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ANALIZA ISPLATIVOSTI UGRADNJE TURBOGENERATORA NA BROD

THE ANALYSIS OF THE MARINE TURBOGENERATOR INSTALLATION COST EFFECTIVENESS

SAŽETAK

U radu su prikazani rezultati provedene simulacije i istraživanja isplativosti ugradnje turbogeneratora na brod. Analiza je provedena primjenom NOR Controlovog simulatora za simulaciju brodskog postrojenja tankera za prijevoz sirove nafte. Simulirana je proizvodnja električne energije s turbogeneratorom ili s dizelskim generatorom. Analiza početnih investicijskih troškova provedena je anketom s proizvođačem brodskih generatora pare te s dobavljačima turbo i dizelskih generatora pri čemu su se koristile trenutne cijene teškog i lakog dizelskog goriva na svjetskom tržištu. Izračunate su uštede u slučaju kada se za proizvodnju električne energije koristi turbogenerator u paralelnom radu s osovinskim generatorom. Rezultati istraživanja pokazuju značajne uštede i neupitnost isplativosti ugradnje jednog takvog uređaja na brod, kao i opravdanost njegovog maksimalnog korištenja, ako je na brodu instaliran.

Ključne riječi: *turbogenerator, isplativost, iskoristivost, potrošnja električne energije*

SUMMARY

Results of the simulation of and research into the cost effectiveness of mounting the turbogenerator on board a ship are dealt with in this paper. The analysis was performed by using the Konsberg NorControl crude oil carrier engine room plant, where the situations of the electrical power generation with turbo generator as well as with diesel generator were simulated. The initial cost analysis was carried out by a questionnaire with the exhaust gas boilers manufacturers, turbo generator and diesel generator suppliers. For the bunker price calculations, the present heavy fuel oil and diesel oil prices on the world market were used. The fuel savings were calculated by comparing the electrical power production situation with two diesel generators and the situation when a turbo generator was paralleled with a shaft generator. The results were additionally verified by using the computer aided program for the economical prediction of the project. The research results have arguably confirmed the thesis that mounting the turbogenerator on board a ship has great benefits and, if it is already mounted, it should be used as much as possible. The research results also confirm a great influence of planning the bunkering – choosing the bunkering ports, as well as the importance of the engine plant optimization and exploitation optimization on the final exploitation costs.

Key words: *turbogenerator, cost effectiveness, bunker price, electrical energy consumption, optimization*

1. UVOD

Turbogenerator je sklop koji se sastoji od generatora električne energije i njegovog pogonskog dijela koji čini parna turbina s reduktorom. Za pogon parne turbine koristi se pregrijana para proizvedena u loženom generatoru pare ili u utilizatoru, odnosno generatoru pare, koji iskorištava toplinu sadržanu u ispušnim plinovima (najčešće) glavnog motora, ali može i iz pomoćnih motora. Kod novijih generacija motora, koji imaju znatno veću iskoristivost od starijih serija, toplina sadržana u ispušnim plinovima je znatno manja. U svrhu dobivanja potrebne energije na pogonima s takvim motorima, preko izmjene topline u izmjenjivačima koji se nalaze u utilizatoru, površina izmjenjivača mora biti znatno veća što poskupljuje i njegovu cijenu.

U radu se analizira isplativosti ugradnje turbogeneratora na brod. Napravljena je komparacija troškova ugradnje turbogeneratora umjesto jednog dizelskog generatora ili osovinskog generatora, te usporedba krajnjih troškova jednog takvog postrojenja. Tu su uračunati početni troškovi ugradnje, troškovi održavanja te troškovi potrošnje goriva.

Početni investicijski troškovi su dobiveni direktno od proizvođača dotične opreme za konkretan primjer postrojenja približnih snaga, dok je potrošnja goriva simulirana na NOR Controlovom simulatoru i predstavlja realne vrijednosti za brod koji je simuliran.

Krajnji su troškovi goriva, odnosno uštede, izračunati na osnovi potrošnje goriva, uzimajući u obzir trenutne cijene goriva na tržištu, te vrijeme provedeno u plovidbi u razdoblju jedne godine, a koje je procijenjeno na osnovi dugogodišnjeg iskustva na brodu, te trenutnih trendova u pomorstvu.

Svrha i cilj rada je dokazivanje isplativosti ugradnje turbogeneratora na brodove čiji pogoni (glavni motor(i)) omogućuju takvu izvedbu, odnosno pogoni koji proizvode dovoljnu količinu ispušnih plinova određene topline za proizvodnju pare. Uštede koje će biti opisane dovoljno govore same za sebe. Premda one mogu biti značajne, neke brodarske kompanije i dalje nisu pristalice takvih izvedbi, već kombiniraju dizelske generatore s osovinskim generatorom ili ugrađuju samo dizelske generatore. Razloge ovakvih stavova opravdavaju složenijim postrojenjem koje zahtijeva kvalitetnije kadrove, što u

1. INTRODUCTION

The turbogenerator is the assembly of a generator, steam turbine and gearbox. For steam turbine running, the superheated steam is used. The steam is produced in an auxiliary boiler or exhaust gas boiler. The exhaust gas boiler utilises the main engine or the auxiliary engines exhaust gas heat. Since the new generation of the marine diesel engines have a higher efficiency as regards the old ones, the available exhaust gas heat is significantly reduced. Due to this fact, the exhaust gas boiler heat exchangers areas should be enlarged, which considerable increases the exhaust gas boiler price.

The paper analyzes the cost effectiveness of installing the turbogenerator on board a ship. The initial cost comparison of installing one turbogenerator instead of one diesel generator or one shaft generator has been done. The final exploitation savings for a period of 20 years were calculated. The installation costs, maintenance costs and fuel costs were considered in this calculation.

The installation costs for a particular engine plant, with approximately the same electric generator power, were obtained directly from the equipment manufacturers. The fuel consumption for each case was simulated on the Konsberg NOR Control Simulator and representing the real values for the simulated ship type.

The final fuel expenses, i.e. savings, were calculated taking into account the simulated fuel oil consumption, current world market heavy fuel oil and diesel oil prices and the annual turbogenerator running hours. The turbogenerator running hours were estimated according to the authors' long-time experience on board the ships and to the present maritime transport trends.

The aim of this paper is to determine the cost effectiveness of installing the turbogenerator on board a ship whenever there is enough main engine power to produce a sufficient amount of heat from exhaust gases to produce steam for running the turbogenerator. The presented savings are in favour of the turbogenerator installation, and, although, the savings could be considerable, some shipping companies are still reserved for this kind of electricity production source and still use the diesel generator or a combination of the diesel generator and shaft stvarnosti ne stoji jer upravljanje turbogeneratorom nije ništa složenije nego upravljanje dizelskim generatorom ili osovinskim generatorom, pogotovo kod tankera za sirovu naftu i derivate gdje se često koristi para za pogon turbopumpi tereta.

2. POČETNI INVESTICIJSKI TROŠKOVI

Početni investicijski troškovi dizelskog i turbogeneratora, utilizacijskog generatora pare te pripadajuće neophodne opreme dobiveni su direktno od proizvođača na osnovi pretpostavljene instalirane snage. Potrebna snaga električne energije broda u plovidbi je definirana na osnovi iskustva i statističke obrade postrojenja većeg broja brodova za prijevoz sirove nafte, rasutih tereta i brodova za prijevoz kontejnera. Snaga je na taj način određena na 750 ÷ 1.000 kW, što zadovoljava većinu današnjih brodova u plovidbi, izuzev brodova za prijevoz kontejnera koji trebaju nešto više električne energije kod prijevoza rashladnih (frigo) kontejnera.

Nabavne cijene dizelskog generatora snage 750 ÷ 1000 kW se kreću 250.000 ÷ 300.000 US$ [2].

Cijena jednog turbogeneratora slične snage zajedno sa svom pripadajućom opremom kreće se u rasponu 350.000 ÷ 400.000 US$ [4]. Ovdje je uračunat i vakumski kondenzator, te sva pripadajuća oprema za pogon jednog takvog postrojenja (pumpe, ventili i ostalo). U cijene oba slučaja uračunat je pogonski sklop zajedno s električnim generatorom (motor s generatorom ili turbina s reduktorom i generatorom).

Na osnovu analize više prikupljenih podataka vidi se da razlika u početnim investicijskim troškovima samih generatorskih sklopova nije velika.

Generator pare na ispušne plinove (utilizator) na brodu s turbogeneratorom mora imati nešto veći kapacitet kako bi zadovoljio potrošnju pare, koja se kreće od 9 ÷10 t/h. Na brodu bez turbogeneratora, s klasičnim postrojenjem, ona se kreće 2 ÷ 3 t/h. Tankeri za prijevoz sirove nafte koriste nešto više pare za grijanje tereta. Ta potreba za većim kapacitetom, kao i potreba za pregrijanom parom nosi sa sobom veće dimenzije (površinu izmjenjivača), pa samim time i veću cijenu.

generator. The reasons for their beliefs are that ship power plants with turbogenerators are much more complex and require a more qualified and educated crew. This statement is wrong because the complexity of the turbogenerator operation is almost the same as for the diesel generator or shaft generator, especially on board crude oil carriers, where steam is continually used for running the cargo turbo pumps and for cargo tanks heating.

2. INITIAL INVESTMENTS

The initial investment costs of a diesel generator, turbogenerator, exhaust gas boiler and the necessary associated equipment are received directly from the producer or representatives. The estimated electric power demand has been taken as the initial comparison parameter. This value has been estimated by experience and by using the statistical evaluation data of crude oil carriers, bulk carriers and 2000 TEU and larger container ships. By this method, the electric power demand was determined to 750 to 1,000 kW per ship. This power is sufficient for most of the present researched ships during navigation, except for large container ships that need more electrical power when carrying frigo containers.

The initial cost for a diesel generator with the power of 750 to 1,000 kW is approximately US$ 250,000 to 300,000 [2].

The initial price of a turbogenerator with the same power and all associated equipment is about US$ 350,000 to 400,000 [4]. The price includes the vacuum condenser and all necessary pumps, valves, pipelines, etc. In both the cases, complete generator sets are included (diesel engine with generator or steam turbine with gear box and generator). When comparing the information from practice, it can be seen that the initial generator cost differences are not so great.

The ship electric power plant with a turbogenerator must be equipped with a exhaust gas boiler with sufficient capacity to provide enough steam for service (9 to 10 t/h). The steam consumption on board a ship without a turbogenerator is approximately 2 to 3 t/h and there is no need for an exhaust gas boiler of that capacity. Steam consumption on board oil tankers is increased due to cargo heating. The increased steam production capacity, as well as the demand for a superheated steam, increases

Te se cijene kreću za generator pare 2 ÷ 3 t/h, 70.000 ÷ 80.000 US$, dok za generator pare kapaciteta 8 ÷ 10 t/h cijena iznosi oko 150.000 US$ [3]. Vidi se da je razlika u početnoj investiciji oko 70.000 US$.

Kada se uzmu u obzir cijene generatorskih sklopova i cijene utilizatora, ukupna razlika u početnim investicijskim troškovima, za uzeti primjer, je oko 150.000 ÷ 200.000 US$. Na prvi pogled velika razlika u početnim investicijskim troškovima pokazat će se zanemarivom u odnosu na uštedu ostvarenu smanjenom potrošnjom goriva.

3. UŠTEDA NA POTROŠNJI GORIVA

Razlika u potrošnji goriva najbolje se vidi iz priloga simulacije, ovisno vozi li brod s ili bez turbogeneratora.

Radi se o brodu za prijevoz sirove nafte i naftnih derivata (tanker), s glavnim motorom snage 15.000 kW i potrebnom snagom za proizvodnju električne energije 750 ÷ 800 kW (u plovidbi).

Usporedbom simuliranih vrijednosti ukupne potrošnje goriva za dotični pogon, označenim na slikama 1. i 2. te ako se pretpostavi da brod u plovidbi godišnje provede 10 ÷ 11 mjeseci, kada je moguće i isplativo koristiti pregrijanu paru za pogon turbogeneratora, razlika u potrošnji goriva Δm_g je 0,15 m^3/h, odnosno:

$$\Delta m_g = \dot{m}_{g2} - \dot{m}_{g1} = 3,65 - 3,50 = 0,15 \left[m^3 / h \right].$$

$$\Delta m_{g,UK} = \Delta m_g \cdot t_{uk} ,$$

gdje je $\dot{m}_{g2}$ potrošnja u prvom slučaju (Slika 1), $\dot{m}_{g1}$ potrošnja u drugom slučaju (Slika 2), Δm_g razlika u volumenskom protoku u $\left[\mathrm{m^3/h}\right]$, t_{uk} je ukupno vrijeme koje brod godišnje provede u plovidbi, a $\Delta m_{g,UK}$ je ukupna razlika u potrošnji goriva.

Za razdoblje od 11 mjeseci;

$$\Delta m_{g,UK} = 0.15 \cdot 7920 = 1188 \left[\mathrm{m^3}\right].$$

Prema današnjoj cijeni teškog goriva *C* (IFO 380 cSt) 540 ÷ 600 US$/MT, i pretpostavku da je približna gustoća teškog goriva oko 1000 [kg/m^3], godišnja ušteda *S* iznosi:

the heat exchanger dimensions (areas) and price. For the exhaust gas boiler with the steam production capacity of 2 to 3 t/h, the initial price is about US$ 70,000 to 80,000, while for the exhaust gas boiler with a capacity of 8 to 10 t/h, the price is more than doubled (approx. US$ 150000).

As it can be seen, when comparing the prices of the generator sets and exhaust gas boilers in this example, the difference in the initial investment cost is around US$, 150,000 to 200,000. In the following chapters it will be pointed out that this large difference in the initial investment cost can be neglected when comparing to the fuel oil savings.

3. FUEL OIL SAVINGS

The difference in fuel economy can be seen from the contributions of simulation, depending on the ship run with or without a turbogenerator (figures 1 and 2).

The simulation has shown the crude oil and product oil carrier fuel oil system with the MCR main engine of 15,000 kW and the electricity production demand of 750 to 800 kW (in navigation).

By comparing the simulated values of the total fuel consumption for the facility, indicated in figures 1 and 2, and assuming that the ship spends at sea 10 ÷ 11 months per year, when it is possible and profitable to use the superheated steam to drive turbo generators, the difference in fuel consumption is 0.15 m3/h or, respectively:

$$\Delta m_g = \dot{m}_{g2} - \dot{m}_{g1} = 3,65 - 3,50 = 0,15 \left[m^3 / h \right].$$

$$\Delta m_{g,UK} = \Delta m_g \cdot t_{uk} ,$$

where $\dot{m}_{g2}$ is the consumption in the first case (Fig. 1), $\dot{m}_{g1}$ is the consumption in the second case (Fig. 2), Δm_g is the difference in the volume flow in $\left[\mathrm{m^3/h}\right]$, t_{uk} is the total time a ship spends at sea per year, $\Delta m_{g,UK}$ is the total difference in fuel consumption.

For a period of 11 months:

$$\Delta m_{g,UK} = 0.15 \cdot 7920 = 1188 \left[\mathrm{m^3}\right]$$

$S = \Delta m_{g,UK} \cdot C$, odnosno

$$S = 1188[t] \cdot 550\left[\frac{\text{US\$}}{t}\right] = 653400[\text{US\$}]$$

Uz pretpostavku eksploatacijskog vijeka broda od 20-tak godina, ušteda koja će se ostvariti na kraju tog razdoblja je oko 13 mil. US$. Naravno da ušteda prvenstveno ovisi o kretanjima cijena goriva na svjetskom tržištu. Usporedbe radi, kada se radila slična analiza 2002. godine, s tadašnjim cijenama teškog goriva gradacije IFO 380, 150 ÷ 160 US$/MT, ušteda za razdoblje od 20 godina bila je oko 3,56 mil. US$.

Kod starijih postrojenja, a i nekih novijih gradnji za pogon dizelskih generatora, umjesto teškog goriva izgara se lako dizelsko gorivo (MDO - Marine Diesel Oil), čija se cijena danas kreće od 830 do 900 US$/MT. Za simulirani slučaj i razdoblje od 20 godina ta ušteda iznosi preko 20 mil. US$. Godine 2002., uz cijenu od 240 US$/MT i razdoblje od također 20 godina, ušteda je iznosila 5,7 mil. US$.

Kad brod nije u plovidbi, potrebno je koristiti dizelske generatore koji mogu koristiti teško gorivo i lako dizelsko gorivo, ovisno o izvedbi. Moguće je koristiti i turbogenerator, ako pomoćni (loženi) generator(i) pare ima(ju) ugrađene pregrijače pare. Postoje i izvedbe turbina s materijalom lopatica koje mogu podnijeti mokru paru, tako da je moguć pogon i s generatorima pare bez pregrijača pare. Inače, zbog samog procesa ekspanzije, mokra para do ulaska u turbinu prelazi u pregrijano područje, pa nije potreban poseban pregrijač pare. Ovakva razmatranja i analize koje uzimaju u obzir pogon turbogeneratora uz pomoć loženog generatora pare nemaju prioritet, jer u tim slučajevima treba izgarati gorivo bilo u dizelskim motorima bilo u generatorima pare. Analiza se odnosi, te ima svrhu samo kod iskorištavanja otpadne topline sadržane u ispušnim plinovima glavnog motora.

Na slici 1. označena je ukupna potrošnja teškog dizelskog goriva u plovidbi broda koja iznosi 3,5 m^3/h. Električnu energiju proizvode turbogenerator i osovinski generator, što je za dotični brod i najpovoljniji slučaj. Konstrukcijski se moglo izvesti da kompletan pogon 'drži' samo turbogenerator uz utilizator neznatno većeg kapaciteta i neznatno više cijene. Tada bi se dodatnih cca 200 kW snage električne energije koju proizvodi osovinski generator proizvodilo

According to present heavy fuel price C (IFO 380 cSt) of US$/MT 540 ÷ 600 and the assumption that the approximate density of heavy fuel is about 1,000 [kg/m3], the annual savings are:

$S = \Delta m_{g,UK} \cdot C$, or

$$S = 1188[t] \cdot 550\left[\frac{\text{US\$}}{t}\right] = 653400[\text{US\$}].$$

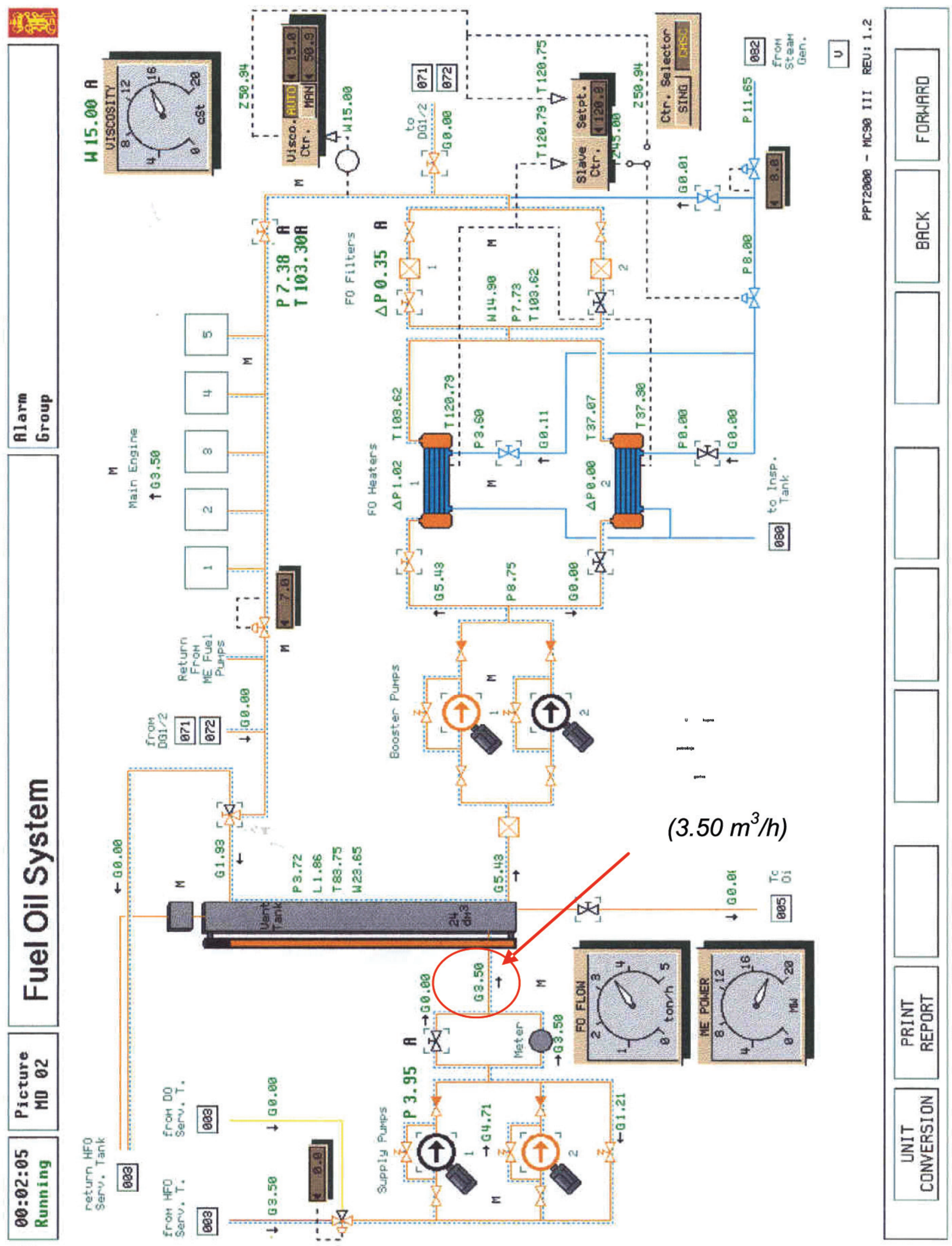
If we assume that the ship exploitation period is about 20 years, the saving at the end of that period is about US$ 13 mil. The fuel oil savings are mainly dependent on fuel oil prices on the world market. For comparison purposes, when the same analysis was done in 2002, with the fuel oil price at that time (US$/MT 150 ÷ 160), the calculated saving for the period of 20 years was US$ 3.56 mil.

The older plants and some newer ship buildings too have diesel generator sets driven with MDO or MGO at the current market price of US$/MT 830 to 900. For the simulated case for the 20 year period, the saving is US$ over 20 mil. In 2002, with the MDO price of US$/MT 240, the saving was US$ 5.7 mil.

When the ship is not sailing (main engine is not working), it is necessary to use the diesel generator set which can run on HFO or MDO (MGO) depending on the type of engine. The turbogenerator can also be used if the superheated steam is produced in the superheater section(s) of an auxiliary boiler(s). The turbogenerator can also work if the boiler(s) produce saturated steam, but in such cases, special types of turbine rotor blades must be used. Normally, there is no need for a superheater because of the expansion process of steam in which the saturated steam is superheated.

This analysis, which takes into account a turbogenerator running on steam produced in the auxiliary boiler, has no economical validity because of the inevitable burning of the fuel oil in a diesel generator or in auxiliary boilers. The analysis refers to and can be applied only when the main engine exhaust gas heat is utilized.

In Fig 1, the total fuel oil consumption of 3.5m^3/h is marked in the case when the ship is in navigation. The electric power is produced by a turbogenerator and a shaft generator and that is the most efficient case for the simulated type of ship. The engine plant could be constructed in such a way that the complete electric power demand is covered by a turbogenerator in combi-

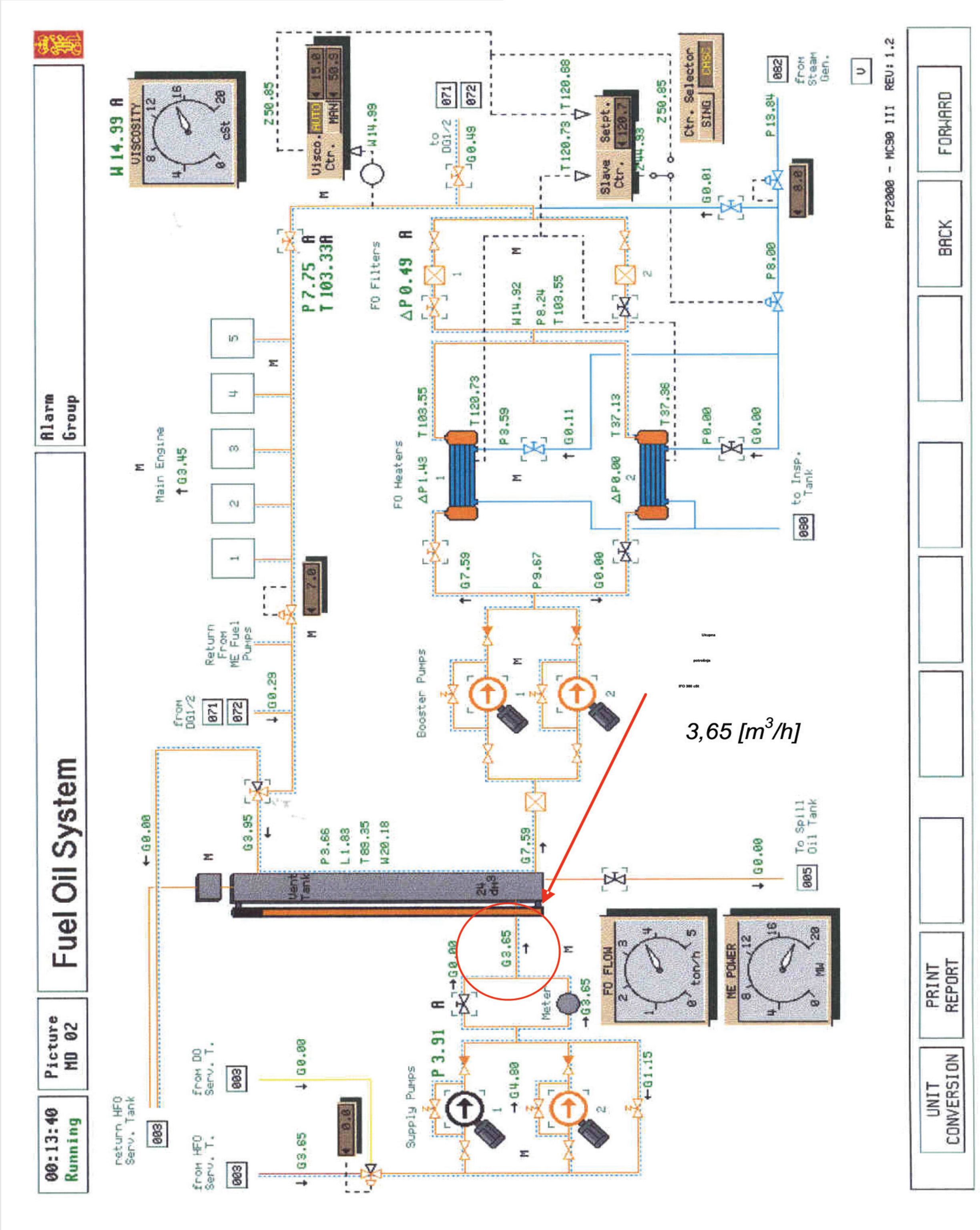


Slika 1. Prikaz potrošnje goriva u scenariju kada električnu energiju proizvode osovinski i turbogenerator
Figure 1 *Fuel oil consumption in the case when electricity production is done by TG and SG*

na turbogeneratoru, što ne bi imalo isti učinak na smanjenje potrošnje kao u slučaju kada se koriste dizelski generatori, ali bi smanjilo potrošnju goriva glavnog motora ili za istu potrošnju povećalo brzinu broda.

Na slici 2. označena je potrošnja goriva u slučaju kada se cjelokupna potreba za električnom

nation with a proportionally larger exhaust gas boiler, but that type of a plant is much more expensive. At such a scenario, the additional 200 kW will be produced with a turbogenerator. That will additionally reduce the fuel oil consumption and, for the same fuel oil consumption, increase the ship speed. In the simulated



Slika 2. Prikaz potrošnje goriva u radu dva dizelska generatora
Figure 2 *Fuel oil consumption in the case of electric power production with two DG*

energijom dobavlja preko dva dizelska generatora koji za dotičnu namjenu koriste teško gorivo. Potrošnja goriva je za 0,15 [m^3/h] veća s obzirom na uvjete prikazane na slici 1.

Ako se napravi ekonomska analiza isplativosti ovakvog projekta vidi se neupitna isplativost ugradnje turbogeneratora, a isplativost se pove-

"full speed ahead" scenario, the turbogenerator produces 500 to 600 kW, according to the available steam pressure that is around 14 bar.

In Fig 2, fuel oil consumption is marked in the case when the electric power is produced by two diesel generators running on HFO. By comparing Fig1 and Fig 2, the difference in the

Tablica 1. Primjer izračuna uštede kod primjene turbogeneratora
***Table 1** A calculation example of savings when using a turbogenerator on board a ship*

USPOREDBA TROŠKOVA DIZELSKOG GENERATORA I TURBOGENERATORA *Diesel generator (DG) and turbogenerator (TG) expenses comparison*		
Potrebna snaga generatora *Required generator power*	kW	1000
Jedinična potrošnja goriva za dizelski generator *Diesel generator SFC*	g/kWh	175
Jedinična potrošnja goriva za turbogenerator *Turbogenerator SFC*	g/kWh	0
Cijena goriva *Heavy fuel oil price*	$/t	550
Godišnja potrošnja goriva za dizelski generator *Yearly DG fuel oil consumption*	t/god	1,386
Godišnja potrošnja goriva za turbogenerator *Yearly TG fuel oil consumption*	t/god	0
Amortizacija za dizelski generator 20godina (0,05) *DG amortization for 20 years (0.05)*	%/100	0.05
Amortizacija za turbogenerator 20 godina (0,05) *TG amortization for 20 years (0.05)*	%/100	0.05
Prosječni godišnji troškovi održavanja dizelskog generatora *Average yearly DG maintenance costs*	$/god	57,000.00
Prosječni godišnji troškovi održavanja turbogeneratora *Average yearly TG maintenance costs*	$/god	55,000.00
Godišnji troškovi goriva za dizelski generator *DG yearly fuel oil costs*	$/god	762,300
Godišnji troškovi goriva za turbogenerator *TG yearly fuel oil costs*	$/god	0
Troškovi ulaganja u opremu (DG + utilizator) *Additional equipment initial expenses (DG+EGB)*	$	380,000
Troškovi ulaganja u opremu (turbogenerator + utilizator) *Additional equipment initial expenses (TG+EGB)*	$	550,000

ćava povećanjem cijene goriva. U tablici 1. i na slici 3. prikazan je izračun isplativosti jednog ovakvog projekta.

Na slici 3. se vidi ušteda u gorivu tijekom eksploatacije pogona koji ima mogućnost korištenja TG-a s cijenom teškog goriva od 550 $/t. Uočljivo je da se početno veća investicija vrati za manje od godinu dana.

Na sličan način može se napraviti usporedna analiza za dotični primjer u slučaju uzimanja teškog goriva u različitim lukama. Prema cijenama goriva IFO 380 na dan 25. 02. 2011. dobiveni su rezultati prikazani u tablici 2.

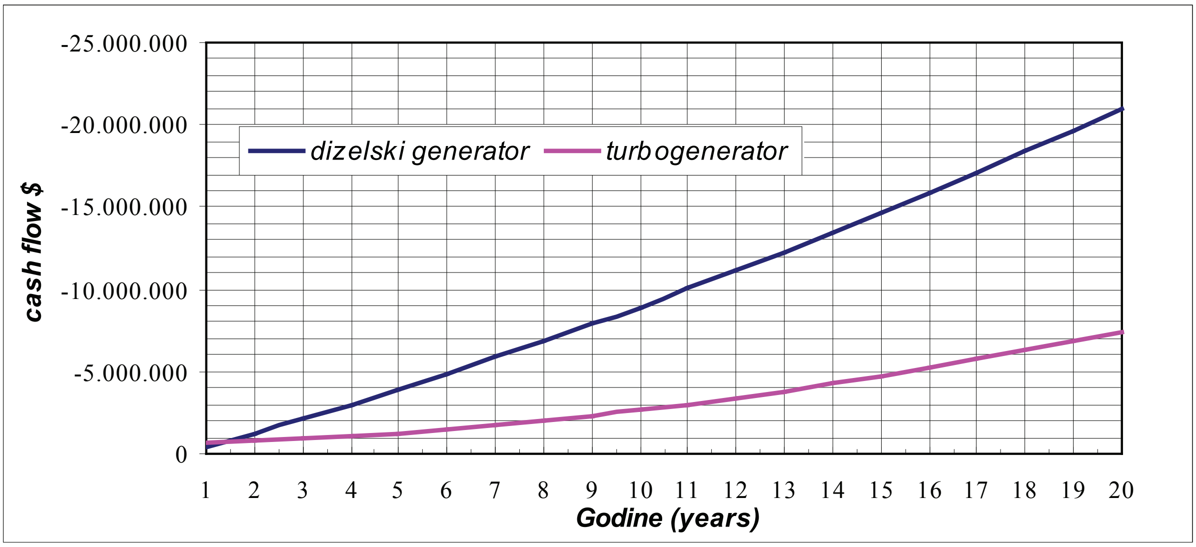
Ono što još treba naglasiti je i ekološki aspekt promatranog slučaja. Naime, pogon koji iskorištava toplinu ispušnih plinova za stvaranje potrebne količine pare za pogon, bilo turbogeneratora, bilo za grijanje tankova tereta, ne treba ili treba znatno manje dodatnog izgaranja goriva za iste potrebe. Kao rezultat imamo

HFO consumption of 0.15 [m^3/h] can be seen. If an additional economic analysis is made, it can be noted that mounting the turbogenerator on board a ship has great benefits and that the cost effectiveness is higher as the fuel oil price increases. Table 1 and Fig 3 present the cost effectiveness analysis of the simulated case.

Fig 3 clearly shows the fuel oil savings during the exploitation of the electric power plant, with the possibility of using a turbogenerator, with the current fuel price of US$/t 550. It can be seen that the initial higher investment is recovered in the period of less than one year.

A similar parallel analysis can be made, comparing the fuel oil price savings dependent on the ports where fuel oil was bunkered. According to the HFO prices on 25th February 2011, the following results were calculated:

A very important environmental aspect of the analyzed topic should be also mentioned. The



Slika 3. Grafički prikaz uštede kod primjene turbogeneratora
Figure 3 *Yearly savings in the case of the TG application*

Tablica 2. Usporedba uštede ovisno o luci ukrcaja teškog goriva za ispitivani primjer
Table 2 *HFO savings comparing different bunkering ports*

Grad – luka *Port*	IFO 380 Cijena *price US$/t*	Nakon 1. god *After 1st year*	Nakon 5 god. *After 5 years*	Nakon 10 god. *After 10 years*	Nakon 20 god. *After 20 years*
	550	-239,700$	2,665,500 $	6,297,000 $	13,560,000 $
Singapore	638	-117,732 $	3.275,340 $	7,516,680 $	15,999,360 $
Rotterdam	618	-145,452 $	3,136,740 $	7,239,480 $	15,444,960 $
Fujairah	710	-17,940 $	3,774,300 $	8,514,600 $	17,995,200 $
Busan	693	-41,502 $	3,656,490 $	9,203,478 $	17,523,960 $

znatno manje emisije NOx-a, SOx-a, CO_2 i krutih čestica. Uzimajući u obzir nove propise (Tier II), koji su stupili na snagu početkom 2011., te znatno strože propise (Tier III) koji dolaze početkom 2016., ugradnja turbogeneratora u kombinaciji s 'pojačanim' utilizatorom i pripadajućom opremom ima velike prednosti.

Također, treba spomenuti i utjecaj buke koji je kod primjene turbogeneratora znatno manji nego kod slučaja kada električnu energiju proizvode dizelski generatori.

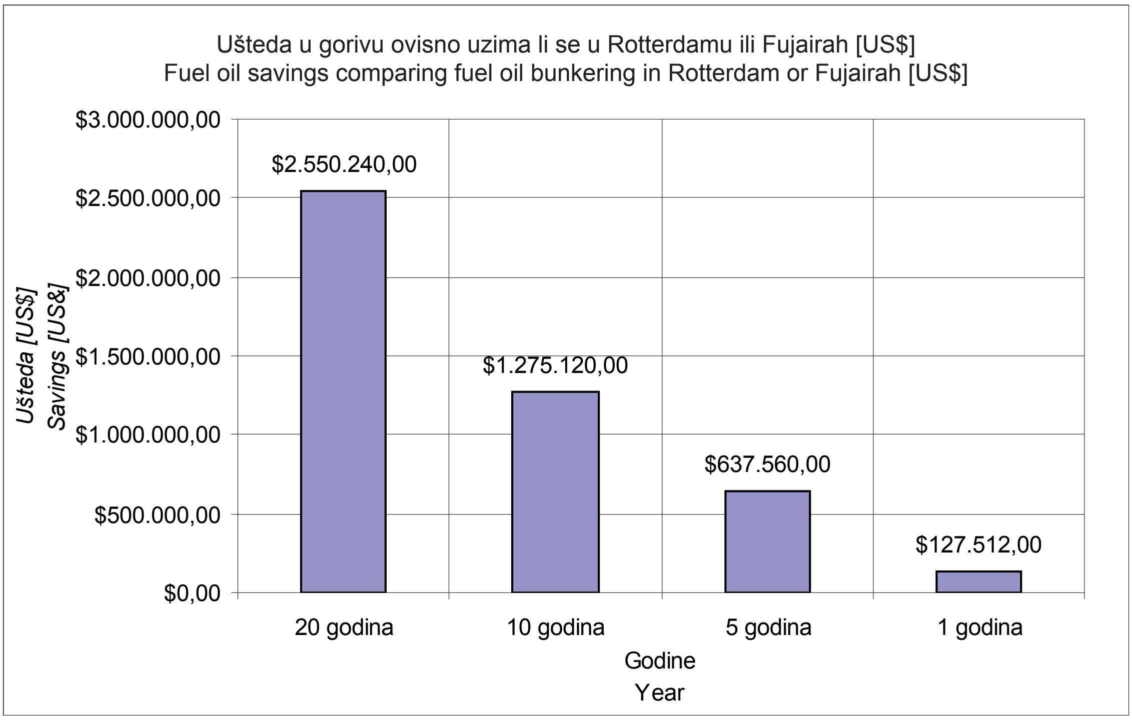
4. TROŠKOVI ODRŽAVANJA

Stvarnu cijenu troškova održavanja tijekom cijelog eksploatacijskog vijeka broda je teško izračunati s obzirom na veliki broj čimbenika koji na nju utječu. Troškovi održavanja se mogu procijeniti ili pokušati predvidjeti. Oni uključuju potrošnju ulja za podmazivanje i rezervne dijelove. Tvornica ih procjenjuje na 10000 do

exhaust gas heat recovery plant, for producing steam that is used either for cargo tank heating or electric power production, consumes much less fuel oil than an electric power plant with a set of diesel generator or shaft generator. The environmental benefits are: less NOx, SOx, CO_2 and PM emissions. By considering the newly applied Tier II regulation (in use from the beginning of 2011) and much more rigorous Tier III regulation (comes into use at the beginning of 2016.), mounting the turbogenerator together with the corresponding exhaust gas boiler on board a ship has huge advantages. It should be also mentioned that noise effect is much lower in the case of using a turbogenerator.

4. MAINTENANCE COSTS

Since there are a huge number of parameters influencing the maintenance costs, it is very difficult to determine the final maintenance expenses. The maintenance costs are therefore estimated



Slika 4: Prikaz uštede na cijeni goriva ovisno o luci ukrcaja goriva te vremenu eksploatacije
Figure 4 *Fuel oil savings comparing bunkering port and exploitation period*

15000 US$/godišnje, bez posade. Za troškove posade se može pretpostaviti da su isti bez obzira o kojem se sustavu proizvodnje električne energije radi, te stoga ne utječu na razliku u cijeni.

Predviđanje kvarova – otkaza i njihovo vrijeme trajanja vrlo je složen problem i zahtijeva matematičko-statističku obradu za svaki pojedini brod i vrstu pogona.

Iskustvo je pokazalo da uz pravilnu upotrebu i održavanje generatora pare, sustava napojne vode te ostalih sustava cjevovoda i ventila, turbina za pogon generatora zahtijeva znatno manje održavanja nego dizelski motor.

Što se tiče vremena otkaza (vremena potrebnog za otklanjanje kvara) na parnim turbinama, ono je nešto duže nego kod dizelskih motora, ali to opet ovisi o vrsti i opsegu kvara (otkaza). Vrijeme potrebno za otklanjanje otkaza duže je kod slučajeva većih havarija kao što su oštećenja lopatica, labirintnih brtvi, ležajeva i sličnih kvarova kad je potrebno otvarati kućište turbine. To vrijeme nije toliko ni važno ako električna centrala ima mogućnost napajanja s dizelskih ili osovinskog generatora ili kombinirano. U tom slučaju brod i dalje obavlja svoju osnovnu funkciju prijevoza robe, dok je otkaz turbogeneratora u fazi popravka.

or predicted. Those expenses include lubrication oil consumption and spare parts. They are estimated, by the equipment manufacturers, at US$ 10,000 to 15,000 a year, without crew salaries. The crew salaries are assumed to be the same, regardless of the electric power plant, so that they have no effect on the overall savings.

Anticipating failures and the duration of the breakdowns is a very complex problem that requires a mathematical and statistical analysis for each particular ship and engine plant.

Practice has shown that a steam turbine generator drive requires less maintenance than diesel generator electric power plants, if the regular maintenance procedures for steam boiler, boiler water quality, pipelines and valves are followed.

The required failure maintenance period on electric power plants with a turbogenerator is longer, but this mainly dependents on the type and range of the breakdown. The repair time is longer in the case of turbine blades damage, labyrinth seals or bearings damage, etc., when the turbine casing should be disassembled. This repairing time is not so important, if the electric power plant has redundancy with an additional diesel generator, shaft generator or a combination of them. In this case, the ship still keeps her basic task of shipping operation, Treba naglasiti i velike uštede u rezervnim dijelovima dizelskih generatora. Naime, kako su znatno manje u pogonu, njihovo vrijeme periodičnih pregleda može se bez većih problema produžiti na više od 4 godine, odnosno na svako drugo, treće ili četvrto dokovanje. Osim uštede na rezervnim dijelovima povećava se fleksibilnost i sigurnost samog pogona, odnosno jedan ili dva dizelska generatora rade samo u luci, što je 10-tak % ukupnog vremena. Po tom modelu i pretpostavkama, oni rade oko 1000 sati godišnje. Ako se zna da se kod današnjih dizelskih motora veliki pregled radi nakon 10.000 do 15.000 radnih sati, lako se izračuna razdoblje u kojem se u dizelske generatore ne treba ulagati veći novac.

Postavlja se pitanje povećane potrošnje napojne vode? Ova potrošnja je povećana, ali su te količine zanemarive, naravno uz pretpostavku da je armatura generatora pare, cjevovodi, ventili, pumpe i ostala oprema u adekvatnom stanju, odnosno da nema većih propuštanja. Drugim riječima, ugradnja turbogeneratora ne zahtijeva znatno veći generator slatke vode koji bi dodatno poskupio početnu investiciju.

Ono što je bitno na takvom postrojenju, ali i na svakom drugom, je održavanje kvalitete napojne vode. Strojarski kadar na brodu je obavezan raditi svakodnevnu analizu vode (ponekad i dva puta dnevno), kako bi se na vrijeme dijagnosticiralo miješanje napojne vode i mora, što dovodi do stvaranja taloga (kamenca) na stijenkama cijevi generatora pare, te uzrokuje oštećenje lopatica i smanjuje iskoristivost turbine.

5. ZAKLJUČAK

Ugradnja turbogeneratora na brodove čiji pogoni svojom instaliranom snagom to omogućavaju, zasigurno pridonosi ukupnoj eksploatacijskoj iskoristivosti broda, bez obzira na nešto veće početne investicijske troškove. Ušteda na gorivu koja je ovdje analizirana nije mala i mjeri se u milijunima dolara. Ta su ušteđena sredstva svakako dovoljna za održavanje nešto "složenijeg pogona", a pokrivaju čak i višestruku zamjenu kompletnog generatora novim uređajem.

Ne stoji tvrdnja da je pogon s turbogeneratorom složeniji i da zahtijeva kvalitetniji kadar. Štoviše, dokazano je, da je uz pravilno održavanje kvalitete napojne vode i periodično održavanje, pogon s turbogeneratorom sigurniji i fleksibilniji od onog sa samo dizelskim generatorima.

while the turbogenerator breakdown is in the repairing procedure.

It should be emphasized that in the case of using the combined electric power plant (shaft generator + diesel generator + turbogenerator or 2 diesel generators + shaft generator), there is a substantial diesel generator spare parts saving. In this case the diesel generators are less in the operation mode and their overhauling period can be extended to more than four years that is every second, third or even fourth docking. Besides spare parts saving, the complete power plant flexibility as well as the safety increases, that is when only one or two diesel generators run in the port, which is about 10% of the complete running time. According to this model and premises they run about 1,000hrs/year. Considering that the overhaul of a modern diesel engine is done approximately every 10,000 to 15,000 working hours, the period in which there is no need to invest greater amount of money into a diesel generator can be easily calculated.

There are questions if the electric power plant with a turbogenerator has a greater boiler feed water consumption? That is partially true, but those quantities are negligible, with the assumption that the boiler equipment, pipelines, valves, pumps and other steam plant equipment are in an adequate condition, that means there are no significantly leaking. In other words, the turbogenerator implementation does not require a much larger fresh water generator, in which case the initial investment will be additionally increased.

The feed water quality control is the most important thing on the engine plants with a turbogenerator, but also on every other engine plant. In order to be able to notice the mixing of feed water and sea water in time, it is very important to analyze the feed water on daily basis (sometimes twice per day). This is a very important task of the engine crew. The sea water and feed water mixing leads to scale formation on boiler pipes and causes turbine blades damages as well as decreases the turbine efficiency.

5. CONCLUSION

The turbogenerator installation on board a ship propelled by a main engine, strong enough to allow such a choice, surely contributes to the total exploitation effectiveness regardless of some higher initial costs. The calculated fuel savings presented in this paper are not negligi-

Samoodržavanje sustava, pa tako i samog turbogeneratora u današnjoj eri komunikacija ne bi trebao predstavljati problem. Dobra logistička podrška s kopna može biti "vodič" pri dijagnosticiranju i otklanjanju bilo kakvog kvara ili zastoja. Održavanje kontakta sa stručnim kadrom na kopnu, pa i sa samim proizvođačem određenog uređaja, može uvelike pomoći pri rješavanju određenog problema na brodu. Upravo zato nije prikladno navoditi problem održavanja generatora pare i parne turbine kao osnovni nedostatak na današnjem stupnju razvoja. Predložene vrste pogona zasigurno imaju prednost u odnosu na čisto dizelgeneratorsko postrojenje.

Može se reći da bi optimalni generatorski sklop predstavljala kombinacija turbogeneratora, osovinskog i dizelskog generatora, s time da svaki od njih pokriva 100% potrebe za električnom energijom tijekom plovidbe broda. Ako brod u luci ima veću potrebu za električnom energijom, imalo bi smisla ugraditi još jedan dizelski generator što bi povećalo i sigurnost koja je kod tankera naročito bitna. Ovakav vid redundancije je važan i kod drugih brodova prilikom prolaska kroz kanale, rijeke i općenito u uvjetima manevra.

Velika učinkovitost primjene ovakvih sustava je i kod kontejnerskih brodova. Oni danas imaju vrlo velike instalirane snage gdje kao rezultat imamo vrlo velike količine topline sadržane u ispušnim plinovima koju je moguće dodatno iskoristiti upravo ugradnjom turbogeneratora.

Analiza je pokazala kako na ekonomsku učinkovitost veliku ulogu ima izbor luke ukrcaja goriva te se pravilnim planiranjem putovanja mogu ostvariti značajne uštede.

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ble and could be measured in a million of US dollars. This money surely covers the maintenance of some more "complex engine plant", and the savings are high enough for a complete, multiple replacement of generator sets during ship exploitation period.

The statement of "some more complex" engine plant with turbogenerator and necessity for a qualified engine crew is not quite true. Furthermore, it is well proved that such a plant, with properly maintained feed water quality and periodic maintenance is more accident-free and flexible, as compared to the diesel generator electric power plant.

The complete system and turbogenerator maintenance today should not be a problem. The good company's technical and logistic support could help to solve any kind of failure or breakdown. By keeping a contact with the company technical department or directly with a particular equipment manufacturer, could greatly help in solving any problem on board a ship. According to the above mentioned facts, the alluding of boiler or turbogenerator maintenance problem as the main disadvantage in the present state of the technical development is not correct. These kinds of power plants surely have an advantage as compared with the classical diesel generator electric power plants.

It can be said that a combination of the shaft generator, turbogenerator and diesel generator should be the optimal electric power plant combination set, regarding that each of the generator covers 100% of the electric power demands during the navigation period. If there are ships with an additional power demand when in a port, an additional diesel generator should be installed thus increasing the safety which is very important on board .tankers. This kind of redundancy is significant on board other types of ships too, especially when passing across channels and rivers and, generally, during the manoeuvring procedure.

The high efficiency of this power system can be utilized on board container ships. These ships usually have high power main engines that produce tremendous amounts of exhaust gas heat that could be additionally utilized by installing a turbogenerator. The presented analysis also confirms the correlation between the bunkering port and the final economic effectiveness, so that a properly voyage planning could lead to significant savings.