methanol; ethanol; hydrogen; electric power batteries; biofuel
converter - methanol
fuel cell
hybrid systems; IC engines; electric engines

Brojne analize koje su razmatrale mogućnosti primjene alternativnih goriva, uzimajući u obzir navedene kriterije za odabir alternativnog goriva, kao i specifičnosti vezane za analizirano područje, pokazale su da je u ovom trenutku prirodni plin optimalno alternativno gorivo za pogon motora SUI, prvenstveno za vozila u urbanom prometu.

4.1 Primjena prirodnog plina za pogon cestovnih vozila

Primjena prirodnog plina za pogon cestovnih vozila doživjela je u svijetu ekspanziju u posljednjih desetak godina. Preko 1.000.000 vozila u svijetu trenutačno koristi prirodni plin kao pogonsko gorivo i taj se broj stalno povećava. Prirodni plin se većinom sastoji od metana što, zbog njegove jednostavne kemijske strukture, pruža znatne mogućnosti smanjenja emisije zagađivača.

Prirodni plin se na vozilu može skladišti na više načina, kao adsorbirani (prirodni plin je adsorbiran u nekoj supstanci, na primjer aktivnom ugljiku, pod tlakom 7 – 10 bara - uobičajeni naziv u literaturi ANG-*Adsorbed Natural Gas*), komprimirani (prirodni plin je uskladišten u rezervoare (boce) pod tlakom 200 – 250 bara – uobičajeni naziv u literaturi CNG-*Compressed Natural Gas*) ili ukapljenii (prirodni plin je uskladišten u rezervoare u tekućem stanju – uobičajeni naziv u literaturi LNG-*Liquefied Natural Gas*). Optimalan kompromis količine uskladištenog goriva, težine rezervoara i troškova uskladištenja pruža uskladištenje plina u boce pod visokim tlakom, pa je komprimirani prirodni plin našao najveću uporabu.

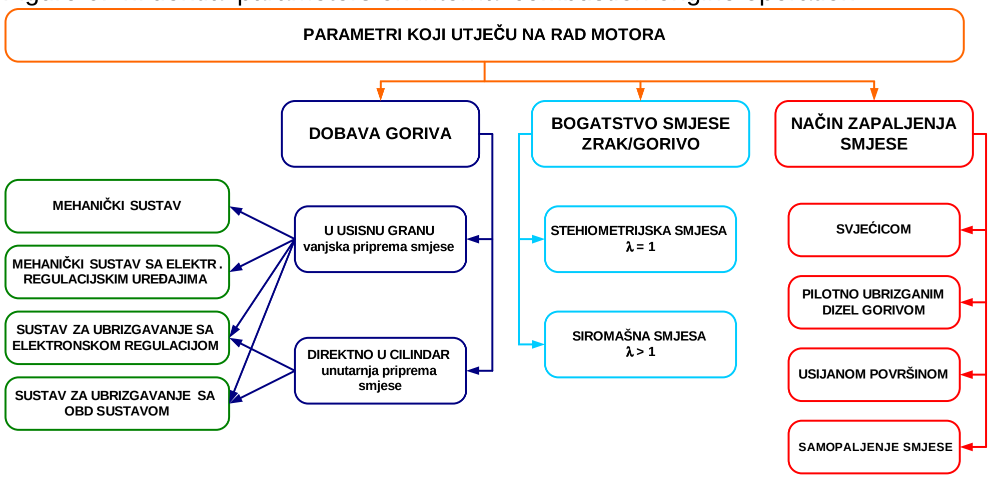
Motori na prirodni plin koji se danas koriste za pogon cestovnih vozila predstavljaju u osnovi konvencionalne motore s unutarnjim izgaranjem koji su prilagođeni korištenju prirodnog plina, bilo da se radi o novim motorima koje isporučuju proizvođači, bilo da se radi o naknadnoj prilagodbi motora. Kako su fizičko-kemijske osobine prirodnog plina mnogo bliže osobinama benzina nego dizelska goriva, motori na prirodni plin rade po Otto ciklusu, odnosno to su motori s prinudnim paljenjem smjese. Na energetsku efikasnost motora, kao i na emisiju ispušnih plinova najveći utjecaj ima proces izgaranja smjese. Ključni utjecaj na proces izgaranja imaju način stvaranja smjese zrak/gorivo, bogatstvo smjese, te način paljenja smjese, a ovi parametri se reguliraju sustavom za dobavu goriva, odnosno sustavom za paljenje. Prema navedenom postoje različite izvedbene varijante na motorima na prirodni plin, a shematski su prikazane na slici 6.

U ovisnosti o načinu i mjestu dobave goriva, načinu stvaranja smjese, bogatstvu smjese i načinu zapaljenja smjese postoje različite izvedbe motora na prirodni plin, koji se mogu podijeliti u četiri kategorije:

1. motori s prinudnim paljenjem smjese zrak/prirodni plin putem svjećice,
2. motori s prinudnim paljenjem smjese zrak/prirodni plin pilotnim ubrizgavanjem male količine dizelskog goriva,
3. motori s direktnim ubrizgavanjem prirodnog plina pod visokim tlakom u cilindar motora i prinudnim paljenjem smjese,
4. motori sa samopaljenjem prethodno pripremljene smjese zrak/prirodni plin.

Svi tipovi motora na prirodni plin mogu se izvesti tako da koriste isključivo prirodni plin kao pogonsko gorivo, tzv. monovalentni plinski motori. Motori s paljenjem smjese pomoću svjećice ili pilotnim ubrizgavanjem dizelskog goriva mogu se izvesti tako da za pogon koriste ili prirodni plin ili kovencionalno gorivo (benzin, odnosno dizelsko gorivo), tzv. bivalentni motori, pri čemu korisnik na vrlo jednostavan način u tijeku vožnje odabire koje će gorivo koristiti. Ova dva tipa motora se već nalaze u komercijalnoj uporabi. Motori s ubrizgavanjem prirodnog plina direktno u cilindar motora su eksperimentalno primijenjeni i ispitani na vozilima i očekuje se njihova komercijalna uporaba. Motori sa samopaljenjem smjese su tek u ranoj fazi razvoja i postoje tek eksperimentalni jednocilindrični motori.

Slika 6: Parametri koji utječu na rad motora
Figure 6: Influential parameters on internal combustion engine operation



parameters impacting engine operation

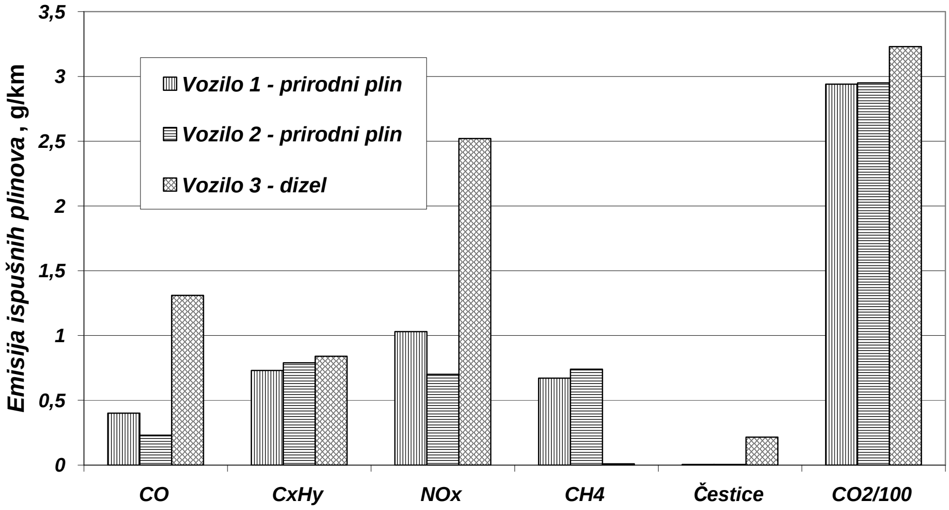
	fuel supply	air-fuel mixture quality	manner of mixture ignition
mechanical system	into the intake manifold - outside mixture preparation	stehiometric mixture	spark
mechanical system with electrically regulated devices	directly into cylinder – inner mixture preparation	lean mixture	pilot injected diesel fuel
injection system with electronical regulation			red-hot surface
other injection system			mixture self-ignition

U područjima sa slabo razvijenom infrastrukturom za punjenje vozila prirodnim plinom očekuje se primjena bivalentnih motora za pogon osobnih vozila i komercijalnih vozila u prijevozu na duže relacije. Za pogon vozila u javnom urbanom prijevozu moguća je primjena i monovalentnih i bivalentnih motora. Treba napomenuti da su u većini slučajeva bivalentni motori optimizirani za rad s konvencionalnim gorivom, zbog čega u potpunosti nisu iskorištene mogućnosti koje pruža prirodni plin. Razvojem infrastrukture može se očekivati povećanje broja vozila koja koriste isključivo prirodni plin, jer su ona sa stajališta emisije ispušnih plinova povoljnija.

4.2 Emisija zagađivača od vozila koja koriste prirodni plin

Uporabom prirodnog plina za pogon motornih vozila postoje realne osnove za smanjenje emisije štetnih ispušnih plinova. U odnosu na benzin postiže se smanjenje emisije CO, C_xH_y i NO_x, uz istodobno smanjenje kancerogenosti ispušnih plinova i njihovog utjecaja na stvaranje smoga. Emisija plinova koji pomažu efekt staklenika, izražena preko ekvivalentne emisije CO_2, također je smanjena. U odnosu na dizelsko gorivo znatno se smanjuje emisija NO_x, uz iznimno nisku emisiju čestica, dok emisija CO i C_xH_y, te ekvivalentna emisija CO_2 ostaje na razini dizelovog motora. Bitno je napomenuti da se navedene karakteristike postižu bez uporabe naknadnog tretmana ispušnih plinova. Primjenom naknadnog tretmana ispušnih plinova kod motora na prirodni plin može se postići dodatno smanjenje emisije.

Slika 7: Prosječna emisija ispušnih plinova dostavnih vozila s pogonom na prirodni plin u usporedbi s emisijom vozila s dizelovim motorom
Figure 7: Average exhaust gas emission from natural gas powered delivery vehicle compared with exhaust emission from diesel vehicles



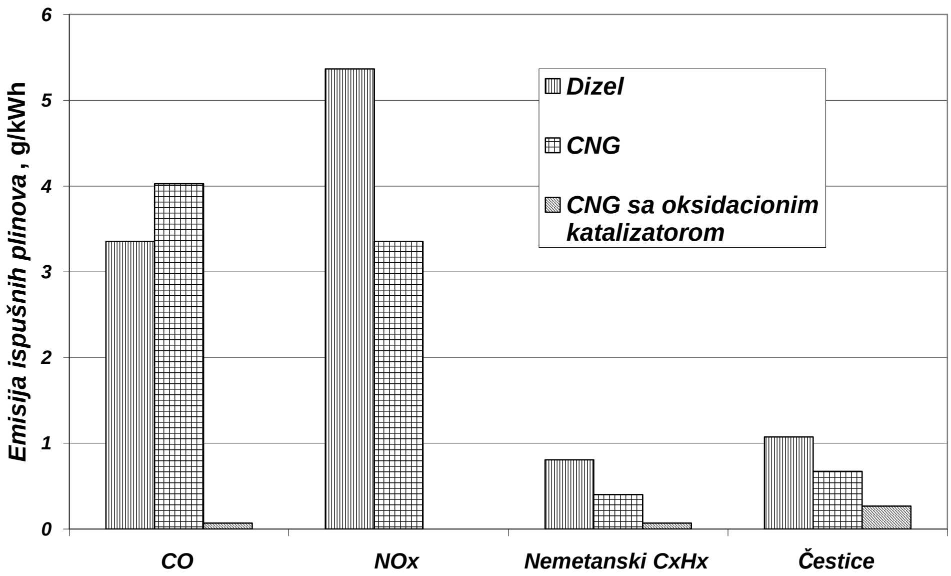
exhaust gas emission / vehicle (…) natural gas diesel fuel / particulates

Na slici 8 je prikazana emisija ispušnih plinova motora na prirodni plin (CNG), s paljenjem smjese pomoću pilotno ubrizganog dizelskog goriva, *Navistar DT 466* (maksimalna snaga 157 kW) i *Cummins L10* (maksimalna snaga 194 kW) usporedno s emisijom baznih dizelovih motora [8]. Navedeni plinski motori su testirani bez i sa primjenom naknadnog tretmana ispušnih plinova. U prvom slučaju uporabom prirodnog plina postignuto je smanjenje emisije NO_x, čestica i nemetanskih C_xH_y, dok je emisija CO nešto povećana. Opremanjem motora oksidacijskim katalizatorima postignuto je značajno smanjenje svih mjerenih zagađivača.

Na slici 9 je prikazana emisija ispušnih plinova motora sa pogonom na prirodni plin (CNG), s paljenjem pomoću svjećice, proizvođača MAN koji se koriste za pogon teretnih vozila i autobusa (E2866 LUH02, E2866 DUH03, E3876 LUH01), usporedo sa Euro normama o emisiji ispušnih plinova [9].

Slika 8: Emisija ispušnih plinova CNG motora Navistar DT 466 i Cummins L10 usporedno s emisijom baznih dizelovih motora

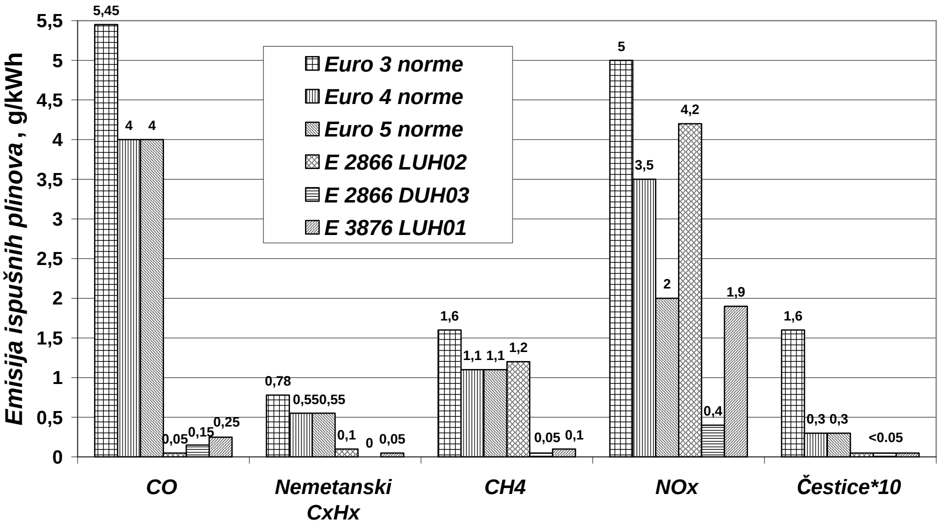
Figure 8: Exhaust gas emission from CNG powered engines Navistar DT 466 and Cummins L10 compared with exhaust gas emission from original (base) diesel engines



exhaust gas emission / /diesel fuel CNG with oxidation catalyst / non-methane CxHx particulates/

Iz primjera prikazanih na slikama 7, 8 i 9 jasno se vide mogućnosti za smanjenje emisije zagađivača koje pruža uporaba prirodnog plina za pogon cestovnih vozila.

Slika 9: Emisija ispušnih plinova CNG motora proizvođača MAN usporedno s Euro normama o emisiji ispušnih plinova
Figure 9: Exhaust gas emission from CNG powered engines produced by MAN compared with EU emission standards



exhaust gas emission / non-methane CxHx particulates

5. Zaključak

U radu je analizirana struktura voznog parka i emisija zagađivača za urbanu sredinu sa cca 100000 vozila, tipičnu za europske tranzicijske zemlje. Starosna struktura razmatranog voznog parka je iznimno loša, s preko 70% vozila starijih od 10 godina, pri čemu je prosječna starost vozila 13 godina. Osobna vozila označena su kao glavni krivac za emisiju zagađivača. Ekološka slika razmatrane urbane sredine uspoređena je s ekološkom slikom sličnih sredina u Zap. Europi i ustanovljeno je da je ona na razini njihove ekološke slike iz 1997. i 1998. g. Rješenja za poboljšanje ekološke slike su u pomlađivanju voznog parka (vozila sa suvremenim motorima koja ispunjavaju Euro norme), organizaciji prometa i uporabi alternativnih goriva. U ovom trenutku optimalno alternativno gorivo za pogon motora SUI, prvenstveno za vozila u urbanom prometu je prirodni plin. Razmotrena su tehnička rješenja korištenja prirodnog plina, te prikazana ekološka slika vozila s pogonom na prirodni plin. Zahvaljujući karakteristikama prirodnog plina postiže se znatno smanjenje emisije CO, NO_x i čestica, dok se kod motora na prirodni plin s paljenjem smjese pilotnim ubrizgavanjem dizelskog goriva uporabom naknadnog tretmana ispušnih plinova može dodatno smanjiti emisija posebno CO i C_xH_y. Ukupna emisija plinova koji doprinose efektu staklenika je na razini emisije kod konvencionalnih goriva, jer je kod plinskih motora pored CO_2 u ispuhu prisutan i metan.

THE APPLICATION OF ALTERNATIVE FUELS FOR THE PURPOSE OF REDUCING ROAD VEHICLES' POLLUTANT EMISSION

Abstract

One of the most influential factors in the process of environmental pollution is road transport, i.e. emission of gaseous pollutants from road vehicles. An especially pronounced problem is the air pollution in urban areas, with a high concentration of road vehicles having very different driving regimes. The largest influence on pollutants emission of road vehicles is that of:

- *Technical and technological solutions used in internal combustion engines, which is directly connected with the given vehicle's particular year of production,*
- *Engine type,*
- *Fuel type and quality,*
- *Vehicles concentration and use in certain areas,*
- *Driving regimes, etc.*

For the purpose of getting a complete image of influences of road vehicles on pollutants emission, we have analyzed pollutants emission in an urban area with 100,000 registered vehicles, 60 % of which had diesel engines, with quite unfavorable age structure. The results have been compared with similar results in the Western European countries.

Also, a review of modern technical accomplishments used in conventionally fueled vehicles for satisfying the European environmental legislation has been done in this paper. A special attention has been paid to alternative fuels, with the emphasis on the presently used fuels. Technical solution for the utilization of natural gas, as a very promising alternative fuel, and its influence on pollutants emission, has also been presented.

1. Introduction

The age of a broad social industrial development, with an abrupt development of technology, constitutes the age when the mass exploitation of natural resources began, resulting in a disturbed relationship between man and environment. The development of automobile industry has in the second half of the 20th century led to an enormous development of the road traffic sector of people and goods transportation. Road vehicles, i.e. noxious components in their exhaust gases, have become one among the most influential factors of environmental pollution. This issue is particularly pronounced in urban areas, where on a relatiely small space there is a high concentration of road vehicles. Urban areas are becoming over-polluted, with major impacts on human health. Such a condition has caused the environmental awareness to awaken in people – clean air has become an imperative. In this sense, the last decade of the past century has been characterized by a number of legal measures, accompanied by appropriate technical solutions, aimed at reducing air pollution. Road vehicles are faced with increasingly stringent requirements as regards pollutants emission, primarily CO, C_xH_y, NO_x and particulates. Regulations of the UN Economic Commission for Europe (ECE Regulations) set the standards of exhaust gases emission which the road vehicles must meet (Euro 1, Euro 2, Euro 3, Euro 4). Currently valid are the Euro 3 norms, while the Euro 4 norms comes into force as of 2005 for passenger vehicles, i.e. 2006 for commercial vehicles. The recent increasing planet's global warming trend has brought into focus the emission of gases contributing to the greenhouse effect, primarily CO_2.

2. Analysis of the Environmental Picture of a Typical Urban Zone

For the purpose of obtaining as complete as possible a picture of the impact of road vehicles on pollutants emission, we have analyzed an urban area with around 100,000 registered vehicles, typical of European transition countries. Out of the said number of vehicles, 90 % were passenger vehicles, while the rest encompasses commercial vehicles, buses, and other vehicles. From the viewpoint of power, around 60 % of vehicles are powered by diesel engines. The age structure of the considered vehicle pool is rather unfavourable. Only 14 % of the vehicles are less than 5 years old, while 70 % of the vehicles are over 10 years old. Out of the total number of considered vehicles, nearly 30 % are 15 or more years old. The average age of the considered vehicle pool is 13 years. The vehicle pool age structure, with the number of vehicles per individual categories, is shown in Figure 1.

Tablica 1: Emisije zagađivača u ispušnim plinovima cestovnih vozila, za analiziranu urbanu sredinu
Table 1: Road vehicles exhaust gas pollutant emission for the analyzed urban area

Pollutants Emission		Passenger Vehicles	Commercial Vehicles	Buses	Other Vehicles	Total
CO_2	tons	276.193	61.924	9.878	6.072	354.067
C_xH_y	tons	1.635	146	8	4	1.793
CO	tons	13.636	229	21	24	13.910
NO_x	tons	1.148	716	84	44	1.992
Particulates	tons	164	54	3	5	226

Based on the analysis of the vehicle pool structure made, we have calculated characteristic pollutants emissions using the Copert III (*Computer program to calculate emissions from road transport*) software, successfully used all over Europe. Verification of results was made through the comparison of calculated and actually consumed volume of individual drive fuels. Aberrations ranged from –1.1 % do +3.7 %, so that the calculation may be considered as valid. Calculation results per individual pollutants and vehicle categories are shown in Table 1.

Percentage share of individual vehicle categories in the total emission of different pollutants is shown in Figure 2.

It may be seen from Figure 2 that the largest volume of totally emitted pollutants comes from passenger vehicles. However, in order for the analysis to be comprehensive, one must take into account also the share of individual vehicle categories in the total number of vehicles. Based on the stated facts, the following conclusions are possible: The largest responsibility for the emission of CO lies on passenger vehiciles. Emission of C_xH_y is proportionate with the share of individual categories in the total number of vehicles, but, due to their numerosity, the largest bearers of the emission of C_xH_y are the passenger vehicles. Commercial vehicles and buses produce a considerable quantity of NO_x and particles, which is especially significant if we take into account the fact that these vehicles account for less than 10 % of the vehicle pool. As regards the category of passenger vehicles, the largest amount of produced NO_x and particles comes from passenger vehicles powered by diesel aggregates, so that vehicles with diesel engines in general may be said to be the principal bearers of particulate emission and to a large extent also that of NO_x. Emission of CO_2 is caused by fuel consumption and here passenger vehicles appear as the main pollution bearers. Still, due to the high power of diesel engines, as well as the larger amount of mileage covered, commercial vehicles also have a considerable impact on the emission of CO_2.

In order to be able to perform a realistic evaluation of the aforementioned results, one must compare the environmental picture obtained with that of other European cities, primarily in developed countries. The Study of OECD [1] has analyzed the results of pollutant emission in the countries of Western Europe and has predicted pollutant emission by 2030. Figure 3 shows the results of pollutant emission in the analyzed urban area for 2003 as compared with the trend of pollutant emission in the countries of Western Europe for the 1990 – 2000 period.

By analyzing values shown in Figure 3, one may conclude that the environmental picture for 2003 in the analyzed area is at the level of the one in Western European countries from 1997 and 1998. The reason why the current environmental picture in the analyzed area is different from that in developed European countries lies primarily in the vehicle pool age. For the purpose of reducing environmental pollution and keeping up with Europe, it is necessary to undertake certain measures regarding the reduction of road vehicles pollutants emisson. The available ways and methods of doing that have been considered in the following text.

3. The Possibilities of Reducing Road Vehicles Pollutant Emission

From the viewpoint of road motor vehicles, pollutant emission is mostly influenced by the following: technological solutions used for internal combustion engines, engine life cycle, fuel type and quality, concentration and propulsion of vehicles in respective countries, driving conditions (regimes).

Looking at an internal combustion engine as a separate whole, road vehicles pollutant emission reduction may be achieved in three ways: by advancing the quality of utilized fuels, by optimizing operating processes in the engine and by a subsequent treatment of exhaust gases, as displayed in Figure 4.

Sulphur content reduction and phasing out of individual noxious additives in conventional fuels enables the achievement of a lower pollutants emission, primarily that of sulphur oxides and other non-regulated components (legally untreated pollutants). By applying modern design solutions and advanced electronic regulation systems, the engine processes are optimized – primarily fuel supply and combustion process, thus obtaining more favourable fuel gas characteristics. As characteristic examples, we may list the following: *common rail* system for high pressure direct fuel injection in diesel engines, direct fuel injection in gasoline engines, recirculation of exhaust gases, variable valve management, etc. An inevitable part of modern vehicles are also the systems for after treatment of exhaust gases (the so called catalysts), achieving additional reduction of pollutant emission. Through a combination of the said solutions, it is possible to achieve low emission of noxious components, capable of meeting requirements set by the ECE regulations. The said technical solutions are directly associated with the vehicle's year of production, so that the refreshement of the vehicle pool may be listed as one of the ways to reduce road vehicles pollutant emission and improve the environmental picture.

Traffic organization in urban areas and use of alternative transportation means is another way of impacting the pollutant emission reduction.

The third way of impacting the road vehicles pollutant emission reduction, especially in urban areas, is the use of alternative fuels. We should point out here that the technological solutions referring to engines for the purpose of achieving a satisfactory environmental picture are becoming too costly, so that alternative fuels constitute solutions keeping a reasonable level of vehicle price.

4. Application of Alternative Fuels in View of Pollutant Reduction

The use of alternative fuels for the drive of road vehicles constitutes one among realistic options for reducing the noxious vehicle exhaust gas emission. Apart from that, the application of alternative fuels leads to the reduction of dependence on conventional drive fuels obtained from oil, whose reserves are limited. That is why the issue of chooisng an adequate alternative fuel may be viewed in a much wider context. Generally, the energy sources may be classified as renewable and non-renewable, while their possibble application as regards road vehicles is shown in Figure 5.

As may be seen from Figure 5, the internal combustion engine plays a nearly inevitable role within the energy transformation chain since it has been shown that its positive properties are, with a corresponding optimization, maintained regardless of the propulsion fuel used.

For a complete understanding of considered issues, it is necessary to define the notion of alternative fuel. Alternative fuels for the drive of IC engines comprise all fuels, apart from gasoline and diesel fuels, which may efficiently combust in an IC engine and which are capable of mass production (e.g. natural gas, methanol, hydrogen, bio-fuel).

In order for an alternative fuel to be successfully applied for the propulsion of a road vehicle, it must meet many requirements. The basic criteria of importance for evaluating the applicability of alternative fuels for the drive of IC engines are:

- exhaust gases emission,
- fuel consumption,
- alternative fuel price,
- performance of vehicles powered by alternative fuels,
- sites, way of recovery and reserves of alternative fuel,
- costs of conversion or of vehicle production,
- ways and possibilities of storing the fuel within the vehicle,
- possibilities of refuelling and the necessary infrastructure,
- overall vehicle safety.

The alternative fuels applied today for the propulsion of IC engines are: alcohol-based fuels (methanol and ethanol), LPG, natural gas, vegetable oils, hydrogen. All the above alternative fuels, due to a simpler chemical structure with regard to gasoline or diesel fuel, have potentials for reducing the emission of noxious exhaust gases. Due to the lower content of carbon atoms, alternative fuels at combustion produce less CO_2, while, in the case of hydrogen use, the emission of CO_2 comes solely from the lubricating oil combustion. It is necessary to point out that the use of alternative fuels cannot entirely reach the so called „zero“ emission of noxious exhaust gases, due both to the chemical structure of the hydrocarbon fuel (even under ideal combustion conditions, CO_2 is present), and the design of the engine mechanism itself, requiring a certain degree of lubrication (the exhaust contains products of burned oil even if hydrogen is used as the propulsion fuel).

Numerous analyses considering the possibilities of applying alternative fuels, taking into account the said criteria for choosing the alternative fuel, as well as the specific character of the area under analysis, have shown that at the present moment natural gas is the optimal alternative fuel for the drive of IC engines, primarily when it comes to urban traffic.

4.1 Application of Natural Gas for the Drive of Road Vehicles

The application of natural gas for the drive of road vehicles has experienced a global expansion over the past around a dozen years. Over 1000,000 vehicles in the world are presently using natural gas as drive fuel, while the number is constantly increasing. Natural gas consistes mostly of methane, which, due to its simple chemical structure, offers considerable possibilities of reducing pollutant emission.

Natural gas may be stored within the vehicle in several ways, as adsorbed (natural gas is adsorbed by a given substance, e.g. active coal, under the pressure of 7–10 bar – usual name in the references ANG-*Adsorbed Natural Gas*), comprised (natural gas stored in containers (bottles) under the pressure of 200–250 bar – usual name in the references CNG-*Compressed Natural Gas*) or liquefied (natural gas stored in containers in liquid state – usual name in the references LNG-*Liquefied Natural Gas*). Optimal compromise among the value of stored fuel, reservoir weight and storage costs is offered by gas storage in bottles under high pressure, which is why comprised natural gas is most videly applied.

Engines running on natural gas used today for the drive of road vehicles basically constitute conventional internal combustion engines adapted for the use of natural gas - whether they are new engines delivered by manufacturers or those adapted subsequently. As the physico-chemical properties of natural gas are much closer to those of gasoline than the diesel fuels, engines running on natural gas operate according to the gasoline motor cycle – they are engines with a spark ignition.The energy efficiency of the engine, as well as the exhaust gas emission, is most influenced by the mixture combustion process. The key impact on the combustion process is that of the manner of generation of the air/fuel mixture; its quality and manner of ignition, while these parameters are regulated by the fuel supply system i.e. by the ignition system. In keeping with this, there are different variants of natural gas-powered engines, as presented in Figure 6.

Depending on the manner and place of fuel supply, manner of mixture generation, mixture quality and the way of its ignition, there are various designs of engines powered by natural gas, which may be divided into the following four categories:

1. engines with compulsive ignition of the air/natural gas mixture by spark,
2. engines with compulsive ignition of the air/natural gas mixture by pilot injection of a small volume of diesel fuel,
3. engines with direct injection of natural gas under high pressure into the engine cylinder and compulsive mixture ignition,
4. engines with self-ignition of the previously prepared air/natural gas mixture.

All engine types running on natural gas may be designed so as to use solely natural gas as propulsion fuel: the so called monovalent gas engines. Engines with mixture ignition by spark or pilot injection of diesel fuel may be designed so as to use either natural gas or conventional fuel for propulsion (gasoline, i.e. diesel fuel): the so called bivalent engines, in which case the driver may very easily during the drive itself decide upon the fuel to use. These two engine types are already in commercial use. Engines with natural gas injection directly into the engine cylinder have been experimentally applied and tested on vehicles and their commercial utilisation is now expected. Engines with mixture self-ignition are only in an early development phase and there are only experimental single-cylinder engines.

In areas with poorly developed infrastructure for the filling of vehicles by natural gas, the application of bivalent engines for powering passenger and commercial vehicles is expected in transportation to long distances. For the propulsion of vehicles in public city transportation, it is possible to use both monovalent andi bivalent engines. We should point out that in most cases bivalent engines are optimized for operation with conventional fuels, which is why possibilities offered by natural gas are not entirely employed. Through the development of infrastructure, one may expect increase in the number of vehicles using exclusively natural gas, because they are more acceptable from the viewpoint of exhaust gases emission.

4.2 Pollutant Emission Caused by Vehicles Using natural Gas

The use of natural gas for the propulsion of motor vehicles opens realistic possibilities for reducing emission of noxious exhaust gases. With regard to gasoline, decrease in the emission of CO, C_xH_y and NO_x emission is achieved, with a simultaneous decrease in the cancerogenic character of exhaust gases and their impact on smog generation. Emission of gases aiding the greenhouse effect, expressed through the equivalent emission of CO_2 is also reduced. With regard to diesel fuel, emission of NO_x is significantly reduced, with an extremely low particulate emission, while the emission of CO and C_xH_y, and the equivalent emission of CO_2 remains on the level of diesel engine. It is important to point out that the said properties are achieved without the use of subsequent exhaust gases treatment. By applying this on engines powered by natural gas, it is possible to achieve an additional pollutants emission reduction.

Figure 7 shows a comparison between exhaust gases emissions of delivery vehicles (mass 3000 kg, bearing capacity ≈ 2000 kg and maximum engine power ≈ 90 kW) by natural gas (CNG) ignited by spark and powered by diesel fuel, measured in the period of 2.5 years [7]. One vehicle on natural gas (vehicle 1) was used mostly under conditions of city traffic, while the other vehicle on natural gas (vehicle 2) was used mostly on open roads. It may be observed that in the vehicle powered by natural gas, a much lower emission of CO, NO_x and particles has been achieved, as well as a somewhat lower emission of CO_2 and C_xH_y with regard to vehicles with diesel engine. As could be expected, the emission of methane has been much higher in the case of vehicle powered by natural gas.

Figure 8 shows exhaust gas emission of engines running on natural gas (CNG), with the mixture being ignited by the pilot-injected diesel fuel, *Navistar DT 466* (maximum power 157 kW) and *Cummins L10* (maximum power 194 kW), parallely with the emission of base diesel engines [8]. The said CNG engines have been tested without and than with the application of subsequent exhaust gas treatment. In the first case, through the use of natural gas, emission reduction of NO_x, particulates and non-methane C_xH_y has been achieved, while CO emission was somewhat increased. After equipping the engine with oxidation catalysts, a considerable reduction of all measured pollutants has been achieved.

Figure 9 shows exhaust gas emission of engines powered by natural gas (CNG), ignited by spark, produced by MAN, used for the drive of commercial vehicles and buses (E2866 LUH02, E2866 DUH03, E3876 LUH01), parallely with the Euro standards on exhaust gas emission [9].

From the examples shown in Figures 7, 8 and 9, possibilities are clearly seen for the reduction of pollutant emission offered by the use of natural gas for the propulsion of road vehicles.

5. Conclusion

The paper analyses the structure of the vehicle pool and pollutant emissions for urban area with ca. 100,000 vehicles, typical of European transition countries. The age structure of the considered vehicle park is extremely poor, with over 70% of the vehicles more than 10 years old, with the average vehicle age being 13 years. Passenger vehicles are considered to be the main cause of pollutant emission. Environmental picture of the considered urban area has been compared to that of similar Western European areas and it has been concluded that it is on the level of theirs from 1997 and 1998. Solutions for improving it are refreshment of the vehicle pool (vehicles with modern engines meeting Euro standards), traffic organization and use of alternative fuels. At present, the optimal alternative fuel for the drive of IC engines, primarily for vehicles in urban traffic, is natural gas. Techhological solutions have been considered for using natural gas, and the environmental picture shown of the vehicles powered by natural gas. Owing to natural gas properties, a considerable reduction of the emission of CO, NO_x and particulates is achieved, while, in case of engines running on natural gas, mixture combustion by a pilot injection of diesel fuel using subsequent treatment of exhaust gases offers the possibilities of a further emisson reduction, particularly that of CO and C_xH_y. Total emission of gases contributing to the greenhouse effect is on the level of that of conventional fuels, because in gas engines, apart from CO_2, methane is also present in the exhaust.

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UDK/UDC	Ključne riječi	Key words
629.113.4	cestovna vozila s motorom na stlačeni plin	road vechicles with compressed gas engines
504.064.4	tehnologija smanjivanja zagađenja	wasteless and low waste technology
621.433	klipni plinski motori	reciprocating gas engines
621.433/.434	dvogorivni motor	dual fuel engine

Autori / Authors:
Prof. dr.sc. Ivan Filipović, mr. sc. Boran Pikula, Dževad Bibić dipl.ing, Mirsad Trobradović dipl.ing.
Mašinski fakultet Sarajevo, Odsjek za motore i vozila, Vilsonovo šetalište 9, 71000 Sarajevo, Bosna i Hercegovina

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