Dragan Škrobonja, Tomislav Beraković, Aleksandar Božunović, Zvonimir Ljubaj, Nevenka Ljubaj

ISSN 0350-350X
GOMABN 43, 4, 291- 309
Stručni rad/Professional paper
UDK 621.436.13 : 621.335.2-833.6 : 621.436.13 : 061 : 656.2:061.5 (497.15) : 620.168.2.001.42.001.45

PRIMJENSKO PRAĆENJE ULJA ZA LOKOMOTIVSKE DIZELOVE MOTORE

Sažetak

Mazivo kao nezaobilazni čimbenik u sustavu motor-gorivo-mazivo ima osim uobičajeno poznate uloge sredstva za podmazivanje i važnu ulogu kod detektiranja uspješnosti rada i stanja motora. To se postiže sustavnim praćenjem ulja u primjeni i stalnim kontaktom između korisnika i proizvođača motornog ulja. Zbog toga, ali i zbog potrebe dokazivanja kvalitete proizvedenog motornog ulja, provode se primjenska ispitivanja radi utvrđivanja raznih postavljenih ciljeva. Hrvatske željeznice u svom voznom parku vučnih sredstava posjeduju priličan broj lokomotiva opremljenih dizelovim motorom tipa 645 E proizvodnje General Motors Corporation. To su lokomotive serije 2 062. Nakon generalnog remonta motora na lokomotivama na zahtjev servisera GMC i radi vlastitog interesa za praćenjem remontiranih motora Hrvatske željeznice u dogovoru s Mazivima Rijeka, proizvođačem specijalnog lokomotivskog motornog ulja, provode praćenje ulja u (eksploataciji) primjeni.

U radu su dani dosadašnji rezultati tog primjenskog ispitivanja s komentarom i zaključcima, koji u konačnici potvrđuju potrebu i isplativost primjenskih ispitivanja. Ujedno pokazuju značaj rada postprodajnog servisa proizvođača i upućuju korisnike u Hrvatskoj na domaćeg proizvođača maziva koji je kvalitetom maziva izjednačen s konkurencijom iz inozemstva, a ujedno svojom blizinom, stručnim osobljem i laboratorijskom podrškom osigurava ispravnu i optimalnu iskoristivost maziva.

1. OPIS LOKOMOTIVE

Dizelove električne lokomotive HŽ serije 2 062 proizvodene su u tvrtki General Motors pod oznakom G 26 CW. Za potrebe željeznice nabavljane su u razdoblju od

1972. do 1974. godine. Kako se nije mogla provesti nabavka novih, odlučeno je da se provede obnova postojećih dizelovih električnih lokomotiva. Ovim programom obnove i modernizacije obuhvaćeno je dvadeset lokomotiva. Prva modernizirana i rekonstruirana lokomotiva isporučena je u srpnju 2002. godine, a zadnja, dvadeseta isporučena je u travnju 2003. godine.

Modernizacijom se htjelo postići povećanje pouzdanosti i raspoloživosti lokomotiva, smanjenje troškova održavanja, smanjenje potrošnje goriva i ulja, smanjenje ispuha štetnih plinova i poboljšanje uvjeta radnom osoblju. Projekt popravka, modernizacije i rekonstrukcije lokomotiva proveden je u suradnji s tvrtkama Turner Rail Service, TŽV "Gredelj" Zagreb i Electro Motive Division.

Nakon izvršenih radova, radi praćenja rada lokomotiva u jamstvenom roku, bila je obveza korisnika pratiti stanje motornog ulja.

2. OPIS DIZELOVOG MOTORA I NAČIN RADA

U lokomotivu je ugrađen 16-cilindrični dvotaktni dizelov motor s prednabijanjem (Rootova puhala) proizvodnje EMD tip 645 E ukupne snage 1641 kW koji pogoni glavni generator za potrebe vuče. Električna snaga glavnog generatora prenosi se na vučne motore. Šest vučnih elektromotora izravno je parom zupčanika spojeno za pripadajuće pogonske osovine.

Tablica 1:Tehnički podaci motora

vrsta		dvotaktni
broj cilindara		16
položaj cilindara		„V" 45°
kompresijski odnos		18:1
promjer cilindra	mm	230,18
hod klipa	mm	254
broj okretaja startni	min^{-1}	50 - 75
broj okretaja (prazni hod/max/prekomjerni)	min^{-1}	255/904/1000
prednabijanje		Rootova puhala
hlađenje		vodom
način ubrizgavanja goriva		pumpa - brizgaljka na svakom cilindru

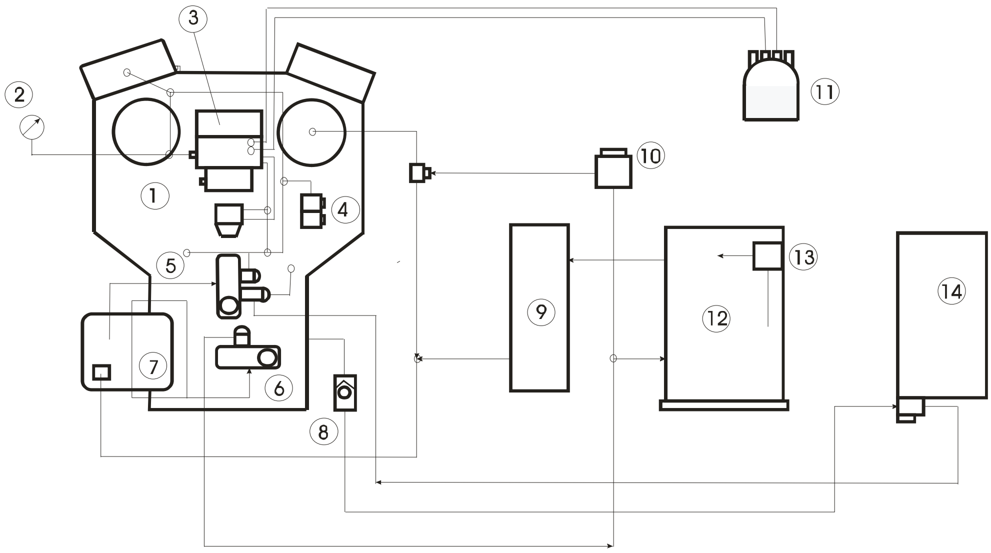
Kod ovog tipa dizelovog motora potrebna su samo dva hoda klipa za obavljanje jednog radnog ciklusa. Usis ili ispuh obavlja se za vrijeme jednog dijela radnog i jednog dijela kompresijskog hoda klipa. Kod dvotaktnog dizelovog motora klip ne funkcionira kao zračna pumpa, pa je potreban poseban vanjski uređaj koji će obaviti opskrbu dizelovog motora zrakom. Ovom tipu dizelovog motora za to služe Rootova puhala koja su ugrađena na zadnjem kraju motora i koja ubacuju veliku količinu zraka malog natpritiska u zračne komore te kroz raspore na košuljicama pune cilindre čistim zrakom potrebnim za izgaranje. Kroz otvore na glavama cilindara izbacuju ispušne plinove.

3. SUSTAV ZA PODMAZIVANJE DIZELOVOG MOTORA

Sustav za podmazivanje motora 645 E sastoji se od tri odvojena podsustava, koji čine jednu cjelinu i to (slika 1):

1. podsustav ulja za podmazivanje dizelovog motora – opskrbljuje uljem razne dijelove motora radi podmazivanja,
2. podsustav ulja za hlađenje klipova – osigurava ulje za hlađenje klipova i njihovo podmazivanje,
3. podsustav za pročišćavanje ulja – opskrbljuje prva dva podsustava ohlađenim i pročišćenim uljem.

Slika 1: Sustav motornog ulja za podmazivanje motora



1.	Dizelov motor	5.	Uljna pumpa	10.	Preljevni ventil
2.	Manometar	6.	Uljna pumpa	11.	Regulator opterećenja
3.	PG regulator	7.	Grubi pročistač	12.	Pročistač Michiana
4.	Detektor niskog tlaka vode i tlaka u karteru	8.	Nepovratni ventil	13.	Preljevni ventil Michiana
		9.	Hladnjak ulja	14.	Uređaj za predgrijavanje motora

U sustavu za podmazivanje motora ima ukupno tri pumpe za ulje. Pumpa za podmazivanje i pumpa za hlađenje, dvije zupčaste pumpe u jednom kućištu potiskuju ulje pod pritiskom kroz motor radi podmazivanja motora i hlađenja klipova.

Nakon što ulje procirkulira kroz motor, cijedi se u karter. Uljna pumpa za pročišćavanje crpi ulje iz sakupljača ulja i kućišta sitastih pročistača i tada ga potiskuje kroz pročistač ulja i hladnjak. Iz hladnjaka ulje odlazi u drugu pregradu kućišta sitastih pročistača otkuda ga pumpa za podmazivanje i pumpa za hlađenje klipova potiskuju dalje.

4. PRIMJENSKO ISPITIVANJE

Ukupno je prepravljeno 20 lokomotiva. Sukcesivno, kako su na kojoj lokomotivi radovi dovršeni, lokomotiva je počinjala rad u normalnoj eksploataciji. Lokomotive prometuju od Ogulina do Splita, Šibenika i Zadra. Konfiguracija pruge je uspon od 0 do 25 ‰, zavojita. Putnički vlakovi su težine do 600 tona, a u tandem vožnji teretnih vlakova težine su do 1 100 tona. Početak praćenja uslijedio je 23.07.2002., a prvi uzorak s prve lokomotive došao je na provjeru u rujnu 2002. Predviđeno razdoblje praćenja ulja bilo je dogovoreno na 1 godinu, što se otprilike poklapalo s očekivanom učinjenom kilometražom od cca 120000 km koliko je i motornom ulju deklarirana uporabnost. Do zaključno s 31.08.2003. sve su lokomotive ušle nakon remonta u eksploataciju. Praćenje ulja nastavit će se do isteka roka praćenja posljednje lokomotive, kada će se korisniku pokazati ukupna dokumentacija praćenja. Naravno, tijekom praćenja ulja korisnik dobiva promptno rezultate s komentarom o stanju ulja.

Laboratorijski su praćena fizikalno kemijska svojstva motornog ulja u skladu sa zahtjevima servisera motora, koji je svojim *Maintenance Instruction* odredio i primjenske granice svojstava ulja u primjeni, te najveće dopuštene sadržaje metala u ulju.

Tablica 2: Fizikalno kemijska svojstva ulja i metode po kojima su ispitivana

Svojstvo	Metoda
- viskoznost na 100 ^{0}C, (mm^2/s)	ASTM D 445
- plamište, PM, (^{0}C)	ASTM D 93
- ukupni bazni broj, TBN, (mg KOH/g)	ASTM D 2896
- netopljivo u n-pentanu, (% m/m)	ASTM D 893
- količina vode, (% v/v)	ASTM D 95
- količina metala, (mg/kg=ppm); i to: Ca, P, Zn, Fe, Cr, Mo, Sn, Pb, Cu, Na, Mg, B, Al, V, Si i Ag.	ICP-0ES

Motorno ulje

Za podmazivanje motora korišteno je specijalno motorno ulje za podmazivanje dvotaktnih dizelovih motora lokomotiva tvrtke General Motors EMD, koji troše gorivo sa sadržajem sumpora do 1 %. Specifičnost ovih motora ogleda se u posjedovanju ležaja osovinice klipa od srebrne legure, što uvjetuje sastav aditivnog sklopa bez prisutnosti cinka (Zn) u većem sadržaju od 10 mg/kg (ppm). Upotrebljavano ulje odgovara zahtjevima specifikacija API CD, GM-EMD M.I. 1761 Rev.F, i LMOA 4. generacije.

Prosječne vrijednosti fizikalno kemijskih svojstava svježeg ulja jesu:

- kinematička viskoznost	14,5 mm^2/s
- indeks viskoznosti	93
- tecište	- 15^oC
- ukupni bazni broj (min)	13 mg KOH/g

Gorivo

Tijekom ispitivanja kao pogonsko gorivo motora korišteno je dizelsko gorivo proizvedeno u skladu s normom INA N 02 – 005/03 (stara oznaka D2).

Rezultati praćenja s komentarom

Učinjeno je ukupno 48 analiza stanja motornog ulja i goriva. Prosječno su po jednom punjenju ulja rađene 3-4 provjere, uz napomenu da se kod posljednjih 6 remontiranih lokomotiva do sada provjerilo ulje samo jednom. Podaci su vođeni u tablicama (nisu priloženi radu), a neka su fizikalno kemijska svojstva i trend porasta količine metala prikazana na dijagramima. Dijagrami pokazuju ukupnost podataka za analizirane uzorke ulja sa svih lokomotiva stavljajući ih u odnos prijeđenih kilometara, kao uvjet izdržljivosti ulja unutar cijelog ciklusa jednog punjenja motora.

Tablica 3: Prijeđeni put lokomotiva tijekom jamstvenog roka

Lokomotiva	Kilometraža
2 062-101	126 572
2 062-102	118 297
2 062-103	130 558
2 062-105	109 297
2 062-107	129 289

Tijekom praćenja, do kraja kolovoza 2003. godine, bilo je oko četrdesetak registriranih zastoja – kvarova, no sve su to bili uglavnom mehanički kvarovi nastali zbog pogrešaka tijekom remontnih radova, pri čemu je u 5 slučaja bila pogreška u sustavu ubrizgavanja goriva (neispravnost rada brizgaljki), te u 2 slučaja radi prodora vode. Niti jednom nije došlo do zastoja radi kvalitete motornog ulja. No, upravo analiza ulja uputila je korisnika na potrebu utvrđivanja neispravnosti motora, što zapravo i potvrđuje značaj analiziranja mazivog ulja tijekom primjene. Tako je u skladu s primjenskim granicama stanja ulja uočen pad viskoznosti motornog ulja na jednom motoru, istovremeno i sniženje plamišta ispod prihvatljive granice, sve kao posljedica prodora goriva (neispravnost brizgaljki). U dva navrata povećana količina netopljivog upozorila je na neispravnosti sustava za pročišćavanje ulja (fitar ulja).

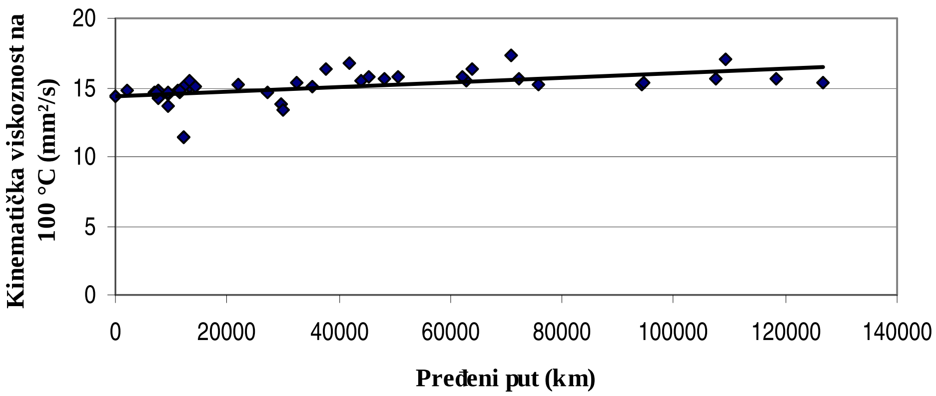
Posebni značaj ima praćenje trenda porasta količine metala iz trošenja, odnosno količina cinka kao nepoželjnog metala u ovoj vrsti motornog ulja.

Zaključno s 1. rujna 203. pet lokomotiva je izašlo iz godišnjeg roka praćenja i pri tome su prevalile kilometražu prema tablici 3 iz koje se vidi da su to sve prijeđeni putovi oko predviđenih 120000 km. To je potvrda kvalitete ulja i uspješnosti obavljenih radova.

Vrijednosti fizikalno kemijskih svojstava kretale su se, uz nekoliko slučaja prethodno navedenih nenormalnosti tijekom eksploatacije motora, unutar očekivanih granica, a o pojedinačnim svojstvima komentar je slijedeći:

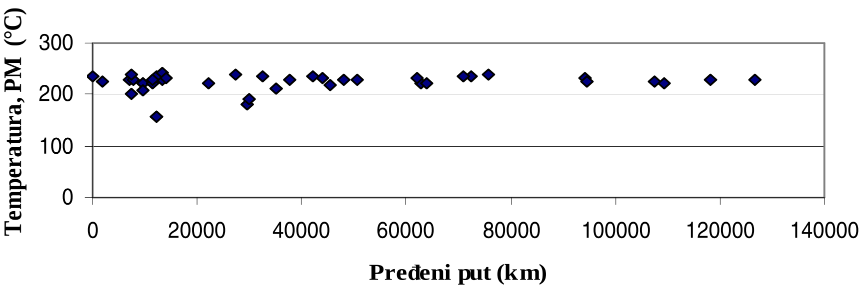
Kinematička viskoznost – Očekivano je da kinematička viskoznost radi prodora goriva s vremenom pada, ili kod dobro održavanih motora dolazi do laganog porasta kao posljedica povišenja netopljivog u ulju, a bez prodora goriva. Općenito nakon remonta motora očito je da je brtvljenje kompresijskog prostora motora učinkovito, da nema prodora goriva, odnosno brizgaljke su dobro podešene (jedan prodor goriva), sustavi održavanja čistoće motora obavljali su uspješno svoju funkciju (2 malo jača zaprljanja), odnosno u dva navrata došlo je, na cca 70000 km, do porasta viskoznosti na granicu 15% porasta od početne vrijednosti, što je unutar prihvatljivog. Da zaključimo: tijekom ispitivanja viskoznost je malo rasla, no čitavo razdoblje ispitivanja ostala je unutar početne gradacije viskoznosti, što znači da je ulje uspješno održavalo svojstvo podmazivosti bez opasnosti za ispravan rad i stanje motora.

Dijagram 1: Promjena kinematičke viskoznosti motornog ulja
Diagram 1: Change of motor oil kinematic viscosity



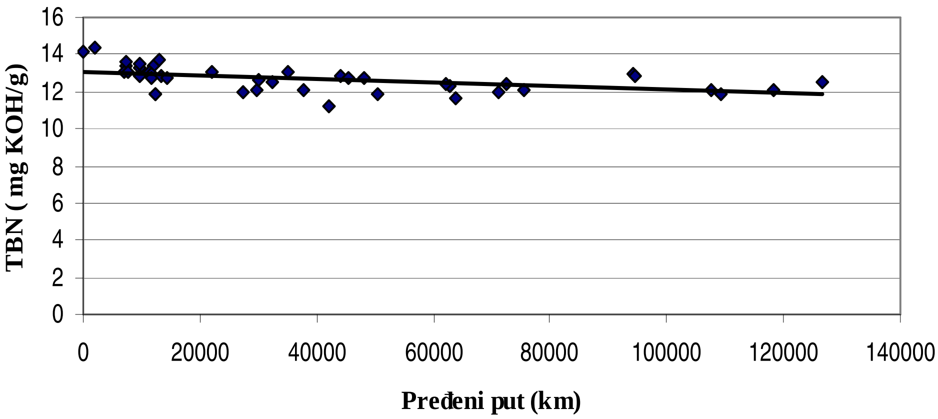
Plamište – Vrijednosti plamišta pokazuju da su tijekom primjenskog ispitivanja sustavi goriva bili ispravni, bez utjecaja goriva na motorno ulje. Samo u jednom slučaju došlo je do pada plamišta, što se signaliziralo korisniku i u skladu s tim poduzete su potrebne mjere za tehničko dotjerivanje motora.

Dijagram 2: Promjena plamišta motornog ulja
Diagram 2: Motor oil flash point change



Količina vode – Uglavnom, nije utvrđena ili se pojavljivala u tragovima tijekom ispitivanja. Vrlo pohvalna činjenica, pogotovo kada iskustva pokazuju vrlo često visok postotak prijevremene zamjene ulja radi prodora rashladne tekućine u ulje. No, u dva slučaja bilo je odmah nakon početka eksploatacije lokomotiva utvrđeno veliko propuštanje rashladnog sredstva, te se pravodobnom reakcijom otklonilo kvar i nastavljena je uporaba lokomotive.

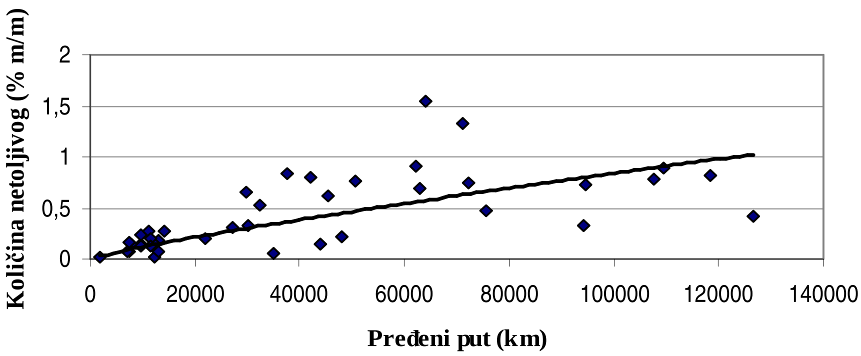
Dijagram 3: Promjena ukupnog baznog broja (TBN)
Diagram 3: TBN change



Ukupni bazni broj (TBN) – Imao je očekivani pad vrijednosti s obzirom na početnu vrijednost, ali i količinu ulja u sustavu. Ulje je dobro štitilo motor i moglo je biti još u uporabi, no radi "pretrčanih" kilometara (120000 km) ulje se zamjenjuje. Ovo potvrđuje i kvalitetu goriva glede sadržaja sumpora.

Netopljivo u n-pentanu – Kod svih motora vrijednosti netopljivog su tijekom ispitivanja bile vrlo male, odnosno lagano su rasle s prijeđenom kilometražom lokomotiva. One pokazuju da su motori imali dobru podešenost, osim u nekoliko navrata kod problema s rasprskačima no nije bilo utjecaja na viskoznost motornog ulja. No, sve su te vrijednosti unutar normalnih granica bez ikakvih bojazni za ukupno stanje ulja/motora.

Dijagram 4: količina netopljivog u n-pentanu
Diagram 4: Volume of n pentane-insoluble



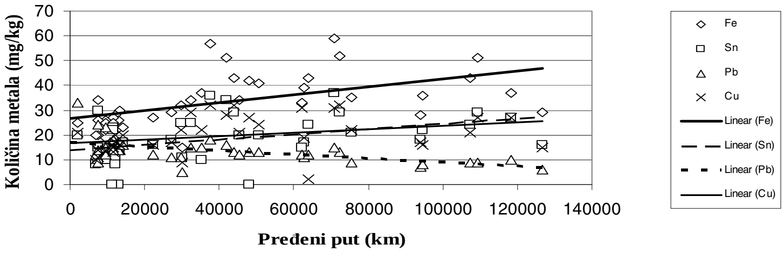
Metali iz trošenja motora – Vrijednosti količine metala koje potječu od trošenja pojedinih dijelova motora su bile male i ukazuju na minimalno trošenje motora.

Brojčano su najveće količine željeza, što je uobičajena pojava, ali su i najviše dopuštene granice za količine željeza u motornom ulju, tako da je sve unutar očekivanih i prihvatljivih graničnih veličina.

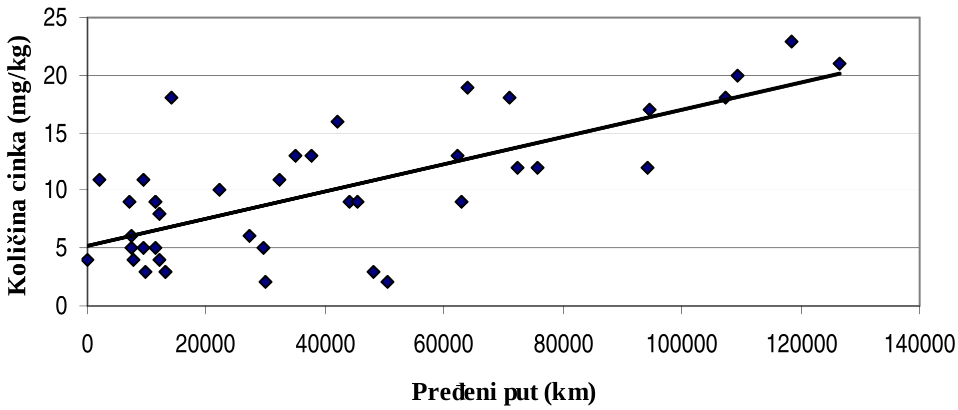
Zanimljivo, da iako je količina cinka rasla (vidi dalje tekst) nije bilo u ulju porasta srebra, što znači da barem u motorima dosada ispraćenih do predviđene kilometraže nije bilo tog trošenja.

Količina cinka (Zn) – Kao metal kojega se prati zbog srebrne legure iz koje su napravljene osovinice klipova, pokazao je zanimljiv trend porasta u ulju. Kako su dopuštene minimalne količine u svježem ulju ograničene na 10 mg/kg, a što je vrlo mala veličina i sa stajališta određivanja, to se posebna pažnja posvetila upravo utvrđivanju stvarne količine cinka u ulju. Iskustva primjenskih ispitivanja u prethodnim godinama su nas učila mogućim pogreškama kod manipulacije s posudama za ulijevanje ulja s kojima se barata u stanicama za tehničko održavanje: Zagreb, Ogulin, Knin i Split. Već 1 % standardnog motornog ulja, a takvog ulja ima u takvim radionicama zbog rada i s drugim tipovima lokomotivskih motora, daje u ovom lokomotivskom ulju 10-ak ppm cinka. Dakle, zaključili smo da se to upravo i dogodilo, da se kod nadolijevanja koristilo zagađeno posuđe cinkom (pocinčana posuda ili ostaci drugog ulja). Nadolijev je inače prilično velik kod ovih motora, tako da već nakon prvih 10000 km počinje rasti količina cinka u motornom ulju. To je veliki problem kojeg moraju službe održavanja korisnika ozbiljno razmotriti i poduzeti odgovarajuće aktivnosti za obuku osoblja i odgovornosti u poslu.

Dijagram 5: Količina metala u motornom ulju
Diagram 5: The motor oil metal content



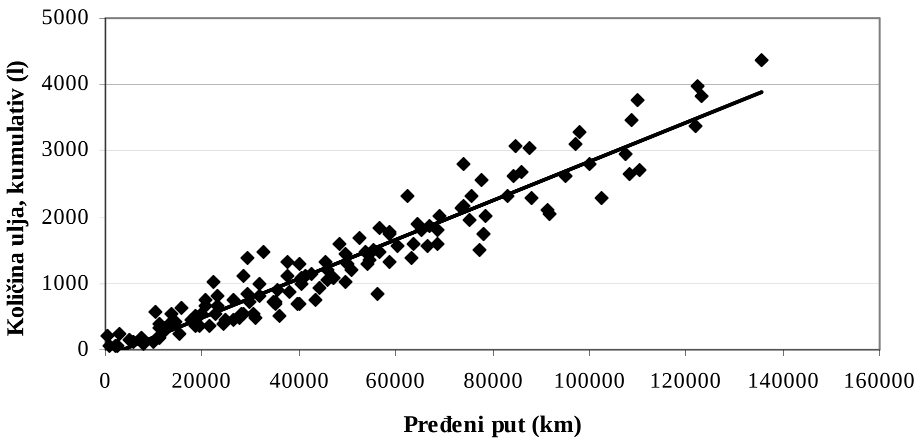
Dijagram 6: Količina metala – cink (Zn) u motornom ulju
Diagram 6: The motor oil metal – zinc (Zn) content



Potrošnja ulja – To je značajan podatak, čija veličina ovisi o konstruktivnim karakteristikama motora, tehničkom stanju motora te uvjetima eksploatacije i kvaliteti motornog ulja. U ovom slučaju smanjenje potrošnje ulja (ali i goriva) bio je i jedan od ciljeva preinaka na motorima, tako da se posebna pažnja korisnika posvetila praćenju potrošnje i to u odnosu na utrošeno gorivo.

Na temelju podataka iz nadolijeva može se već nešto zaključivati, no sve još nije do kraja kompletirano. Na kraju praćenja moći će se napraviti ukupna analiza, a za sada imamo podatak o omjeru potrošnje ulja prema gorivu od 0,57 % do 1,05 %. Takve razlike tumačimo velikom raznolikošću opterećenja lokomotiva i načina korištenja. Posebno valja naglasiti, kako zbog određenih razloga nisu sve lokomotive mogle iskorististiti novougrađene uređaje za održavanje radne temperature pogona kod dužeg zaustavljanja jer svuda nije omogućen električni priključak za napajanje lokomotive u stajanju. Jasno da je to direktno utjecalo i na ukupni potrošak goriva, pa su i omjeri u širokom rasponu. Što se potroška ulja tiče, iz dijagrama možemo vidjeti kumulativnu količinu nadolijeva tijekom eksploatacije (do kraja kolovoza 2003.) uzimajući u obzir sve lokomotive. Pojedinačna količina nadolijeva sigurno utječe na stanje uljnog punjenja i doprinosi produženju intervala zamjene uljnog punjenja, no valja prihvatiti kao osnovnu potrebu nadolijevanja ulja u nadoknadi ulja radi propuštanja, trošenja/izgaranja u kompresijskom prostoru i dijelom isparenja ulja. Za lokomotive koje su prešle ukupno predviđeni broj kilometara (120000 km) imamo uz početnih 672 litre ulja u uljnom sustavu po motoru prosječni nadolijev od cca 3400 litara što je u granicama normalne očekivane potrošnje.

Dijagram 7: Količina nadolivenog ulja u motor
Diagram 7: Engine topping up volume



5. ZAKLJUČAK

1. Mazivo kao nezaobilazni čimbenik u sustavu motor-gorivo-mazivo ima osim uobičajeno poznate uloge sredstva za podmazivanje i važnu ulogu kod detektiranja uspješnosti rada i stanja motora. To se postiže sustavnim praćenjem ulja u primjeni i stalnim kontaktom između korisnika i proizvođača motornog ulja.
2. Nakon generalnog remonta motora na GMC lokomotivama radi vlastitog interesa za praćenjem remontiranih motora korisnik je u dogovoru s proizvođačem motornog ulja za lokomotivske dizelove motore proveo praćenje ulja u eksploataciji.
3. U dosadašnjem ciklusu praćenja rezultati stanja ulja potvrdili su kvalitetu upotrebljavanog motornog ulja i ujedno bili koristan pokazatelj stanja motora i mogućih neispravnosti koje upućuju korisnika na potrebne zahvate u dovođenju tehničkog stanja motora u zahtijevane granice.
4. Predstavljeni rezultati praćenja su dio ukupnog praćenja, koje će biti kompletirano nakon isteka jamstvenih rokova i za posljednju lokomotivu, kada će se sastaviti i završni izvještaj.
5. Rezultati primjenskog ispitivanja potvrđuju potrebu i isplativost primjenskih ispitivanja. Ujedno pokazuju značaj rada postprodajnog servisa proizvođača i upućuju korisnike u Hrvatskoj na domaćeg proizvođača maziva koji je kvalitetom maziva izjednačen s konkurencijom iz inozemstva, a ujedno svojom blizinom, stručnim osobljem i laboratorijskom podrškom osigurava ispravnu i optimalnu iskoristivost maziva.

APPLICATIVE MONITORING OF LOCOMOTIVE DIESEL ENGINE OIL

Abstract

Lubricant, as a factor that cannot be avoided in the engine-fuel-lubricant system, besides its normally known lubricating function, plays a highly important role in detecting the efficiency of operation and the condition of engine. This is obtained by a systematic observation of oil in application and by a permanent contact between user and motor oil producer. For this reason, but also in order to prove the quality of produced motor oil, applicative tests are being performed for the purpose of *establishing various set goals. "Hrvatske željeznice" (HŽ) have in their tow pool a considerable number of locomotives equipped with diesel engine type 645 E, produced by the General Motors Corporation. These are locomotives of the 2 062 series. After general overhaul performed on the locomotives upon request of the GMC service, and because of their own interest in observing the repaired engines, HŽ are, together with "Maziva Rijeka" (specialized locomotive motor oil producer), implementing the observation of oil in field service.*

The paper presents the so far results of the trial tests, with comments and conclusions, in the long run confirming the need for trial tests and their payability. It furtherly points out the importance of "after sale" manufacturer services, and directs the users in Croatia to the domestic lubricant producer whose quality matches that of foreign competitors, while the vicinity, skilled experts and laboratory support ensure a correct and optimal utilization of the lubricant.

1. LOCOMOTIVE DESCRIPTION

Diesel-electric locomotives owned by HŽ of the series 2062 were manufactured at the General Motors Corp. under the mark G 26 CW. They were being acquired for the needs of HŽ in the period from 1972 to 1974. Since it was not possible to acquire new ones, it has been decided that the existing ones should be renewed. The said modernization and reconstruction program encompassed 20 locomotives. The first one was delivered in July, 2002 and the last, 20th one in April, 2003.

The purpose of the modernization was to increase the locomotives' reliability and availability; reduce maintenance costs, fuel and oil consumption and exhaust gas emission, as well as to improve the occupational conditions. The project was implemented as a joint venture of Turner Rail Service company, TŽV "Janko Gredelj" Zagreb and GMC Electro Motive Division.

After the works were performed, in order to monitor the locomotives during the warranty period, the user was obliged to observe the motor oil condition.

2. THE DIESEL ENGINE DESCRIPTION AND OPERATING PRINCIPLE

The locomotive has a 16-cylinder two-stroke diesel-engine with supercharging by Rootes blowers prod. EMD type 645 E with the total power of 1641 kW driving the main generator for the needs of traction. Electric power of the main generator is being transferred to traction motors. Six traction electric motors are directly connected to the pertaining traction axes by a couple of gears.

This diesel-engine type requires only two piston plays per operating cycle. Intake or exhaust is performed during a part of the operating and a part of compression piston play. In two-stroke diesel-engines, the piston does not function as an air pump, so that a special external system is required in order to supply diesel-engine with air. This type of diesel-engine has Rootes blowers for the purpose, built into the end part of the diesel-engine, supplying large volume of low overpressure air into the air chambers, and, through cylinder openings, fill the cylinders with pure air necessary for combustion. Through the openings on cylinder heads, they discharge combustion gases.

Table 1: Technical data on the engine

type		two-stroke
n° of cylinders		16
position of cylinders		“V” 45°
compression ratio		18:1
cylinder diameter	mm	230,18
piston play	mm	254
rpm (start)	min^{-1}	50-75
rpm (neutral/max/excessive)	min^{-1}	255/904/1000
supercharging		Rootes blowers
cooling		water cooling
fuel injection		pump-injector on every cylinder

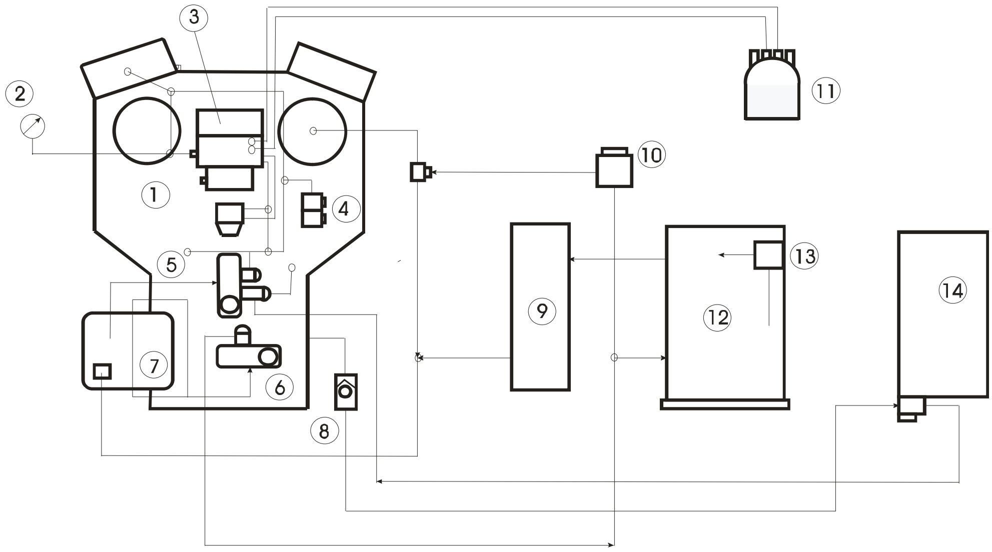
3. DIESEL ENGINE LUBRICATION SYSTEM

Lubrication system of diesel-engine 645 E consists of three separate subsystems, constituting a single unit, as follows (Figure 1):

1. diesel-engine lubrication subsystem – supplies various diesel-engine parts with oil for lubrication,
2. piston cooling oil subsystem – ensures oil for piston cooling and lubrication,
3. oil filtering subsystem – supplies the first two subsystems with cooled and filtered oil.

Diesel-engine lubrication system has the total of three oil pumps. Lubrication pump and cooling pump, two gear pumps in a single casing, push the oil under pressure through the engine, for its lubrication and piston cooling. After the oil circulates through the engine, it is drained into the oil-sump. Oil pump takes oil for filtering from the oil sump and mesh filters and pushes it through the oil filter and cooler. The oil from the oil cooler, goes to the second set of mesh oil filters, where the lubrication pump and the piston cooling pump pushes it forward.

Figure 1: Motor oil system for engine lubrication



1. Diesel engine
2. Manometer
3. PG regulator
4. Low water pressure and oil-sump pressure detector
5. Oil pump
6. Oil pump
7. Coarse filter
8. Irreversible valve
9. Oil cooler
10. Overflow valve
11. Load regulator
12. Michiana filter
13. Overflow Michiana valve
14. Engine preheating device

4. TRIAL TESTS

The total of 20 locomotives was reconstructed. Successively, as the works were completed on a respective locomotive, it was being returned to normal service. The locomotives are traveling from Ogulin to Split, Šibenik and Zadar. Track configuration is ascending from 0 do 25 ‰, and winding. Passenger trains weigh up to 600 tons, and in tandem drive of cargo trains up to 1,100 tons. The monitoring was begun on 23/07/2002, while the first sample from the first locomotive came for checkup in September, 2002. The envisaged oil monitoring period was set to 1 year, more or less matching the expected mileage of ca. 120,000 km, which is at the same time the montored oil declared service life. Up to 31/08/2003, all the locomotives regained exploitation after overhaul. Oil monitoring shall continue until the last locomotive monitoring term, after which the user will be supplied with overall monitoring documentation. It goes without saying that, during oil monitoring, the user was being timely supplied with the comments on oil condition.

Laboratory tests were used for monitoring the physico-chemical properties of motor oil in keeping with the engine servicer requirements, who set in his *Maintenance*

Instruction also the application limits of the oil properties in service, as well as the highest permissible metal content in oil.

Table 2. Physico-chemical properties of oil and methods according to which they were monitored

Property	Method
- viscosity at 100 ^{0}C, (mm^2/s)	ASTM D 445
- flash point, PM, (^{0}C)	ASTM D 93
- total base number, TBN, (mgKOH/g)	ASTM D 2896
- n-pentane insoluble, (%m/m)	ASTM D 893
- water content, (%v/v)	ASTM D 95
- metal content, (mg/kg=ppm); for: Ca, P, Zn, Fe, Cr, Mo, Sn, Pb, Cu, Na, Mg, B, Al, V, Si and Ag.	ICP-0ES

Motor Oil

For lubrication of engines manufactured by General Motors EMD consuming fuel with up to 1 % sulphur content, a special two-stroke locomotive diesel motor oil was used. Specific property of these engines is the piston pin bearing made of silver alloy, conditioning the composition of the lubricating oil additive package without zinc (Zn) in the amount exceeding 10 mg/kg (ppm). The oil used matches the requirements of API specifications CD and GM-EMD M.I. 1761 Rev.F, and LMOA, 4th generation.

Average values of the fresh oil physico-chemical properties are as follows:

- kinematic viscosity	14.5 mm^2/s
- viscosity index	93
- pour point	- 15^{o}C
- total base number (min)	13 mgKOH/g

Fuel

During tests, the diesel fuel manufactured in accordance with the INA N 02 – 005/03 standard was used.

Monitoring Results and Comment

The total of 48 motor oil and fuel condition analyses were performed. The average of 3-4 checkups were performed per oil fill, noting that for the last 6 overhauled locomotives the oil has been checked only once so far. The data were presented in Tables (not included in the paper), while some physico-chemical properties and metal content increase trend are shown in diagrams. Diagrams show overall data for analyzed oil samples from all locomotives, relating them to the mileage covered, as oil perseverance condition within an entire cycle of individual engine fill.

During monitoring, by the end of August this year, there were some (around 40) registered halts – failures, but they were mostly mechanical failures caused by errors made during overhaul, including 5 cases of the fuel injection system failure (injector failure), and 2 cases of water penetration. There was not a single halt that would be associated with motor oil quality. However, it was the oil analysis that notified the user of the need for an engine checkup, which actually confirms the significance of analyzing lubricant oil in application. Thus, it was in accordance with the applicative limits of oil condition that motor oil viscosity reduction was observed at an engine, with a simultaneous flash point lowering below the acceptable limit, all resulting from fuel penetration caused by incorrect operation of injectors. In two cases, increased insoluble content pointed to the failure of the oil filtering system (i.e. the oil fiter). Of special importance is the monitoring of metal content increase trend as a result of wear, i.e. zinc content, being an undesirable metal in this kind of motor oil.

Table 3. Locomotives' mileage covered during the warranty period

Locomotive	**Milleage**
2062-101	126.572
2062-102	118.297
2062-103	130.558
2062-105	109.297
2062-107	129.289

By 1 September, the total of 5 locomotives finished the annual monitoring term, having covered the mileage indicated in Table 3, showing that it more or less corresponds to the envisaged 120,000 km. This confirms oil quality and efficiency of works performed.

The values of physico-chemical properties were, apart from several aforementioned cases of irregularities during engine exploitation, ranging within expected limits, while the comment on individual properties is as follows:

Kinematic viscosity – As expected, kinematic viscosity usually decreases in time due to fuel penetration, or - in well maintained engines, there occurs a slight increase as a result of the increase of the oil insolubles, without fuel penetration. Generally speaking, after engine overhaul, it is obvious that the engine compression area sealing is efficient, that there is no fuel penetration i.e. the injectors are well adjusted (single fuel penetration), the engine cleanliness maintenance systems were performing their function successfully (2 considerable cases of impurities accumulation), i.e. in two cases, after ca. 70,000 km, viscosity was increased to the limit of 15% of the initial value, which is still acceptable. In conclusion: during testing, viscosity was slightly increasing, but throughout the testing period it remained within the initial grade, which means that oil was successfully maintaining its lubricating property without threat to the engine's safe operation and condition.

Flash Point – Flash point values show that during field testing the fuel systems were correct, without fuel impact on motor oil. Only in one case the flash point dropped, of which the user was notified and hence the necessary measures were undertaken for a technical correction of the engine.

Water Content – Generally, was not identified or appeared only in traces during the testing. This is most commendable, especially with the experience showing that there is a very high percentage of early oil fill change caused by coolant penetration into oil. However, in 2 cases, right after the beginning of locomotive exploitation, a great leakage of the cooling system was established. After the failure was repaired, the locomotive was put back in use.

Total base number (TBN) – had the expected value drop with regard to the initial value, but also to the oil volume in the system. The oil was protecting the engine well and could have remained in use, but, due to the mileage covered (120,000 km), it was replaced. This also confirms fuel quality in terms of sulphur content.

n-pentane insoluble – For all engines the values of the insoluble were very low during tests i.e. were slightly raising with the locomotives' envisaged mileage. They show that the engines were well adjusted, except in a few cases when there were problems with fuel injectors, but there was no impact on the viscosity of motor oil. The values were still within normal limits without any threat to the overall oil/engine condition.

Metals from the engine wear – The values of metal content originating from the wear of individual engine parts were low and indicate a minimal engine wear.

Highest were the iron volumes, which is usual, and also have the highest permissible content limits, so that everything was within the expected and permissible limit values.

It is interesting to note that although the zinc content was increasing (see below) there was no oil silver content increase, which means that at least the engines that have so far reached the envisaged mileage did not have that kind of wear.

Zinc content (Zn) – As a metal being monitored because of the silver alloy from which the piston pin bearings are made, it has shown an interesting oil content increase trend. Since the permissible minimal fresh oil content is limited to 10 mg/kg, which is a very low volume to determine, special attention was paid to determining the exact oil zinc content. The experience of trial tests in previous years taught us the possibility of error when manipulating oil handling vessels used at the technical maintenance stations: Zagreb, Ogulin, Knin and Split. As much as 1% of standard motor oil, which is present at such workshops due to the work with other types of locomotive engines, provides this locomotive oil with some 10 ppm of zinc. Our conclusion was that this is exactly what happened, because vessels polluted by zinc were used for topping up (galvanized vessel or another residual oil). Topping up is quite extensive in these engines, so that already after the first 10,000 km the zinc content starts to grow. This is a major issue that user maintenance services need to take into account and undertake appropriate measures in terms of personnel training and occupational responsibility.

Oil Consumption - is an important piece of information, whose value is dependent on the structural properties of the engine, its technical condition, exploitation conditions and motor oil quality. In the present case of reduced oil (and also fuel) consumption, one among the goals was engine adaptation, so that the user paid a special attention to consumption monitoring in terms of fuel consumption.

Based on topping up data, we may already make some conclusions, but the whole picture isn't complete yet. At the end of monitoring, final analysis will be possible, while for the time being we have the information on the oil: fuel consumption ratio of 0.57 % to 1.05 %. Such differences are explained by great differences of locomotive load and service conditions. We should point out in particular that for certain reasons all locomotives were not able to use the newly installed devices for maintaining the engine operating temperature during longer standstills, because the electric coupling for locomotive charging at a standstill is not always available. This of course had a direct impact on total fuel consumption, which is why the ratios have a rather wide range. As far as oil consumption is concerned, the diagram shows a cummulative topping up value during service (by the end of August 2003), taking into account all locomotives. Individual topping up volume definitely impacts the oil fill condition and contributes to the oil fill interval, but the basic need for topping up is caused by leakage, wear/combustion in the compression area and partially also oil evaporation. For locomotives that have covered total envisaged mileage (120,000 km), we have – with the initial 672 litres of oil in the oil fill per engine, an average topping up of ca. 3,400 litres, which is within the limits of normal expected consumption.

5. CONCLUSION

1. The lubricant, being an inevitable factor in the engine-fuel-lubricant system has – apart from the usual lubricating role, also an important role in detecting the engine operation efficiency and condition. This is achieved through a systematic monitoring of oil in application and a permanent contact between the motor oil manufacturer and user.
2. After engine overhaul on GMC locomotives, the user has, due to his own interest for the monitoring of overhauled engines, in agreement with the manufacturer of motor oil for locomotive diesel engines, performed the monitoring of oil in exploitation.
3. In the so far monitoring cycle, the oil condition results have confirmed the quality of the motor oil used, at the same time proving to be a useful indicator of engine condition and of possible malfunctions, instructing the user about the necessary interventions in order to bring the engine's technical condition within required limits.
4. Presented monitoring results are a part of overall monitoring, which will be completed upon the expiry of warranty period for even the last locomotive, when the final report will be drawn up.
5. The results of field tests confirm the need and payability of trial testing. They also point to the importance of manufacturer's aftersale servicing and direct users in Croatia towards local lubricant producers whose lubricant quality matches that of the foreign competition, while at the same time ensuring a

correct and optimal lubricant usability owing to their availability, expert personnel and laboratory support.

Literatura / References:

1. TURNER, Turner Diesel Limited / TZV GREDELJ d.o.o. Zagreb, (2000.), "Uputa za upravljanje i rukovanje dizel-električnom lokomotivom HŽ serije 2062 100";
2. Electro-Motive Division Of General Motors Corporation, Illinois, USA, "Maintenance Instruction" M.I.1761 *Rev.F: Lubricating oil for export locomotive engines;
3. INA Industrija nafte d.o. Zagreb, MAZIVA RIJEKA, (2000), QAM MR Poslovnik osiguranja kvalitete u Mazivima Rijeka, QPS 1901 Postupak postprodajnog servisa maziva;
4. Norma INA N 12-122 za lokomotivsko ulje INA Lokomol HS 40;
5. Norma INA N 02-005/03 za kvalitetu dizelskih goriva;
6. Norme ASTM za provjeru fizikalno kemijskih svojstava mazivih ulja;

ključne riječi:	key words:
621.436.13 dvotaktni dizelovi motori lokomotiva	locomotive two stroke diesel engine
621.335.2-833.6 dizelove električne lokomotive	diesel-electric locomotives
General Motors Odjel elektro vuče	General Motors Electro Motive Division (GM EMD)
656.2:061.5 (497.15) Hrvatske željeznice (HŽ)	Croatian Railways
620.168.2 ispitivanje, primjensko eksploatacijsko (field conditions)	field application testing
.001.42 gledište praćenja kvaliteta ulja tijekom uporabe	oil quality in use period monitoring viewpoint
.001.45 gledište praćenja stanja i održavanja motora	engine operation and maintenance monitoring viewpoint

Autori / Authors:
Dragan Škrobonja[1], dipl.ing., Tomislav Beraković[2], dipl.ing., Aleksandar Božunović[1] dipl.ing., Zvonimir Ljubaj[2], dipl.ing. Nevenka Ljubaj[2], dipl.ing.
[1]INA Maziva Rijeka, Marketing, Tehnički servis, Rijeka, M. Barača 26
[2]Hrvatske željeznice d.o.o., Zagreb, Mihanovićeva 12

Primljeno / Received:
4.12.2003.