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MOGUĆNOSTI PROIZVODNJE MOTORNIH GORIVA U INI PREMA NOVIM ZAHTJEVIMA KVALITETE

Sažetak

Proizvodnja i potrošnja goriva posljednjih je godina obilježena velikim promjenama povezanim sa sve strožim zakonskim regulativama koje se odnose na smanjenje štetne emisije. U Europi i svijetu izrađen je zakonodavni ustroj s detaljnim vrijednostima svih parametara kvalitete goriva na osnovi kojih će se oblikovati tehnologija i kvaliteta goriva počevši od 2000. godine, što zahtijeva kompleksne zahvate u strukturi rafinerijske prerade, od izgradnje novih preradbenih jedinica, preko preinaka postojećih pa do preispitivanja optimalnosti tokova prerade. Prva dva rješenja podrazumijevaju velike kapitalne investicije pa naftna industrija u svijetu prolazi kroz niz dinamičnih promjena ulaganja i modifikacije organizacije vlasništva.

Cilj rada je ispitivanje mogućnosti proizvodnje goriva koja zadovoljavaju nove specifikacije (nakon 2002. godine u Hrvatskoj) prema postojećoj tehnološkoj konfiguraciji RN Rijeka pomoću LP modela za optimiranje proizvodnje. Mogućnosti proizvodnje i isplativost ispituju se za različite opcije odabira nafti, preusmjeravanje tokova i blendinga.

1.UVOD

Europski model kontrole emisije, njegova strategija i načela utvrđeni su Auto Oil programom unutar kojeg je precizno definirana kvaliteta goriva, počevši od 2000. godine. Opći zahtjevi kvalitete goriva odnose se na:

a) kvalitetu motornih benzina

- smanjenje sadržaja sumpora (↓ 150 ppm)
- smanjenje napona para (↓ 600 mbar RVP)
- smanjenje sadržaja benzena (↓ 1 vol%) i ukupnih aromata (↓ 42 vol%)
- smanjenje sadržaja olefina (↓18 vol%)

b) kvalitetu dizelskog goriva

- smanjenje sadržaja sumpora (↓ 350 ppm)
- smanjenje sadržaja poliaromata (↓ 11 vol%)
- povećanje cetanskog indeksa (↑ 51)

U pripremi je novi paket mjera koji bi trebao stupiti na snagu 2005. godine i regulirati daljnje smanjenje sadržaja sumpora (↓ 50 ppm u motornim benzinima i dizelskom gorivu) te daljnju regulaciju ostalih parametara kvalitete.

Europskim zemljama slabije ekonomske moći (u koje spada i Hrvatska) je za primjenu navedenih parametara kvalitete dopušten određeni vremenski pomak. Zbog toga kvaliteta motornih goriva koja se danas proizvode u Hrvatskoj, kao i njezina korekcija predviđena za 2002. godinu*, odstupa od kvalitete goriva u EU.

2. PROIZVODNJA GORIVA PREMA BUDUĆIM ZAHTJEVIMA KVALITETE

Proizvodnja goriva prema propisanim parametrima kvalitete podrazumijeva različite opcije, ovisno o konfiguraciji rafinerije i tržišnim zahtjevima, koje se mogu svrstati u nekoliko grupa: opcije za snižavanje sadržaja sumpora, benzena, aromata i olefina u motornim benzinima te opcije za smanjenje sadržaja sumpora i aromata i povećanje cetanskog broja u dizelskom gorivu.

a) Opcije zadovoljavanja kritičnih zahtjeva kvalitete motornih benzina

Osnovni izvor sumpora u motornim benzinima je FCC benzin pa opcije smanjenja sumpora podrazumijevaju zahvate kojima se smanjuje udio sumpora u FCC benzinu:

- odabir nafti s manjim sadržajem sumpora (kratkoročno i skupo rješenje),
- frakcioniranje FCC benzina i na srednje destilacijsko područje (130-160°C) te njegovo usmjeravanje na reforming nakon hidroobrade,
- predobrada FCC sirovine,
- hidroobrada FCC benzina,
- kombinacija predodrade i postobrade.

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* U razdoblju između izrade i objave ovog rada stupio je na snagu Sporazum o pridruživanju Hrvatske WTO-u te će se sukladno tome morati tražiti dozvola za kontigente proizvoda koji odstupaju od zahtjeva iz Uredbe o standardima kakvoće tekućih naftnih goriva.

Smanjenje sadržaja benzena i aromata u motornim benzinima odnosi se na reguliranje rada reforminga, odnosno tretiranje reformata jer predstavlja osnovni izvor benzena. Opcije za smanjenje sadržaja aromata na 42, odnosno 35 vol% i benzena na 11 vol% su:

– predfrakcioniranje primarnog teškog benzina na temperature ispod 80°C, isključujući temperaturno područje vrenja benzena, odnosno uklanjanje prekursora benzena, čime se dobiva i do 50% manje benzena, ali se smanjuje oktanski broj reformata,
– snižavanje oštrine reforminga,
– uklanjanje benzena i aromata iz reformata (frakcioniranje, zasićenje, ekstrakcija).

Kako se obradbom reformata smanjuje njegov oktanski broj, manjak oktanskog doprinosa treba nadoknaditi drugim komponentama, koje ne povećavaju kritične ekološke parametre kvalitete motornih benzina. Opcije održavanja oktanske razine su:

– izomerizacija,
– eterifikacija,
– alkilacija,
– polimerizacija.

b) Opcije zadovoljavanja kritičnih zahtjeva kvalitete dizelskog goriva

Opcije za smanjenje sadržaja sumpora u dizelskom gorivu je hidrodesulfurizacija srednjih destilata, preusmjeravanje tokova lošije kvalitete na tržišno manje atraktivne proizvode, a smanjenje sadržaja poliaromata postiže se zasićenjem i otvaranjem prstena. Dearomatizacija se postiže dubokom hidroobradom ili hidrokrekingom. Otvaranje prstena poliaromata omogućuje dostizanje i ostalih zahtjeva kvalitete dizelskog goriva: povećanje cetanskog broja, smanjenje gustoće i snižavanje točke T95.

3. OPTIMIRANJE PROIZVODNJE POMOĆU LP MODELA

U LP modelu su rafinerijski procesi i operacije predstavljeni sustavom linearnih jednadžbi, (nejednadžbi) koje predstavljaju masene bilance, prinose procesnih jedinica, kvalitetu sirovina, međuprodukata i produkata, cijene i dr. Rješenja navedenog sustava jednadžbi moraju zadovoljavati ograničenja (tržište, kapaciteti, kvaliteta produkata i dr.) uz istovremeno maksimiziranje funkcije cilja (rafinerijska marža). Model RN Rijeka omogućuje simuliranje i optimiranje rafinerijskih procese i operacije, a rezultat optimiranja je maksimalna dobit koju je moguće ostvariti u okvirima zadanih ograničenja (cijene, količine, kapaciteti, specifikacije i dr.). Elementi rafinerijskog modela prikazani su u tablici 1.

Tablica 1: Struktura i elementi LP modela za optimiranje rafinerijske proizvodnje
Table 1: Structure and elements of LP model for refinery production optimization

<table>
<tr><td rowspan="2">Ulazni podaci za svaki slučaj
Input data for any case</td><td colspan="2">CIJENE/PRICES</td><td>KOLIČINE/VOLUMES</td></tr>
<tr><td colspan="2">SPECIFIKACIJE PRODUKATA
PRODUCT SPECIFICATIONS</td><td>RADNA OGRANIČENJA
OPERATION LIMITATIONS</td></tr>
<tr><td rowspan="3">Podaci iz modela
Data from the model</td><td colspan="2">BAZA PODATAKA O NAFTAMA
CRUDES DATABASE</td><td>KAVALITETE TOKOVA
FLOW QUALITY</td></tr>
<tr><td colspan="2">PRINOSI PROCESNIH JEDINICA
PROCESS UNITS YIELDS</td><td>TROŠKOVI RADA
OPERATING COSTS</td></tr>
<tr><td colspan="2">PROCESNE JEDINICE
PROCESS UNITS</td><td>NAMJEŠAVANJE PROIZVODA
PRODUCT BLENDING</td></tr>
<tr><td rowspan="3">Struktura modela
Model structure</td><td>ULAZNE SIROVINE
INPUT FEEDS</td><td>PRODUKTI PROCESNIH JEDINICA
PROCESS UNIT PRODUCTS</td><td>TOKOVI
FLOWS</td></tr>
<tr><td colspan="3">LP SUSTAV (KORISNIČKO SUČELJE) / LP SYSTEM (USER INTERFACE)</td></tr>
<tr><td colspan="3">LP PROGRAM (SOLVER)</td></tr>
</table>

Rezultat optimiranja rafinerije je maksimalna dobit koju je moguće ostvariti u okvirima zadanih ograničenja (cijene, količine, kapaciteti, specifikacije i dr.) tijekom zadanog vremenskog razdoblja (dnevno, mjesečno, itd.). Za svaki kreirani slučaj, koji sadržava odgovarajući skup podataka, optimiranjem je moguće dobiti sljedeće rezultate:

- optimalne vrste i količine sirovina i proizvoda,
- optimalna razina prerade u rafineriji,
- optimalne strategije rada procesnih postrojenja,
- optimalne recepture namješavanja produkata,
- pregled strukture cijena optimalnih razina prerade rafinerija,
- optimalne kapacitete i konfiguracije procesnih postrojenja.

3.1. DEFINIRANJE ULAZNIH PODATAKA LP MODELA

Ispitivanje mogućnosti proizvodnje goriva prema novim specifikacijama provedeno je simuliranjem rafinerijske proizvodnje za nafte prikazane u tablici 2.

Tablica 2: Opis nafti
Table 2: Crude description

Nafta Crude	Cijene[1], $/ Prices	°API	S (mas%)	Porijeklo Origin
Marib Lt	230,00	50,9	0,06	Jemen
Sarir	198,35	38,1	0,14	Libija
Amna	195,08	37,4	0,14	Libija
Es Sider	200,15	36,9	0,37	Libija
Ural Lt	185,14	32,7	1,49	Rusija

Optimiranje je provedeno za sljedeće slučajeve odabira nafti (prema sadržaju sumpora): 1. Ural Lt i Marib Lt, 2. Ural Lt i Amna, 3. Es Sider i Sarir. Cijene[2] i vrste proizvoda prikazane su u tablici 3.

Tablica 3: Cijene proizvoda
Table 3: Product prices

Proizvod / Product	**Cijena[2]/Price**(USD/t)
Motorni benzin s 0.15 g/l olova **Super 98** / Motor gasoline with 0.15 g/l lead	283.82
Bezolovni motorni benzin / Unleaded motor gasoline **Normal 91**	273.82
Bezolovni motorni benzin / Unleaded motor gasoline **Eurosuper 95**	278.62
Bezolovni motorni benzin / Unleaded motor gasoline **Eurosuper plus 98**	298.62
Dizelsko gorivo / Diesel fuel **Eurodizel**	255.12
Loživo ulje ekstra lako / Fuel oil, extra light, **LU EL**	248.12
Loživo ulje srednje / Fuel oil, medium **, LU S I**	177.52
Loživo ulje srednje / Fuel oil, medium, **LU S II**	162.52
Primarni benzin / Naphtha	238.12
Mlazno gorivo / Jet fuel, **GM 1**	267.32
Ukapljeni naftni plin, **UNP** / Liquefied natural gas, LNG	274.02

Cijene proizvoda fiksne su u cijelom razdoblju, odnosno jedinstvene su za razdoblje na koji se odnose specifikacije i nema podjele na različita tržišta prema kvaliteti i cijeni proizvoda. Osim toga, cijena proizvoda je ista, bez obzira na kvalitetu (npr. BMB 95 ima istu cijenu za sadržaj sumpora 1000, 500, 150 i 50 ppm). Količine proizvoda predstavljaju projekciju današnje

[1] Cijene nafti u odnosu se na cijenu nafte Brent 25.5 $/bbl (202.68 $/t)
[2] Cijene proizvoda u odnosu na cijenu nafte Brent 25.5 $/bbl (202.68 $/t)

strukture proizvodnje i potražnje na tržištu, s time da minimalni zahtjevi tržišta nisu ograničeni pa optimalno rješenje podrazumijeva proizvodnju koja ne premašuje maksimalne zahtjeve tržišta. Zbog navedenih tržišnih ograničenja rafinerijsku maržu u optimalnim rješenjima treba promatrati kao "uvjetnu maržu". Optimiranje proizvodnje odnosi se na sljedeće kvalitete proizvoda, čiji su ključni parametri kvalitete prikazani u tablici 4:

I. Kvaliteta proizvoda u INI za razdoblje 2000.-2002. godine[3]
II. Smanjenje sadržaja sumpora u proizvodima 2002. godine[4]
III. Kvaliteta goriva u EU nakon 2000. godine[5]
IV. Prijedlog kvalitete goriva u EU nakon 2005. godine[5]

Tablica 4: Kvalitete proizvoda
Table 4: Product quality

Bezolovni motorni benzin Unleaded motor gasoline	**I** **2000. HR**	**II** **2002. HR**	**III** **2000. EU**	**IV** **2005. EU**
sumpor/Sulphur, mas. ppm.	1000	500	150	50
ukupni aromati/Total aromatics, vol.%	-	-	42	35
benzen, vol. %	5	5	1	?
olefini, vol.%	-	-	18	?
kisik/Oxygen, mas.%	-	-	2.7	?
E 100, % min.	40	40	46	?
E 150, % min.	71	71	75	?
RVP, mbar	700	700	600	?
Eurodizel	**I** **2000. HR**	**II** **2002. HR**	**III** **2000. EU**	**IV** **2005. EU**
sumpor/Sulphur maks., mas. ppm	5000	500	350	50
gustoća/Density maks., kg/m^3	860	860	845	?
T 95 (D 86), ºC	370	370	360	?
cetanski indeks	46	46	51	?
poliaromati maks., mas.%	-	-	11	?
ukupni aromati/Total a. maks., mas.%	-	-	-	-

Radna ograničenja:

- rad svih instaliranih kapaciteta RN Rijeka s ograničenjem na maksimalnom kapacitetu,
- optimiranje proizvodnje motornih goriva kvaliteta I, II i IV uključuje opciju rada postrojenja izomerizacije.

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[3] Interna norma INE
[4] Uredba o kvaliteti tekućih naftnih proizvoda, INA interna norma
[5] EU Auto Oil Program

3.2. Ograničenja rezultata optimiranja

Ispitivanja mogućnosti prerade odabranih nafti pomoću LP modela ima ograničenja zbog načina optimiranja LP modela. Dobivene rezultate treba promatrati kao optimalna rješenja sa sljedećim ograničenjima:

- Ograničenje zbog doprinosa cijena nafti ostvarenju maksimalne rafinerijske marže.

Optimalna rješenja podrazumijevaju zadovoljavanje zahtjeva kvalitete uz otvorene mogućnosti izbora ulaznih količina odabranih nafti, a budući da povećanje količine prerađene niskosumporne nafte znatno smanjuje rafinerijsku maržu, optimalni odabir ne ovisi samo o sadržaju sumpora u naftama, nego i o cijeni nafte.

- Ograničenje zbog cijena proizvoda

Relativni odnosi prikazanih cijena proizvoda (tablica 3) odlučujući su u procesu optimiranja proizvodnje, čija je funkcija cilja maksimiziranje rafinerijske marže (zarade). Optimalna rješenja su dvojako ovisna o cijenama: iznosi cijena sirovina i proizvoda utječu na iznos ostvarene rafinerijske marže, a relativni odnosi cijena utječu na optimalni proces prerade (npr., ako je cijena loživog ulja visoka u odnosu na druge proizvode, maksimiziranje zarade će se optimirati maksimizacijom proizvodnje loživih ulja).

Osim toga, budući da su cijene proizvoda i sirovina fiksne u svim slučajevima zahtjeva kvalitete (I-IV), a pooštravanjem specifikacija poskupljuje se proizvodnja goriva, optimalna rješenja balansiraju između isplativosti procesa i mogućnosti namješavanja drugih proizvoda iz istih resursa sirovine (primjer motornog benzina: ako je npr. za dostizanje sadržaja sumpora ispod 150 ppm u motornom benzinu potrebna predobrada FCC sirovine, a taj proces poskupljuje motorni benzin u toj mjeri da njegova cijena ne ostvaruje dobit zbog fiksne cijene proizvoda, optimalna rješenja balansiraju između mogućnosti proizvodnje FCC benzina iz blago hidrokrekirane sirovine i mogućnosti namješavanja resursa FCC sirovine u loživa ulja). Zbog toga se, ovisno o primjeni rezultata optimiranja, moraju ograničiti tržišta (vrste i količine proizvoda) na način koji u granicama ostvarenja pozitivne rafinerijske marže usmjeravaju taj balans u željenom smjeru.

- Ograničenja zbog simultanosti optimiranja svih procesa i operacija

Simultanost optimiranja svih rafinerijskih procesa i operacija omogućuje dobivanje rezultata koji su u granicama zadanih ograničenja (kvaliteta proizvoda, cijene, tržište, kapaciteti i dr.), ali sprječava sagledavanje različitih opcija skladištenja, režima rada i sl.

Na osnovi navedenih ograničenja postavljeni su kriteriji procjene rezultata optimiranja:

- optimalno rješenje je održivo, odnosno proces je stabilan u zadanim uvjetima,
- uvjeti potrebni za dostizanje optimuma mogu se ostvariti u praksi,
- dobiveno optimalno rješenje ne može se poboljšati,
- utjecaj loše definiranih parametara uzet je u obzir.

4. REZULTATI OPTIMIRANJA

Niže navedeni rezultati predstavljaju rezultate optimiranja prerade sljedećih nafti u RN Rijeka, prema prije navedenim uvjetima pomoću LP modela. Rezultati su razmatrani u skladu s navedenim ograničenjima.

4.1. Visokosumporna i ekstremno niskosumporna nafta (32.7°API, **1.49%** S i 50.9°API, **0.06%** S)

Marib Lt je vrlo laka nafta s malim sadržajem sumpora (50.9° API, 0.06 mas% S) zanimljiva za praćenje simulacijske prerade u svrhu dobivanja proizvoda prema novim zahtjevima kvalitete zbog svojih ekstremnih svojstava. Kako je njezina cijena relativno visoka, optimalna rješenja s otvorenim odabirom ulaznih količina odabranih nafti ne uključuju njezinu preradu (optimalna prerada ove nafte ne zadovoljava maksimizaciju funkcije cilja-rafinerijske marže, tj. neisplativa je) pa je njezina količina ograničena minimalnom količinom (~1/4 ukupne količine nafte). Rezultati optimiranja prikazani su u tablici 5 preko udjela motornih goriva u ukupnom proizvodu, prosječnog sastava "poola" motornih benzina, prosječnog sastava "poola" dizelskog goriva, udjela pojedine nafte u preradi te rezultirajuće rafinerijske marže optimalnog rješenja za ispitane gradacije kvalitete.

Optimalna rješenja prerade ovih nafti prema trenutačno važećim specifikacijama goriva u Hrvatskoj (kvaliteta proizvoda **I**) omogućuju proizvodnju vrlo visokog udjela motornih goriva u ukupnom proizvodu (~63%). Optimiranjem proizvodnje motornih goriva prema zahtjevima kvalitete **II** dobiva se rješenje koje ne ukazuje na bitne promjene u strukturi prerade, namješavanja proizvoda i ostvarenoj rafinerijskoj marži u odnosu na prethodni slučaj.

Međutim, optimiranje proizvodnje motornih goriva prema trenutačno važećim specifikacija u EU (kvaliteta **III**) ne omogućuje dobivanje rješenja s pozitivnom rafinerijskom maržom. Povećanje minimalne ulazne količine niskosumporne nafte preko ¼ ukupne količine nema pozitivan efekt. Zbog toga se navedena rješenja odnose na proizvodnju motornih goriva sljedećih karakteristika:

- dobivene kvalitete motornih benzina u optimalnom rješenju ne zadovoljavaju propisni maksimalni sadržaj benzena pa se prikazani rezultati odnose na višu vrijednost sadržaja benzena (2 vol%) koja omogućuje pozitivnu optimalnu rafinerijsku maržu,
- optimalno rješenje podrazumijeva kvalitetu dobivenog dizelskog goriva koje u potpunosti zadovoljava propisane parametre kvalitete **III**.

Zbog navedenih odstupanja u dobivenim specifikacijama proizvoda rezultati prikazani u tablici 5 prikazuju veći udio količine proizvedenih motornih benzina i višu vrijednost rafinerijske marže. Međutim, ovi rezultati omogućuju promatranje utjecaja zadovoljenja ostalih parametara kvalitete (ponajprije smanjenje sadržaja sumpora), a to su:

- pad rafinerijske marže (~40%), kao i udjela motornih goriva u ukupnom proizvodu (~20%),
- povećanje udjela reformata u prosječanom benzinskom “poolu” (~60% reformata), što doprinosi zadovoljenju oktanskih zahtjeva (i ne doprinosi povećanju sadržaja sumpora), ali onemogućuje dostizanje specifikacija sadržaja benzena (reformat sadržava preko 3 vol% benzena).
- udio FCC benzina u prosječnom “poolu” motornih benzina se smanjuje (udio 21%), a ukupni sadržaj sumpora u FCC sirovini iznosi 0.36% (2/3 sirovine su blago hidrokrekirana teška plinska i vakuum plinska ulja),
- smanjenja kapaciteta FCC postrojenja ispod 40% kapaciteta, što je tehnološki neprihvatljivo, a posljedica je ograničenja sadržaja sumpora u motornim benzinima, ali i sastava niskosumporne nafte (Marib Lt sadržava 1.5 vol% teškog plinskog ulja i 16 vol% atmosferskog ostatka),
- kvaliteta dizelskog goriva u potpunosti zadovoljava specifikacije, a sastav “poola” koji to omogućuje sadržava ~10% frakcija s atmosferske destilacije, a ostatak sačinjavaju frakcije plinskog ulja s HDS-a i MHC-a.

Opravdanost prerade ovih nafti radi smanjenja sadržaja sumpora u motornim benzinima procijenjena je praćenjem optimalnog rada FCC postrojenja, kvalitete i resursa FCC sirovine te kvalitete i količine FCC benzina. Na osnovi dobivenih rezultata može se zaključiti da prikazana opcija odabira nafti nije povoljna za dostizanje zadane kvalitete motornih benzina (sumpor do 150 mas. ppm) jer resursi FCC sirovine visokosumporne nafte imaju ograničenje u sastavu sumpora, a resursi FCC sirovine niskosumporne nafte su nedovoljni.

Table 5 Key

Product Quality/ Product structure/ Average MG pool composition/ DF pool composition/ Crudes/ Margin

MB (motorni benzin) = MG (motor gasoline)	Reformat = Reformate	Kero / pl. ulje atm. dest. = kero / gas oil atm. dist.
DG (dizelsko gorivo) = DF (diesel fuel)	FCC benzin = FCC gasoline	HDS kero + pl. ulje = HDS kero + gas oil
Ostalo = Other	VBK benzin = VBK gasoline	MHC pl. ulje = MHC gas oil
	Primarni benzin = Naphtha	FCC teški benzin = FCC heavy gasoline
	Izomerat = Isomerate	VBK pl. ulje = VBK gas oil

Rezultati optimiranja proizvodnje motornih goriva kvalitete **IV** zbog istih razloga (resursi i kvaliteta FCC sirovine, kapacitet rada FCC ispod minimalnog i količina FCC benzina te kapacitet hidroobrade srednjih destilata) nisu prihvatljivi.

4.2. Visokosumporna i niskosumporna nafta (32.7° API, 1.49% S i 37.4°API, 0.14% S)

Sljedeći slučajevi dobiveni su optimiranjem proizvodnje iz nafte sa sadržajem sumpora ~1.5 mas% sumpora (iz prethodnog primjera) u kombinaciji s težom naftom i većim sadržajem sumpora u odnosu na prethodni primjer (37.4° API, 0.14 mas% sumpora). Izbor ulaznih količina odabranih nafti u navedenim slučajevima je slobodan, što znači da postoji samo ograničenje ukupne količine nafte, a s kojim će udjelom svaka nafta sudjelovati u preradi ovisi o optimalnom rješenju. Rezultati optimiranja prikazani su u tablici 6. Rješenja dobivena optimiranjem prerade opisanih nafti prema trenutačno važećim specifikacijama goriva u Hrvatskoj (kvaliteta **I**) omogućuju proizvodnju velikog udjela motornih goriva u ukupnom proizvodu (~61%) s većim udjelom dizelskog goriva (36%).

Optimiranjem proizvodnje motornih goriva prema zahtjevima kvalitete **II** dobiva se rješenje u kojem se smanjuje optimalna količina proizvodenog dizelskog goriva (~10% manji udio u ukupnom proizvodu). Povećava se optimalna količina prerađene nafte s nižim sadržajem sumpora, što uz smanjenje proizvodnje dizelskog goriva, utječe na smanjenje rafinerijske marže. Smanjenje sadržaja sumpora u motornom benzinu s 1000 na 500 ppm ne utječe bitnije na sastav prosječnog "poola", s time da otvaranje opcije izomerizacije omogućuje namješavanje i komponente izomerizata. Smanjenje sadržaja sumpora u dizelskom gorivu s 5000 na 500 ppm rezultira povećanjem udjela hidrodesufuriziranih komponenti "poola".

Optimalna rješenja koja u potpunosti zadovoljavaju kvalitetu goriva **III** nisu moguća pa su kreirani slučajevi koji daju rješenja za proizvodnju goriva koja su po kvaliteti najbliža zahtjevima. To se odnosi na zadovoljenje ograničenje sumpora u motornom benzinu 150 ppm, a u dizelskom gorivu 350 ppm, a vrijednosti ostalih parametara kvalitete (sadržaj benzena) balansirane su na najniže vrijednosti koje omogućuju pozitivna rješenja optimiranja. Osim toga, optimiranje prerade s otvorenom opcijom odabira ulaznih količina datih nafti nisu dovodili do prihvatljivih rješenja (rad FCC postrojenja ispod minimalnog kapaciteta uz preusmjeravanje resursa FCC sirovine u "pool" loživih ulja). Optimalno maksimiziranje rafinerijske marže opcijom slobodnog odabira ulaznih količina nafti nije postignuto povećanjem ulazne količine niskosumporne nafte, što ide u prilog činjenici da je zadovoljavanje specifikacija preradom niskosumpornih nafti ekonomski nepovoljna opcija. Zbog toga je ulazna količina niskosumporne nafte ograničena na minimalno ~73% ukupne količine nafte i to je minimalna količina niskosumporne nafte koja omogućuje dobivanje prihvatljivih optimalnih rješenja (kriteriji procjene rezultata, 3.2. Ograničenja rezultata optimiranja). Rezultati optimiranja slučaja postavljenog na opisani način su:

- udio motornih benzina i dizelskog goriva u ukupnom proizvodu ~42% ("bijelih derivata" ~52%),
- kvaliteta dobivenih proizvoda zadovoljava specifikacije sumpora (150 ppm u motornim benzinima i 350 ppm u dizelskom gorivu),
- udio benzena u motornim benzinima je iznad propisanih kvalitetom **III** i iznosi ~1.6%,
- kvaliteta dizelskog goriva u potpunosti zadovoljava specifikacije.

Ova opcija ograničenja minimalne količine niskosumporne nafte rezultira nižom rafinerijskom maržom, u odnosu na otvorenu opciju odabira ulaznih količina nafti, ali omogućuje balansiran rad FCC postrojenja, čija se sirovina sastoji od ~80% teških plinskih ulja i vakuum plinskih ulja (smanjen udio predobrađene, odnosno blago hidrokrekirane FCC sirovine). Ova rješenja, iako nisu optimalna u smislu maksimizacije rafinerijske marže, jer su troškovi proizvodnje veći, omogućuju dobivanje većeg udjela motornih goriva u ukupnom proizvodu (45.47%, od toga 21.8% motornih benzina i 23.68% dizelskog goriva).

Optimiranje prizvodnje motornog benzina i dizelskog goriva sa smanjenim sadržajem sumpora na 50 ppm prema zahtjevima kvalitete **IV** (prijedlog nakon 2005.g u EU) nemoguće je ostvariti prema trenutačnoj tehnološkoj konfiguraciji RN Rijeka, a dobivena rješenja su neprihvatljiva s aspekta kriterija prihvatljivosti optimalnih rješenja (nizak udio motornih goriva u ukupnom proizvodu, neprihvatljivo preusmjeravanje resursa FCC sirovine, rad FCC postrojenja ispod minimalnog kapaciteta, kapaciteti hidroobrade srednjih destilata nedovoljni).

Table 6 Key

Product Quality / Product structure / Average MG pool composition / DF pool composition / Crudes / Margin

MB (motorni benzin) = MG (motor gasoline)	Reformat = Reformate	Kero / pl. ulje atm. dest. = kero / gas oil atm. dist.
DG (dizelsko gorivo) = DF (diesel fuel)	FCC benzin = FCC gasoline	HDS kero + pl. ulje = HDS kero + gas oil
Ostalo = Other	VBK benzin = VBK gasoline	MHC pl. ulje = MHC gas oil
	Primarni benzin = Naphta	FCC teški benzin+LCO = FCC heavy naphta+LCO
	Izomerat = Isomerate	VBK pl. ulje = VBK gas oil

4.3. Dvije niskosumporne nafte (36.9°API. 0.37 mas% S i 37.4°API, 0.14 mas% S)

Optimiranje prerade navedenih nafti razlikuje se od prethodna dva slučaja po tome što obje nafte sadržavaju ispod 1 mas% sumpora, imaju višu ulaznu cijenu pa su i optimalne rafinerijske marže niže u odnosu na prethodne slučajeve. Rezultati optimiranja prikazani su u tablici 7.

Optimiranjem proizvodnje motornih goriva prema trenutačno važećim specifikacijama na hrvatskom tržištu dobivena su rješenja u kojima je optimalna prerada nafte s većim sadržajem sumpora, što rezultira proizvodnjom ~52% motornih goriva (~70% “bijelih derivata”). Kvaliteta motornih benzina zadovoljava i kvalitetu **II**, a kvaliteta dizelskog goriva dobivena optimiranjem zadovoljava zahtjeve sumpora (5000 ppm) bez hidrodesulfurizacije srednjih destilata. Optimiranjem proizvodnje motornih goriva prema zahtjevima kvalitete **II** daje rješenja s manjim udjelom dizelskog goriva, nego u prethodnom stupnju kvalitete s time da zadovoljenje sadržaja sumpora od 500 ppm dovodi do hidrodesulfurizacije plinskih ulja s atmosferske destilacije što, uz povećanje optimalnog udjela nafte s nižim sadržajem sumpora, rezultira smanjenjem rafinerijske marže.

Kvaliteta motornih goriva dobivenih optimiranjem proizvodnje prema specifikacijama u EU nakon 2000. godine, kao u i prethodnim primjerima ne zadovoljava smanjenje sadržaja benzena (min. 1.5 vol%) u motornim benzinima, dok dizelsko gorivo u potpunosti zadovoljava specifikacije. Međutim, za razliku od prethodnih primjera, optimalni rad FCC postrojenja je većeg kapaciteta (~60% ukupnog kapaciteta), a sirovina za FCC se sastoji od manjeg udjela blago hidrokrekiranih teških plinskih ulja (75% sirovine su teška plinska ulja s atmosferske i vakuum destilacije), bez ograničavanja minimalne količine nafte s manjim sadržajem sumpora (nafta više cijene). Usporedba rezultata optimiranja u ovom primjeru i odgovarajućim primjerima prethodnih nafti (za iste zahtjeve kvalitete proizvoda), ukazuje na veću primjerenost optimiranja prerade dvije niskosumporne nafte.

Table 7 Key

Product Quality / Product structure / Average MG pool composition / DF pool composition / Crudes / Margin

MB (motorni benzin) = MG (motor gasoline)	Reformat = Reformate	Kero / pl. ulje atm. dest. = kero / gas oil atm. dist.
DG (dizelsko gorivo) = DF (diesel fuel)	FCC benzin = FCC gasoline	HDS kero + pl. ulje = HDS kero + gas oil
Ostalo = Other	VBK benzin = VBK gasoline	MHC pl. ulje = MHC gas oil
	Primarni benzin+i-C_5 = Naphta+i-C_5	FCC teški benzin+CO = FCC heavy naphta+CO
	Izomerat = Isomerate	VBK pl. ulje = VBK gas oil

Naime, u prethodnim primjerima su zbog ograničenja sadržaja sumpora na maks. 150 ppm rezultati optimiranja ukazivali na problematiku sadržaja sumpora u FCC sirovini, što je dovodilo do povećanja udjela blago hidrokrekiranih komponenti u FCC sirovini i rezultiralo smanjenom kapacitetom rada FCC postrojenja. Otvorenost opcije optimalnog odabira ulazne količine nafte s manjim sadržajem sumpora nije doprinosila maksimizaciji rafinerijske marže pa je bilo potrebno ograničenje minimalne ulazne količine nafte s manjim sadržajem sumpora. U ovom primjeru je optimalno rješenje posljedica isplativosti rada FCC postrojenja, a odabir ulaznih količina nafti je ovisan u manjoj mjeri o cijeni nafte. Optimalna rješenja prethodnih primjera, koja u resurse FCC sirovine usmjerava samo ili u najvećoj mjeri hidrokrekirane komponente ne zadovoljavaju zbog ograničenja kapaciteta blagog hidrokrekinga.

Rezultati optimiranja prikazani u tablici 7 odnose se na proizvodnju ~43% motornih goriva kvalitete **III** u ukupnom proizvodu s podjednakim udjelima motornih benzina i dizelskog goriva (~60% bijelih derivata).

Smanjenje sadržaja sumpora u motornom benzinu i dizelskom gorivu na 50 ppm prema zahtjevima kvalitete (prijedlog nakon 2005.g u EU) nemoguće je ostvariti prema trenutačnoj tehnološkoj konfiguraciji RN Rijeka zbog istih razloga kao i u prethodnom primjeru.

5. ZAKLJUČCI

Ispitivanja mogućnosti proizvodnje motornih goriva prema budućim zahtjevima kvalitete u RN Rijeka provedena su opcijom odabira niskosumpornih nafti. Opisana ispitivanja pomoću LP modela imaju svoja ograničenja zbog logike rada modela (naslov 3.2.), što posebno dolazi do izražaja u postupku optimiranja prerade visokosumporne i niskosumporne nafte u slučajevima optimiranja proizvodnje goriva sa sadržajem sumpora ispod 150 ppm u motornom benzinu i 350 ppm u dizelskom gorivu. Na osnovi prikazanih rezultata optimiranja i njihovim valoriziranjem u skladu s navedenim ograničenjima, moguće je donijeti sljedeće zaključke:

- optimiranjem prerade visokosumporne i ekstremno niskosumporne lake nafte (~50°API) ne mogu se zadovoljiti budući zahtjevi kvalitete goriva zbog problema resursa FCC sirovine jer su resursi iz visokosumporne nafte ograničeni sadržajem sumpora, a resursi lake niskosumporne nafte su nedovoljni (4.1.),
- optimiranjem prerade prerade visokosumporne i niskosumporne nafte moguće je zadovoljiti zahtjeve sadržaja sumpora do 150 ppm u motornom benzinu i 350 ppm u dizelskom gorivu, ali uz ograničenje udjela visokosumporne nafte na manju količinu od optimalne (4.2.),
- optimiranjem prerade niskosumpornih nafti (ispod 1 mas% sumpora) u postojećim kapacitetima RN Rijeka moguće je postići isto, ali bez ograničenja optimalnih ulaznih količina nafti (4.3.)
- za dostizanje zahtjeva sadržaja benzena u motornim benzinima 1 vol% potrebno je primijeniti druge opcije (tehnološka rješenja) koja nisu razmatrana u ovom radu,
- optimiranjem prerade niskosumpornih nafti ne mogu se dostići predloženi zahtjevi sadržaja sumpora u motornim gorivima prema zahtjevima kvalitete predloženima nakon 2005. godine:
  - zbog kvalitete FCC sirovine (potrebna primjena drugih opcija),
  - zbog kapaciteta hidroobrade srednjih destilata.

POSSIBILITIES OF PRODUCING MOTOR FUELS AT INA IN COMPLIANCE WITH NEW QUALITY REQUIREMENTS

Abstract

Fuel production and consumption have over the past years been marked by major changes associated with increasingly stringent legal regulations referring to harmful emission reduction. In Europe and in the world, a legislative system has been elaborated detailing values of all the fuel quality parameters based on which fuel technology and quality shall be shaped as of 2000. This requires complex undertakings within the refinery processing structure, from building new processing units, through reconstruction of the existing ones, to the questioning of the processing flows' optimal character. The first two solutions imply *major capital investments, so that the global oil industry is passing through a series of dynamic investment changes and ownership organization modifications.*

The purpose of the paper is to examine the possibilities of producing fuels meeting new specifications (in Croatia, after 2002) according to the existing technological configuration of the Rijeka Oil Refinery, using the LP production optimization model. Production possibilities and payability are examined for various options regarding crude choice, flow redirectioning, and blending.

1. INTRODUCTION

The European emission control model, its strategy and principles, are determined by the Auto Oil programme, precisely setting the fuel quality starting from 2000. General fuel quality requirements refer to the following:

a) motor gasoline quality

- sulphur content reduction (down to 150 ppm)
- vapour pressure lowering (down to 600 mbar RVP)
- benzene (down to 1 vol%) and total aromatic content reduction (down to 42 vol%)
- olefin content reduction (down to 18 vol%)

b) diesel fuel quality

- sulphur content reduction (down to 350 ppm)
- polyaromatic content reduction (down to 11 vol%)
- cetane index increase (up to 51)

A new package of measures, due to come into force in 2005 and regulate further sulphur content reduction (down to 50 ppm in motor gasoline and diesel fuel), as furtherly regulate other quality parameters, is currently under preparation.

European countries with lower economic power (including Croatia) have been allowed a certain delay for the implementation of the said quality parameters. That is why the quality of motor fuels currently produced in Croatia, as well as its correction envisaged for 2002* deviates from the EU fuel quality.

*(*In the period between the elaboration of this paper and its publication, the Agreement on Croatia's Joining of the WTO has come into force. This means that a permission will have to be sought for product quotas not complying with*

the requirements set in the Regulation on Quality Standards for Liquid Oil Fuels.)

2. FUEL PRODUCTION IN COMPLIANCE WITH FUTURE QUALITY REQUIREMENTS

Fuel production in compliance with the set quality parameters implies various options, depending upon refinery configuration and market requirements, which may be classified into several groups: Options for reducing the motor gasoline sulphur, benzene, aromatic, and olefin content, and options for reducing diesel fuel sulphur and aromatic content and increasing its cetane number.

a) Options for meeting the motor gasoline critical quality requirements

The basic source of sulphur in motor gasoline is the FCC gasoline, which is why sulphur reduction options imply undertakings reducing the FCC gasoline sulphur content:

- choosing crudes with lower sulphur content (short-term and costly solution),
- FCC gasoline fractionation also to the medium distillation area (130-160^{0}C) and its direction towards reforming after hydrotreatment,
- FCC feed pretreatment,
- FCC gasoline hydrotreatment,
- a combination of pre- and post-treatment.

Lowering of the motor gasoline benzene and aromatic content refers to the reforming operation regulation i.e. reformate treatment, since it constitutes the basic source of benzene. Options for reducing aromatic content down to 42 i.e. 35 vol%, and that of benzene down to 11 vol%, are as follows:

- pre-fractionation of heavy naphtha to temperatures below 80^{0}C while excluding the temperature range of benzene distillation i.e. removal of benzene precursors, obtaining up to 50% less benzene, but also lowering the reformate octane number,
- reducing the reforming severity,
- removing benzene and aromatics from the reformate (fractionation, saturation, extraction).

Since reformate treatment reduces its octane number, the lower octane contribution has to be made up for by other components which do not increase the critical motor gasoline environmental parameters. The options for maintaining the octane level are as follows:

- isomerization,
- etherification,

- alkylation,
- polymerization.

b) Options for meeting the diesel fuel critical quality requirements

Options for lowering the diesel fuel sulphur content are medium distillate hydrodesulphurization and redirecting lower quality flows towards products less attractive for the market, while polyaromatic content reduction is achieved through ring saturation and opening. Dearomatization is achieved by deep hydrotreatment or hydrocracking. Opening of the polyaromatic rings enables also the reaching of other diesel fuel quality parameters: Cetane number increase, density lowering, and lowering of the T95 point.

3. PRODUCTION OPTIMIZATION USING LP MODEL

In the LP model, refinery processes and operations are presented by a system of linear equations (inequations) representing mass balances, process unit yields, quality of feed, intermediary products, products, prices, and so on. The solutions of the said equation system must meet the limits (market, capacities, product quality and so on), while at the same time maximizing the goal function (refinery margin). The model of the Rijeka Oil Refinery enables simulation and optimization of refinery processes and operations. The optimization result is the maximum profit that may be raised within the set limits (prices, volumes, capacities, specifications, and so on). Refinery model elements are shown in Table 1.

The result of refinery optimization is maximum profit that may be raised within the set limitations (prices, volumes, capacities, specifications, and so on) over a given period (daily, monthly, etc.). For each created case, containing a given data group, the following results may be obtained through optimization:

- optimal feed and product types and volumes,
- optimal refinery processing level,
- optimal process plants operating strategies,
- optimal product blending ratios,
- price structure review of optimal refinery processing levels,
- optimal process plants capacities and configurations.

3.1. DEFINITION OF THE LP MODEL INPUT DATA

Examination of the possibility of fuel production in compliance with new specifications has been performed by simulating refinery procesing of crudes shown in Table 2. Optimization was performed for the following cases of crude selection (according to sulphur content):

1. Ural Lt i Marib Lt
2. Ural Lt and Amna
3. Es Sieder and Sarir

Product prices[2] and types are shown in Table 3.

Product prices are fixed for the entire period i.e. unique throughout the period the specifications refer to. There is no division to various markets according to product quality and price. Apart from that, the product price is the same regardless of quality (e.g. UMG 95 has the same price for the sulphur content of 1,000, 500, 150, and 50 ppm). Product volumes represent a projection of the current market supply and demand structure. Minimal market requirements have not been limited, which means that the optimal solution implies production not exceeding maximum market requirements. Due to the said market limitations, refinery margin in optimal solutions needs to be viewed as "conditional margin".

Production optimization refers to the following product qualities, the key quality parameters of which are shown in Table 4:

I Product quality at INA for the 2000-2002 period[3]
II The products sulphur content reduction in 2002[4]
III EU fuel quality beyond 2000[5]
IV EU fuel quality proposal beyond 2005[5]

Operating limitations:

- operation of all Rijeka Oil Refinery's installed capacities with a limitation of the maximum capacity,
- optimization of the quality I, II and IV motor fuels implies the option of the isomerization plant operation.

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[1] Oil price with regard to the Brent crude price of US$ 25.5/bbl (US$ 202,68/t)
[2] Product price with regard to the Brent crude price of US$ 25.5/bbl (US$ 202,68/t)
[3] INA's internal standard
[4] Regulation on the Quality of Liquid Oil Products, INA's internal standard
[5] EU Auto Oil Programme

3.2. LIMITATIONS OF OPTIMIZATION RESULTS

Examination of the selected crudes' processing possibilities using the LP model has its limitations due to the said model's optimization manner. The results obtained need to be viewed as optimal solutions with the following limitations:

- Limitation due to the oil price contribution to the realization of maximum refinery margin.

Optimal solutions imply the meeting of quality requirements with open possibilities of choosing the input volumes of selected crudes. Since increase in the volume of processed low-sulphur oil considerably reduces refinery margin, the optimal choice is not dependent only on the crudes sulphur content, but also on the oil price.

- Limitation due to product prices

Relative relations among the presented product prices (Table 3) are decisive in the production optimization process, the function of which is to maximize refinery margin (profit). Optimal solutions are doubly dependent on prices: The amounts of feed and product prices impact the amount of the achieved refinery margin, while relative price ratios impact optimal processing (e.g. if the price of fuel oil is high with regard to other products, profit will be maximized by maximizing fuel oil production).

Apart from that, since product and feed prices are fixed in all quality requirement cases (I-IV), while more stringent specifications cause fuel production to be costlier, optimal solutions are balancing between process payability and the possibility of blending other products from the same feed resources (the example of motor gasoline: If, for instance, the achievement of motor gasoline sulphur content below 150 ppm requires FCC feed pre-treatment, while the said process is rendering motor gasoline costlier to the extent that its price raises no profit whatsoever due to the fixed product price, the optimal solutions are balancing between the possibility of producing FCC gasoline out of mildly hydrocraked feed and the possibility of blending FCC feed resources into fuel oils). That is why, depending on the application of optimization results, markets (product types and volumes) must be limited in the manner directing the balance in the desired way, within the limits of achieving positive refinery margin.

- Limitations due to simultaneous optimization of all processes and operations

Simultaneous optimization of all processes and operations enables the obtaining of results that are within the limitations set (product quality, prices, market, capacities, and so on), but prevents consideration of various storage options, operating regimes, and the like.

Based on the said limitations, criteria have been set for estimating optimization results:

- the optimal solution is viable i.e. the process is stable within the set terms,

- conditions necessary for reaching the optimum may be realized in practice,
- the obtained optimal solution cannot be improved,
- the impact of badly defined parameters has been taken into account.

4. OPTIMIZATION RESULTS

The results presented below are the results of optimizing the processing of the following crudes at the Rijeka Oil Refinery, in compliance with the terms specified earlier, using the LP model. The results have been considered with regard to the above mentioned limitations.

4.1. HIGH-SULPHUR AND EXTREMELY LOW-SULPHUR OIL (32.7 API, 1.49% S and 50.9 API, 0.06% S)

Marib Lt is a very light crude with low sulphur content (50.9 API, 0.06 mas% S), interesting for monitoring simulation processing for the purpose of obtaining products in compliance with new quality requirements due to its extreme properties. Since its price is rather high, optimal solutions with an open selection of the selected crudes' input volumes does not include its processing (optimal processing of this crude does not meet the maximization of the goal function which is the refinery margin i.e. it is not payable), which is why its volume is limited to the minimum (~1/4 of the total oil volume). The optimization results are shown in Table 5 through motor fuel share in total product, average composition of the diesel fuel pool, share of individual crudes in processing and the resulting refinery margin of the optimal solution for the tested quality grades.

Optimal solutions for processing these crudes in compliance with the fuel specifications currently valid in Croatia (product quality **I**) enable the production of a very high share of motor fuels in total product (~63%). By optimizing motor fuel production in compliance with quality requirements **II**, a solution is obtained not pointing to any essential changes in the processing structure, product blending, or achieved refinery margin with regard to the previous case.

However, motor fuel production optimization in compliance with specifications currently valid in EU (quality **III**) does not enable the obtaining of solution with a positive refinery margin. Increasing the low-sulphur oil minimal input volume over 1/4 does not have a positive effect. That is why the solutions given refer to the production of motor fuels with the following properties:

- motor gasoline quality obtained in the optimal solution does not meet the maximum benzene content set, which is why the results presented refer to a higher benzene content value (2 vol%), enabling an optimal positive refinery margin.
- an optimal solution implies the quality of the diesel fuel obtained completely matching the set parameters of quality **III**.

Due to the said aberrations in the product specifications obtained, the results shown in Table 5 present a higher share of the produced motor gasoline volume and a higher refinery margin value. However, these results enable the monitoring of influence of meeting other quality parameters (primarily the sulphur content reduction), being as follows:

- decrease of the refinery margin (~40%), as well as of the motor fuels share in total product (~20%),
- increase of reformate share in the average gasoline pool (~60% of reformates), contributing to the meeting of octane requirements (and not contributing to the sulphur content increase), but preventing the meeting of benzene content specifications (the reformate contains over 3 vol% of benzene)
- FCC gasoline share in the average motor gasoline pool is decreasing (share: 21%), while the total sulphur content in the FCC feed amounts to 0.36% (2/3 of the crude are mildly hydrocracked heavy gas and vacuum gas oils)
- lowering the FCC plant capacity below 40%, which is technologically unacceptable, resulting from the limitation of the motor gasoline sulphur content, but also of the low-sulphur crude composition (Marib Lt contains 1.5 vol% of heavy gas oil and 16 vol% of atmospheric residue)
- the diesel fuel quality fully meets the specifications, while the composition of the pool enabling it contains ~10% of atmospheric distillation fractions, while the rest are the HDS and MHC gas oil fractions.

The justifiability of processing these crudes in order to reduce the motor gasoline sulphur content has been estimated by monitoring optimal operation of the FCC plant, the quality and resources of FCC feed, and the quality and volume of FCC gasoline. Based on the results obtained, we may conclude that the presented crude selection option is not favourable for achieving the set motor gasoline quality (sulphur up to 150 mas. ppm), since the high-sulphur crude FCC feed resources are limited by the sulphur composition, while the low-sulphur crude FCC feed resources are not sufficient.

For the same reasons (FCC feed resources and quality, FCC operating capacity below minimum, FCC gasoline volume, and medium distillates hydrotreatment capacity), the results of optimizing quality **IV** motor gasoline production are not acceptable.

4.2. HIGH-SULPHUR AND LOW-SULPHUR OIL (32.7^{0}API, 1.49% S and 37.4^{0}API, 0.14% S)

The following cases were obtained by optimizing production from the oil with the sulphur content of ~1.5 mas% of sulphur (from the previous example) in combination with heavier oil and higher sulphur content with regard to the previous example (37.4^{0}API, 0.14 mas% of sulphur). The choice of the selected crudes' input volumes in the said cases is free, which means that the only limitation refers to the total oil volume. The share of each individual crude in the processing depends on the optimal solution. The optimization results are shown in Table 6.

The solutions obtained by optimizing the processing of the above described crudes according to the fuel specifications currently valid in Croatia (quality **I**) enable production of a high share of motor fuels in the total product (~61%), with a majority diesel fuel share (36%).

By optimizing motor fuel production in compliance with quality **II** requirements, the solution is obtained reducing the optimal volume of the diesel fuel produced (~10% lower share in total product). The optimal volume of the oil processed with a lower sulphur content is increased, impacting not only diesel fuel production reduction, but also refinery margin lowering. The lowering of the motor gasoline sulphur content from 1,000 to 500 ppm does not bear any major impact on the average pool composition. The opening of the isomerization option enables also the blending of the isomerisate component. The lowering of the diesel fuel sulphur content from 5,000 to 500 ppm results in an increased share of the hydrodesulphurized pool components.

Optimal solutions entirely meeting the fuel quality **III** are not feasible, which means that we are here dealing with created cases providing solutions for the production of fuels the quality of which is the nearest possible to the requirements set. This refers to the meeting of the motor gasoline sulphur content limitation to 150 ppm, and that in diesel fuel to 350 ppm, while the values of other quality parameters (benzene content) have been balanced to the lowest values enabling positive optimization results. Apart from that, the optimization of processing with an open option of choosing the given crudes' input volumes has not lead to acceptable solutions (the FCC plant operation below minimal capacity with redirecting of FCC feed resources into the fuel oils pool). Optimal refinery margin maximization through the option of freely choosing the input oil volumes has not been achieved by increasing the low-sulphur oil input volume, which only substantiates the fact that the meeting of specifications by processing low-sulphur crudes constitutes an economically unfavourable option. That is why the low-sulphur oil input volume has been limited to the minimum of ~73% of total oil volumes, being the minimal low-sulphur oil volume enabling acceptable optimal solutions (result estimation criteria, 3.2. Limitations of Optimization Results). Optimization results of the case set in the described way are as follows:

- the share of motor gasoline and diesel fuel in total product is ~42% (that of "white oil products" is ~52%)
- the quality of products obtained meets sulphur specifications (150 ppm in motor gasolines and 350 ppm in diesel fuel)
- the motor gasoline benzene content is above that set by quality **III** and amounts to ~1.6%
- diesel fuel quality entirely meets the specifications.

This option of limiting the minimal low-sulphur oil volume results in lower refinery margin with regard to the open option of choosing input crude volumes, but enables balanced operation of the FCC plant whose crude consists of ~80% of heavy gas oils and vacuum gas oils (lowered share of the pre-treated i.e. mildly hydrocraked FCC feed). These solutions, although not optimal in the sense of refinery margin maximization, since production costs are higher, enable a higher share of motor fuels in total product (45.47%, of which 21.8% of motor gasoline and 23.68% of diesel fuel).

Optimization of the production of motor gasoline and diesel fuel with the sulphur content lowered down to 50 ppm according to quality **IV** requirements (proposal in EU beyond 2005) is impossible to achieve given the current technological configuration of the Rijeka Oil Refinery, while the obtained solutions are unacceptable from the aspect of optimum solutions' acceptability criteria (low motor fuels share in total product, unacceptable redirection of the FCC feed resources, FCC plant operation below minimal capacity, insufficient medium distillates hydrotreatment capacities).

4.3. TWO LOW-SULPHUR OILS (36.9^{0}API, 0.37 mas% S and 37.4^{0}API, 0.14 mas% S)

Processing optimization of the said crudes differs from the previous two cases in the sense that both crudes contain below 1 mas% of sulphur and have a higher input price, which means that optimal refinery margins are lower with regard to the previous cases. Optimization results are shown in Table 7. Motor gasoline production optimization in compliance with specifications currently valid on the Croatian market has provided solutions enabling optimal processing of oil with higher sulphur content, resulting in the production of ~52% of motor fuels (~70% of "white oil products"). The quality of motor gasoline matches also quality **II**, while diesel fuel quality obtained through the optimization meets sulphur requirements (5,000 ppm) without medium distillate hydrodesulphurization.

Motor gasoline production optimization in compliance with quality **II** requirements provides solutions with a lower diesel fuel share than in the previous quality level. The meeting of sulphur content in the amount of 500 ppm leads to atmospheric distillation gas oils hydrodesulphurization. Coupled with the increase of the optimal share of oil with lower sulphur content, this results in refinery margin lowering.

The quality of motor fuels obtained through production optimization in compliance with EU specifications beyond 2000, same as in the previous examples, does not meet the motor gasoline benzene content reduction (min. 1.5 vol%), while diesel fuel entirely meets the specifications. However, unlike the previous examples, the optimal FCC plant operation has a larger capacity (~60% of total capacity), while the FCC feed consists of a lower share of mildly hydrocracked heavy gas oils (75% of the feed are heavy atmospheric and vacuum distillation gas oils), without limiting the minimal volume of oil with lower sulphur content (oil with the higher price). The comparison of optimization results in this case and the corresponding examples of previous crudes (for the same product quality requirements) points to the better suitability of optimizing the two low-sulphur crudes. Namely, in the previous examples, due to the sulphur content limitation to max. 150 ppm, the optimization results were pointing to the issue of sulphur content in FCC feed, bringing to an increased share of mildly hydrocracked components in FCC feed and resulting in lowered capacity of the FCC plant operation. The open option of optimally choosing the input volumes of oil with lower sulphur content did not contribute to refinery margin maximization, which is why it was necessary to limit the minimal input volume of oil with lower sulphur content. In this example, the optimal solution is the consequence of the FCC plant operation payability, while the choice of input crude volumes is dependent on the oil price to a lesser extent. Optimal solutions of the previous examples, directing merely or mostly hydrocracked components into the FCC feed resources, are not satisfactory due to limited mild hydrocracking capacities.

Optimization results shown in Table 7 refer to the production of ~43% of quality **III** motor fuels in total product with mostly equal shares of motor gasoline and diesel fuel (~60% of white oil products).

Lowering of the sulphur content in motor gasoline and diesel fuel down to 50 ppm in compliance with quality requirements (proposal in EU beyond 2005) is impossible to achieve given the present technological configuration of the Rijeka Oil Refinery for the same reasons as in the previous example.

5. CONCLUSIONS

Examination of the possibility of producing motor fuels in compliance with the future quality requirements at Rijeka Oil Refinery has been performed through the option of low-sulphur crudes selection. The examinations described, performed using the LP model, have their limitations because of the model's operational logic (Title 3.2). This is particularly visible in the procedure of optimizing the processing of high-sulphur and low-sulphur oil in cases of optimizing the production of fuels with sulphur content below 150 ppm in motor gasoline and 350 ppm in diesel fuel. Based on the optimization results shown and their evaluation in compliance with the said limitations, we may pass the following conclusions:

- processing optimization of the high-sulphur and extremely low-sulphur light oil (~50^0API) does not meet the future fuel quality requirements due to problems associated with the FCC feed resources, since resources from the high-sulphur oil are limited by sulphur content, while the resources of light low-sulphur oil are insufficient (4.1.),
- processing optimization of the high-sulphur and low-sulphur oil enables the meeting of sulphur content requirements of 150 ppm in motor gasoline and 350 ppm in diesel oil, but by limiting the high-sulphur oil share to a less than optimal volume (4.2.),
- by processing optimization of the low-sulphur crudes (below 1 mas% of sulphur) in the existing Rijeka Oil Refinery capacities it is possible to achieve the same, but without limiting the optimal oil input volumes (4.3.),
- in order to meet the motor gasoline benzene content requirements of 1 vol%, it is necessary to apply other options (technological solutions) which have not been considered in this paper,

- by optimizing the processing of low-sulphur crudes it is impossible to achieve the proposed motor fuels sulphur content in compliance with quality requirements proposed beyond 2005:
  - due to the FCC feed quality (it is necessary to apply other options)
  - due to the medium distillates hydrotreatment capacities.

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65.012.022 linearno programiranje	linear programing
665.613.033 izbor naftnih sirovina, po sastavu	crude oil selection by composition
665.6.011 izbor postupaka prerade nafte	processing selection

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