(ж/д, авто), что будет способствовать значительному приросту объемов и скорости обработки грузов, что особенно актуально в условиях повышения эффективности мультимодальных, транзитных и экспортно-импортных операций через отечественные порты.

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УДК 681.215
DOI: 10.34046/aumsuomt100/3

ЗЕЛЕНЫЙ ТАНКЕР» ТИПА VLCC - ОДИН ИЗ СПОСОБОВ СООТВЕТСТВОВАНИЯ НОВЫМ ЭКОЛОГИЧЕСКИМ ТРЕБОВАНИЯМ В МИРЕ

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В данной статье основное внимание уделяется особенностям эксплуатации танкеров типа «VLCC». Предлагается использование танкера типа «VLCC» для перевозки сырой нефти на маршруте Новороссийск - Самсун. Специфика данного исследования включает сравнение работы как для стандартного, так и для «зеленого» танкера, включая общие технические характеристики, эскиз генерального плана расположения, расчет проектного индекса энергоэффективности ИМО, выбросов энергии и выхлопных газов для обоих проектов VLCC. Проект «зеленого танкера VLCC» был предложен как «обновленная» версия стандартного танкера VLCC с уменьшенной на 10% скоростью судна и с неизменным (вместимость х скорость) стандартным VLCC = (вместимость х скорость) соотношением «зеленого» VLCC. Кроме того, предлагается дополнительный «зеленый профиль» для проекта VLCC, в плане поддержания его в актуальном состоянии в течение 10-летнего периода между 1-м и 3-м специальным обследованием в сухих доках с использованием съемки в воде с видео вместо сухого дока, реализация метода оптимальной балансировки с использованием выработки электроэнергии с регулируемой скоростью сокращает количество генераторных установок на 25% и, конечно же, с использованием системы эффективного управления мощностью на судне.

Ключевые слова: танкер для сырой нефти типа VLCC, зеленый танкер, оптимальное покрытие корпуса, управление мощностью, расчет энергии и выбросов выхлопных газов.

VLCC "GREEN TANKER" PROJECT IS ONE OF THE WAYS TO MEET THE NEW ENVIRONMENTAL REQUIREMENTS IN THE WORLD

A. I. Epikhin, D. S. Tormashev

This paper has been focused on "VLCC" tanker design. It is offered to use "VLCC" crude oil tanker for Novorossiysk – Samsun project. The specifics of the study have been contained the design work for both the standard and green ship including Outline specification, sketch of the general arrangement plan, calculation of IMO's Energy Efficiency Design Index, Energy and Exhaust Emission for the both VLCC projects. "VLCC" "green tanker" project has been offered as an updated design of standard VLCC tanker at reduced 10 per cent vessel's speed and having unchanged (capacity x speed) standard VLCC = (capacity x speed) green VLCC ratio. In addition, it is offered the additional "green profile" for VLCC project such as keeping VLCC Afloat for 10-year period between the 1st and 3rd Special Survey Dry-Dockings' using In Water Survey with Video in Lieu of Dry-docking, implementation of Optimal trim method, using variable speed electric power generation reduces number of generating sets by 25% and of course using Effective Power management system on vessel.

Ключевые слова: VLCC crude oil tanker, green tanker, optimal trim, hull coating, power management, energy and exhaust emission calculation.

1. Introduction

Around 90% of global merchandise is transported by sea. For many countries, sea transport represents the most important mode of transport for trade. Taking into account the historical developments in energy efficiency in shipping and the principles for any future climate regulation of shipping, the industry is prepared to enter into discussions on the different legislative options that can be both practical and attainable. One option is to introduce a CO2 index limit for new ships. For the purpose of identifying and developing mechanisms needed to achieve reduction of GHG emissions from international shipping, IMO is in the process of evaluating the organization's CO2 emission indexing expressing the amount of CO2 emissions per tonne/km of actual net transport work carried out. Setting a limit for such an index could have an environmentally positive impact on the specification and performance of new ships [1].

Classification Society DNV GL on 18 December 2020 said it teamed up with the world's largest shipyard Hyundai Heavy Industries (HHI) to embark on the development of future-proof tanker designs and the joint development has yielded positive results.

In a recent "Green Tankers towards 2050" industry webinar, DNV GL and HHI Group presented the results of new joint research and explained how eco-friendly maritime solutions can help shipowners and managers to cope with stricter environmental regulations now and in the future.

A memorandum of understanding (MOU) signed at Gastech trade fair in Houston 2019, when DNV GL and HHI agreed to develop low and zero carbon solutions for shipping initiated the joint research.

To respond to these regulations, HHI Group introduced their range of eco-friendly ships that are equipped with alternative fuel technologies and energy-reducing systems, among them 40 LNG dual-fuelled ships already delivered or under construction.

"The International Maritime Organization (IMO) is strengthening environmental regulations, including a 50% reduction in ship greenhouse gas emissions by 2050 compared to 2008," added H. J. Shin, Head of Future Ship Research Department at KSOE.

"We will help the shipping industry to reach these ambitious goals by taking a leading position in the eco-friendly maritime era through research and development."

By applying DNV GL's data-based carbon robust model to its very large crude carrier (VLCC) and Medium Range (MR) tanker ships, HHI Group noted it found that an LNG fuel propulsion system in combination with advanced energy saving devices (ESDs) can enable a vessel to meet the new Carbon Intensity Indicator over its expected lifetime.

The specifics of the study include Samsun-Ceyhan project the trade flow survey and prospects for future volumes, together with an actor survey/analysis for shipowners, charters and other active, analysis of Tonnage demand calculation, calculation of Transportation Costs, calculation of Transportation Costs related to Bunker Cost and influence of existing and problem of the Bosporus and Dardanelles Straits.

Table 1 shows the calculation of transportation cost. It is easily seen that using "VLCC" is the most profitable for Samsun-Ceyhan project. Transportation cost is 1.64 USD per tonne in such case.

Table 1. Samsun – Ceyhan project round voyage costs

Vessel's type		"VLCC"	"Suezmax"	"Aframax"
Vessel hire, USD (Fearnleys' March 2020) related to Total days per voyage [2]		65,000	37,500	27,500
Bunker Cost, USD	Loaded	22,140	15,990	13,530
	Ballast	18,548	11,652	9,988
In port Novorossiysk	Loading	7,811	2,985	2,558
In port Ceyhan	Discharge	44,649	27,552	22,386
Total		158,148	95,679	75,962
Port expenses, USD	Novorossiysk/Samsun	335,000	265,000	195,000
Per tonne, USD		**1.64**	**2.40**	**2.58**

Calculation of break-even rate, Table 2, shown that "VLCC" (new Building, price Million USD 95 and T/C daily rate USD 49,500) is profitable for this project as well (keeping in mind 10% Capital Recovery Factor).

Keeping in mind these facts "VLCC" type of crude oil tanker was chosen for carrying cargo to Novorossiysk – Samsun project. Moreover, there is no vessel's length or draft restriction in crude oil shipping between both terminals.

This assignment is focused on "VLCC" tanker design. The specifics of the study include design work for both the *standard* and *green ship* including Outline specification, sketch of the general arrangement plan, IMO's Energy Efficiency Design Index, Energy and Exhaust Emission etc

General Description of *standard* VLCC tanker

The "VLCC" having deadweight 317 400 mt at scantling draft is designed as a single screw diesel engine direct driven "Crude Oil Tanker" with bulbous bow, transom stern and a continuous deck with sunken deck as shown on the General Arrangement (G.A.) Appendix D. All accommodation including Navigation Bridge and propulsion are located aft. The Vessel has fore/aft peak tank, cargo oil tanks, water ballast tanks, fuel oil tanks and engine room as shown on the G.A.

The cargo area constructs with double bottom and double hull, with five (5) triple cargo tanks, one (1) pair of slop tanks and six (6) pairs of segregated water ballast tanks. Heavy fuel oil storage tanks are protected by double structure. One (1) combined signal and radar mast on the top of wheelhouse and one (1) foremast on the forward upper deck are fitted. Pump room is protected by the void space and arranged as shown on the G.A.

Intended cargoes

"Crude oil" having a flash point below 60 deg.C.

2.1. Calculation of principal dimensions for "Standard tanker"

The following Principal Dimensions were calculated for *"Standard tanker"*:

Design deadweight is assumed to be 0,916194 pct. (for VLCC) of the scantling deadweight which means that Design deadweight is:

- The design deadweight of "Standard tanker" = 317 400 x 0,916194 = 290 800 mt
- Lpp [m] of "Standard tanker" = 7,72 (Scantling dw [t]) 0,30 = 345.22 m
- Breadth [m] of "Standard tanker" = 0,187 Lpp [m] - 1,96 = 62.6 m
- Scantling draught [m] of "Standard tanker" = 0,064 Lpp [m] + 0,42 = 22.51 m
- Lightweight [t] of "Standard tanker" = 0,00001425 Lpp4 - 0,009134 Lpp3 + 2,454 Lpp2 – 206,1 Lpp + 6547 = 54 460.02 t.
- Displacement = Scantling Deadweight + Lightweight = 317 400 + 54 460 = 371 860 mt

The design draught, Tdesign, is calculated using following formula:

$$T_{design} = T_{scantling} - \frac{ScantlingDw - DesignDw}{\rho \times Lpp \times B \times Cw}$$

where p = 1.025 t/m3 (density of sea water) and the water plane area coefficient, Cw (mean value of design and scantling draught Cw), depends on the block coefficient, Cb (at scantling draught).

Cw is calculated using following empirical formula: Cw = 0.5 + 0.5 Cb

- Cb "Standard tanker" = 371,860/(1.025x345.22x62.6x22.51)= 0.745778

- Cw “Standard tanker”= 0.5+0.5x0.745778= 0.872889
- Tdesign “Standard tanker”= 22.51-(317 400-290 800) / 1.025 x 345.22 x 62.6 x 0.872889 = 21.134 m

“Standard tanker” calculated Principal Dimension

- Water line length = 1.01 x Lpp: abt. 348.67 m
- Length Lpp: 345.22 m
- Breadth (mld): 62.6 m
- Scantling draft (mld): 22.51 m

“Standard tanker” calculated Deadweight

- At design draft: 290,800 mt
- At scantling draft: 317,400 mt
- Displacement:3 71, 860 mt

“Standard tanker” calculated Capacity (100% volume)

- Cargo tanks incl. slop tanks approx.: 354,300 m3
- Ballast water capacity, m3 = 0.000867 (Lpp(m))3.242: 146,732 m3
- Heavy fuel oil tanks approx. : 9,100 m3
- Diesel oil tanks approx.: 400 m3
- Fresh water tanks including drink water tank: 550 m3

2.2. “Standard tanker” Main Engine

Calculation of design condition and maximum continuous main engine power (MCR).

The main engine power for *“Standard tanker” is* calculated by the power prediction program as documented in Appendix A. It is envisaged that the power requirement at the design speed of 15.0 knots is 24 809 kW, which has to be developed at 90 pet, MCR which means that the maximum installed power is: *26 621/0 .90 = 27 566 kW*. It is offered two Main Engine configurations shown in Table 2 which can be installed.

Table 2. Main engine configurations

Main Engine particulars	Engine type	
	MAN 7S80MC-C8	Wärtsilä 7RT-flex84T
MCR:	29,260 kW x 78.0 RPM	29,400 kW x 76.0 RPM
NCR:	26,158 kW x 75.3 RPM (90% of MCR).	24,678 kW x 74.4 RPM (90% of MCR).
S.F.O.C at MCR:	Abt. 167 g/kW.h + 5% based on low calorific value 10,200 kcal/kg under ISO reference conditions.	Abt. 171 g/kW.h + 5% based on low calorific value 10,200 kcal/kg under ISO reference conditions.

These are Two (2) stroke, single acting, airless injection, cross head, Alpha cylinder oil lubricator, direct reversible type marine diesel engine with high efficiency exhaust gas turbocharger, Nox emission approved type in accordance with MARPOL Annex VI, Regulation 13. The main engines are designed for using heavy fuel oil having a viscosity of 700 cSt at 50C (ISO RMH 700). [3]; [4].

It is offered to use MAN 7S80MC-C8 engine for *“Standard tanker”*.

2.3. “Standard tanker” Speed

Service speed on the design draft of 21.134 m when: 15.0 knots running at NCR (90% of MCR) of main engine with 15% sea margin.

2.4. “Standard tanker” Cruising Range

Cruising range on the basis of following condition is about 29,000 sea miles.

Main engine running at NCR.

2.5. “Standard tanker” Fuel Oil Consumption of Main Engine

Daily fuel oil consumption at NCR of main engine: abt. 104.5 MT/Day

2.6. “Standard tanker” Electrical part

In addition to the power for propulsion, power is also required for generation of electricity onboard for the different electrical users. It is seen that the auxiliary power can be approximated by following linear equation expressing that the power is linear proportional to length between pp: Auxiliary power in kW = 9.35 Lpp [m] + 811.

Thus, auxiliary power in kW for *“Standard tanker”* = 9.35 x 345.22 + 811 = 4038.8 kW

The generators are served as follows:

- Main diesel generators: Three (4) sets. Diesel engine driven, self excited type. AC 450 V, 60 Hz, 3 Ph, abt. 1,200 kW.

• Diesel engine: abt. 1,260 kW x Max 900 RPM.

• Emergency generator: One (1) set. Diesel engine driven, self excited type. AC 450 V, 60 Hz, 3 Ph, 300 kW, 1,800 RPM.

The main gen. engines are designed for using heavy fuel oil having a viscosity of 700 cSt at 50C (ISO RMH 700). The emergency generator set is designed for using light diesel oil (ISO DMX).

Table 3. Auxiliary engines service condition

Service condition	Generator in use Slop Tanks Heat Without	 With
At normal sea going	DG x 1	DG x 2
Manoeuvring	DG x 2	DG x 2
Cargo handling	DG x 2	DG x 2
Tank Cleaning	DG x 2	DG x 2
In Harbour	DG x 1	DG x 1
At emergency	EG x 1	

Table 3 indicates auxiliary engines service condition related operational needs.

4 General Description of VLCC *"green tanker"*

4.1 Calculation of principal dimensions for "Green tanker"

The following Principal Dimensions were calculated for *"Green tanker"*:

Scantling deadweight of *"Green tanker"* is: Scantling deadweight of "*Standard tanker*" x 10% = 349,140 mt.

Design deadweight is assumed to be 0,916194 pct. (for VLCC) of the scantling deadweight which means that Design deadweight is:

• The design deadweight of "Green tanker" = 349,140 x 0,916194 = 319,880 mt

• Lpp [m] of "Green tanker" = 7,72 (Scantling dw [t]) 0,30 = 355.236 m

• Breadth [m] of "Green tanker" = 0,187 Lpp [m] - 1,96 = 64.47 m

• Scantling draught [m] of "Green tanker" = 0,064 Lpp [m] + 0,42 = 23.16 m

• Lightweight [t] of "Green tanker" = 0,00001425 Lpp4 - 0,009134 Lpp3 + 2,454 Lpp2 – 206,1 Lpp + 6547 = 60,474.45 t.

• Displacement = Scantling Deadweight + Lightweight = 349,140 + 60,474 = 409, 614 mt

• Cb "Green tanker" = 409,614/(1.025x355.24x64.47x23.16)= 0.753413

• Cw "Green tanker"= 0.5+0.5x0.753413= 0.876707

• Tdesign "Green tanker"= 23.16-(349,140-319,880) / (1.025*355.24*64.47*0.876707) = 21.7382 m

"Green tanker" calculated Principal Dimension

Water line length = 1.01 x Lpp:	abt. 358.79 m
Length Lpp:	355.24 m
Breadth (mld):	64.47 m
Scantling draft (mld):	23.16 m

"*Green tanker*" calculated Deadweight

At design draft :	319,880 mt
At scantling draft:	349,140 mt
Displacement:	409,614 mt

"*Green tanker*" calculated Capacity (100% volume)

Cargo tanks incl. slop tanks approx.:	389,730 m3
Ballast water capacity, m3 = 0.000867 (Lpp(m))$^{3.242}$:	160,995 m3
Heavy fuel oil tanks approx.:	9,900 m3
Diesel oil tanks approx.:	400 m3
Fresh water tanks including drink water tank:	550 m3

4.2 "Green tanker" Main Engine

The main engine power for *"Green tanker" is* calculated by the power prediction program as documented in Appendix B. It is envisaged that the power requirement at the design speed of 13.5 knots is 19 400 kW, which has to be developed at 90 pet, MCR which means that the maximum installed power is: *19 400/0 .90 = 21 556 kW*).

It is offered Main Engine with following configurations:

Number of set : One (1) set

Type:	Wärtsilä 7RT-flex84T
MCR:	29,400 kW x 76.0 RPM
NCR (90% MCR):	24,678 kW x 74.4 RPM (90% of MCR).

These is Two (2) stroke, single acting, airless injection, cross head, Alpha cylinder oil lubricator, direct reversible type marine diesel engine with high efficiency exhaust gas turbocharger, NOx emission approved type in accordance with MARPOL Annex VI, Regulation 13. The main engines are designed for using heavy fuel oil having a viscosity of 700 cSt at 50C (ISO RMH 700). [4]

4.3 "Green tanker" Electrical part

Auxiliary power in kW for *"Green tanker"* = 9.35 x 355.24 + 811 = 4132.5 kW

The generators configuration and feature are the same as for *"Standard tanker"*.

5. Additional *"green profile"* for VLCC project

Fuel consumption is becoming a critical issue as the price of energy is increasing and the need to cut emissions is evident. On this site it is offered some actions and measures how to reduce energy consumption for VLCC project. The aim is to cut operating costs while, at the same time, reduce emissions.

5.1 Hull coating

Modern hull coatings have a smoother and harder surface finish, resulting in reduced friction. Since typically some 50-80% of resistance is friction, better coatings can result in lower total resistance. A modern coating also results in less fouling, so with a hard surface the benefit is even greater when compared to some older paints towards the end of the docking period.

It is offered a project for keeping VLCC Afloat for 10 year period between the 1st and 3rd Special Survey Dry-Dockings' using In Water Survey with Video in Lieu of Dry-docking. All other Survey and Inspection requirements will remain the same, using external purpose made blanks for internal removals to facilitate Close-up Inspections as required. Subject has discussed in detail with Authority LISCR and Classification Society DNV. Accepted in principal.

All comparisons done in our investigations (Appendix F) have been proven that BRUNEL ENVIROMARINE is the superior of the short listed three HARD COATING products ECOSPEED/BRUNEL/CAPPS.

It is expected up to 9 629 487 USD saving over fifteen years VLCC trading (Including 4%, about 1 059 mt / 487 140 USD of fuel savings per annum) at 1 138 850 USD spent during dry dock for hull treatment.

5.2 Vessel trim

The optimum trim can often be as much as 15-20% lower than the worst trim condition at the same draught and speed. As the optimum trim is hull form dependent and for each hull form it depends on the speed and draught, no general conclusions can be made. However, it should be noted that correcting the trim by taking ballast will result in higher consumption (increased displacement). If possible, the optimum trim should be achieved either by repositioning the cargo or rearranging the bunkers. It is expected up to 5% of fuel consumption saving for VLCC (about 1 324 mt / 609 040 USD of fuel savings per annum).

5.3 Variable speed electric power generation

The system uses generating sets operating in a variable rpm mode. The rpm is always adjusted for maximum efficiency regardless of the system load.

The electrical system is based on DC distribution and frequency controlled consumers. Reduces number of generating sets by 25%. Optimised fuel consumption, saving 5% (about 1 324 mt / 609 040 USD of fuel savings per annum). It is assumed that equipment cost is 650 000 USD.

5.4 Power management

Correct timing for changing the number of generating sets is critical factor in fuel consumption for auxiliary power installations. An efficient power management system is the best way to improve the system performance. Running extensively at low load can easily increase the SFOC by 5% (about 1 324 mt / 609 040 USD of fuel savings per annum). It is assumed that equipment cost is 80 000 USD. Meantime, we have to remember that low load increases the risk of turbine fouling with a further impact on fuel consumption.

5.5 Exhaust Gas Scrubber

Unlike nitric oxide emissions, sulphur oxides cannot be reduced by modifying the combustion process inside the engine. All of the sulphur contained in the fuel is output in the exhaust gas. A dramatic reduction in sulphur emissions can be achieved, however, by switching from heavy fuel oil to fuels with a lower sulphur content – such as marine diesel oil (EU Directive, subject to effect from January 1st 2010, relating to the sulphur content of marine fuels burned as bunker in ships requires to use 0,1% sulphur limit on marine fuel used by ships at berth in EU ports). This fuel is significantly more expensive than conventional heavy fuel oil. It must be kept in mind that the operating costs of a ship are largely made up of fuel costs.

The exhaust gas scrubber, known as the open loop scrubber, reduces the sulphur oxide content of the exhaust gases by 90 to 95 per cent. Spray jets similar to the design of shower heads drench the exhaust gas with sea water just before the flue. Water and sulphur react to form sulphuric acid, which is neutralized with alkaline components in the sea water. Filters separate particles and oil from the mixture before the cleaned water is given back into the sea. Meantime, the disadvantage of scrubber technology is its relatively large space requirements on board. Its operation requires a capacity of 40 to 50 cubic metres of sea water per Megawatt hour of engine power.

Some companies are nevertheless already working on a version known as the closed loop scrubber that uses fresh water in combination with caustic soda as the neutralizing additive. The scrubber then requires less space and its water requirements drop to 0.1 cubic meter per Megawatt hour output, and virtually no wash-water is produced that would have to be lead into the sea. Also in development is a dry scrubber, in which the exhaust gas flows through granulated limestone. This combines with the sulphur to form gypsum, which can then be disposed of on land. The advantage: the sulphur is locked in, meaning it cannot burden the biosphere any more. The disadvantage: a storage room has to be created on board for the granulate, which means sacrificing cargo capacity. Estimated cost for installation of Exhaust Gas Scrubber is approx. 1 000 000 USD.

6 IMO's Energy Efficiency Design Index calculation for the *"Standard ship"* and for the *"Green ship"*.

Following particulars have been estimated by a design procedure for the 317,400 dwt VLCC *"Standard tanker"* and 349,140 dwt VLCC *"green tanker"* and it will be used in further calculations.

Table 4. Principal dimension of *"Standard tanker"* and *"Green tanker"* VLCC.

Principal Dimension	*"Standard tanker"*	*"Green tanker"*
Length between pp, m	345.22	355.24
Water line length = 1.01 x Lpp, m	348.67	358.79
Breadth, m	62.6	64.47
Scantling draught, m	22.51	23.16
Scantling deadweight, Mt	317 400	349 140
Design deadweight, Mt	290 800	319 880
Design draft, m	21.134	21.73
Light ship weight, t	54 406	60 474
Design displacement, Mt	345 260	380 354
Propeller diameter, m	10.0	10.0
Design service speed at 90 pct. MCR with 10 pct. service allowance	15,0 knots	13,5 knots

6.1 Principal dimension of “Standard tanker” *and* “Green tanker” *VLCC.*

As EEDI has to be determined at 100 pct. scantling deadweight (for tanker). This deadweight and corresponding draught have to be calculated as well:

- 100 pct. Scantling deadweight “Standard tanker” = 1x 317 400 = 317 400 t
- T100 % dw “Standard tanker”= Tscantling = 22.51 m;
- 100 pct. Scantling deadweight “Green tanker” = 1x 349 140= 349 100t
- T100 % dw “Green tanker” = Tscantling = 23.16 m;

The so-called reference speed, Vref, in the EEDI equation has to be determined at 75 % MCR “Standard tanker”= 0.75 X 27 566 kW = 20 675 kW at a displacement of 317 400 + 54 406 = 371 860 t. Vref = 13,8 knots.

- MCR “Green tanker” 0.75 X 21 556 kW = 16 167 kW at a displacement of 349 140 + 60 474 = 409 614 t. Vref = 12,4 knots.

A power prediction calculation for determination of Vref is done with the DTU program.

The auxiliary power at sea is calculated by the formulas proposed by IMO:

- PAE for “Standard tanker”=250+0.025 MCRME=250 + 0.025 x 29 579=989.5 kW
- PAE for “Green tanker”=250+0.025 MCRME=250 + 0.025 x 23 444 = 836.1 kW

For the actual main engine SFC is 190 g/kWh while SFC for the auxiliary engines is 210 g/kW h. The EEDI is then calculated as follows:

- EEDI “Standard tanker” = (20 675*190*3.114+989.5*210*3.114)/317 400*13,8 = 2.940477 g/t/nm
- EEDI “Green tanker” = (16 167*190*3.114+836.1*210*3.114)/ 349 140*12,4 = 2.335722 g/t/nm

Table 5. Calculation of EEDI condition and reference speed at 75 % MCR for *“Standard tanker”* and *“Green tanker”.*

Data for calculation of EEDI condition and reference speed at 75 % MCR	“Standard tanker”	“Green tanker”
Scantling deadweight, Mt	317 400	349 140
Tscantling, m	22.51	23.16
75 % MCR at displacement, kW	20 675	16 167
Auxiliary power at sea, kW	989.5	836.1
EEDI, g/t/nm	2.892766	2.555483

7 Energy and exhaust emission calculation

Based on the speed and power prognosis for the both VLCC *“Standard tanker”* and *“Green tanker”* projects involved into Novorossiysk – Samsun crude oil shipping, now it is time to determine:

- The specific energy demand for the ship, i.e. the energy demand per transport unit
- The specific emissions, i.e. emissions per transport unit
- The specific external costs, i.e. costs per transport unit

The emissions and the external costs evaluation is done for the *“Standard tanker”* and *“Green tanker”*, which shipped 71.83 million tonnes cargo yearly on distance of 213 nautical miles. There are no natural trade combinations, so the vessels will have to sail in ballast condition back to Novorossiysk. *“Standard VLCC”*- 290 800 dwt at design draft (cargo intake 275 000 tonnes) and *“Green VLCC”*- 319 880 dwt at design draft (cargo intake 305 000 tonnes) from four SPMs, CPC Oil Terminal “Yuzhnaya Ozereika, Novorossiysk” are utilized. Cargo handling capacity for “VLCC” in port Novorossiysk is 14,000 tonnes per hour and in port Samsun 15,000 tonnes per hour. Loading and unloading work is done on a continuous, 24 hours, basis all week days in port Novorossiysk and Samsun (SHINC = Sundays and Holidays included). It should be added 0.4 days for cargo document formalities/cargo tanks stripping/cargo tanks crude oil washing at disport and 0.2 days at loading port [6]. The sailing speed and bunker consumption are set at 15.0 knots (nautical miles per hour) on 104 tonnes of IFO 380 (heavy fuel oil) per day for *“Standard tanker”* when loaded and 15 knots on 95 tonnes IFO 380 per day when sailing in ballast and 13.5 knots on 78 tonnes of IFO 380 (heavy fuel oil) per day for *“Green tanker”* when loaded and 13.5 knots on 70 tonnes IFO 380 per day when sailing in ballast”. Assume 355 operational days per vessel per year and use a sea margin of 5% compared to optimal calculated sailing time.

Table 6. Novorossiysk – Samsun trading feature calculation.

Vessel's type		"Standard tanker"	"Green tanker"
At sea, voyage time	Loaded	0.60 days	0.67 days
	Ballast	0.60 days	0.67 days
In port Novorossiysk	Loading	1.02 days	1.11 days
In port Samsun	Discharge	1.16 days	1.25 days
Total days per voyage		3.38 days	3.7 days
Number of voyages per vessel per year		105	96
Cargo per vessel per voyage, mt		275 000	305 000
Cargo per vessel per year, mt		28 875 000	29 280 000
Total bunker per cargo voyage, mt		62.4	52.3
Total bunker per cargo voyage per year, mt		6 552	5 021

7.1 Calculation of the specific energy demand

It is assumed that the *"Standard VLCC"* with payload - 275 000 tonnes, fuel consumption per cargo trip - 62,4 tonnes, Lower Calorific Value for IFO 380 - 42, 707 MJ requires an energy demand of 0.0246 MJ/payload/km. *"Green VLCC"* with payload -305 000 tonnes, fuel consumption per cargo trip - 52,3 tonnes, Lower Calorific Value for IFO 380 - 42, 707 MJ requires an energy demand of 0.0186 MJ/payload/km.

Thus, total energy demand for *"Standard VLCC"*: 395 x 0,0246 = 9,7 MJ/payload and for *"Green VLCC"*: 395 x 0,0186 = 7,3 MJ/payload [7].

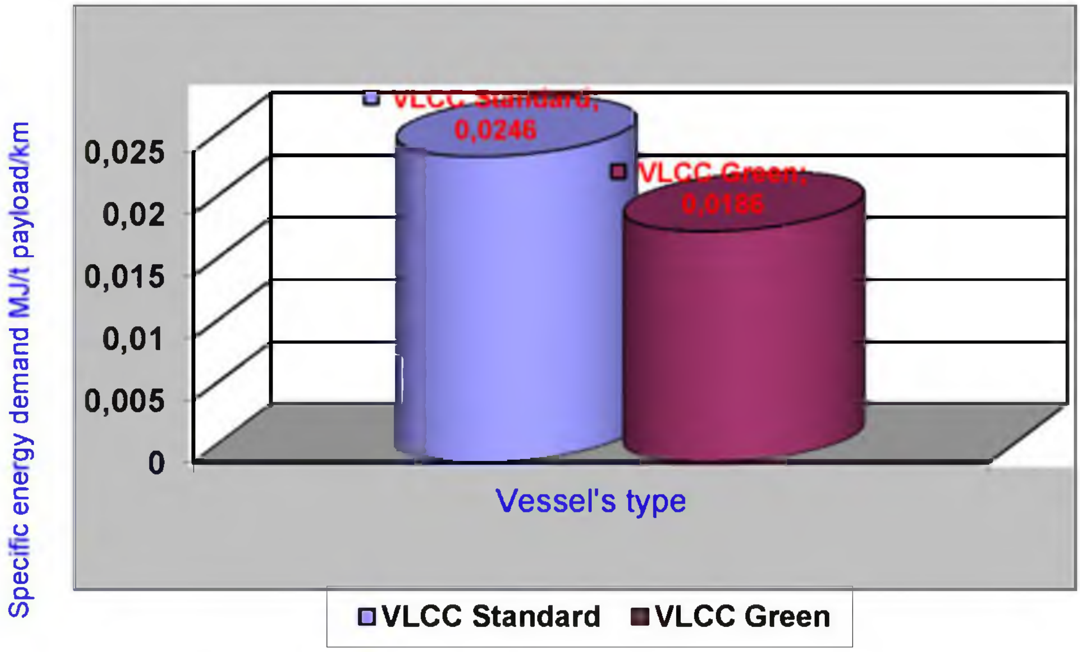

Figure 1. Specific energy demand MJ/payload/km related vessel's type

It is seen that the specific energy decreases with increasing ship size.

7.2 Calculation of the specific emissions

The specific emission factors for a Crude oil tanker are taken from Appendix C assuming that the ship is powered by a slow speed engine. Following emission quantities are calculated:

Table 7. Specific emissions for different crude oil tanker type.

Emissions	Vessel's type "Standard tanker"	"Green tanker"
CO_2, kg	0.745	0.561
NO_x, kg	0.0204	0.0153
SO_2, kg	0.00097	0.00073
CO, kg	0.00223	0.00168
HC, kg	0.000708	0.000533
Particulates, kg	0.000271	0.000204

7.3 Calculation of the specific external costs

The external costs due to emissions are calculated based on the specific costs listed in lecture "Assessment of environmental impact from sea-borne transport compared with land based transport" written by Hans Otto Holmegaard Kristensen. Table 3, page 26.

Table 8. External costs due to emissions.

External Cost, Euro	Vessel's type "Standard tanker"	"Green tanker"
CO_2	0.022	0.016
NO_x	0.053	0.04
SO_2	0.005	0.004
CO	close to 0	close to 0
HC	close to 0	close to 0
Particulates	0.014	0.011
Climate change	0.02	0.016
Total	0.114	0.087

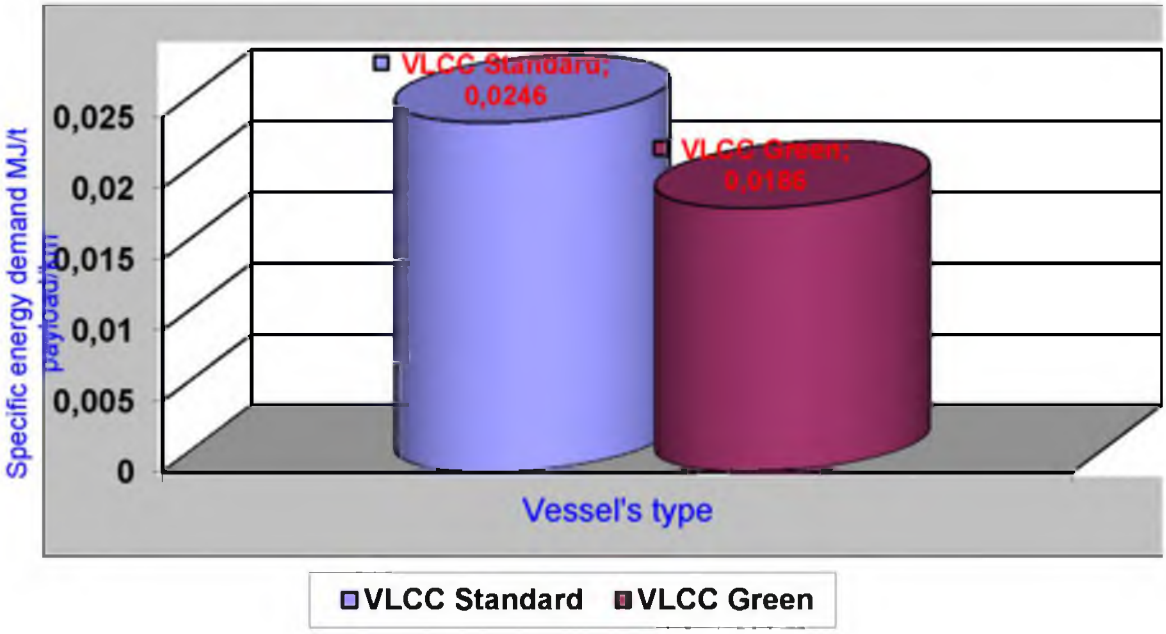

Figure 2. Calculation of the specific external costs

8 Conclusion

This paper has been focused on "VLCC" tanker design. It is offered to use "VLCC" crude oil tanker for Novorossiysk – Sansun project. The specifics of the study have been contained the design work for both the *standard* and *green ship* including Outline specification, sketch of the general arrangement plan, calculation of IMO's Energy Efficiency Design Index, Energy and Exhaust Emission for the both VLCC projects etc "VLCC" *"green tanker"* project has been offered as an updated design of *standard* VLCC tanker at reduced 10 per cent vessel's speed and having unchanged (capacity x speed) *standard* VLCC = (capacity x speed) *green* VLCC ratio.

In addition, it is offered the additional *"green profile"* for VLCC project such as:

- The new hull treatment project for keeping VLCC Afloat for 10 year period between the 1st and 3rd Special Survey Dry-Dockings' using In Water Survey with Video in Lieu of Dry-docking. All other Survey and Inspection requirements will remain the same, using external purpose made blanks for internal removals to facilitate Close-up Inspections as required. It is expected up to 9 629 487 USD saving over fifteen years VLCC trading (Including 4%, about 1 059 mt / 487 140 USD of fuel savings per annum) at 1 138 850 USD spent during dry dock for hull treatment.
- It is expected up to 5% of fuel consumption saving for VLCC (about 1 324 mt / 609 040 USD of fuel savings per annum) due to implementation of Optimal trim method.
- Using variable speed electric power generation reduces number of generating sets by 25%. Optimised fuel consumption, saving 5% (about 1 324 mt / 609 040 USD of fuel savings per annum). It is assumed that equipment cost is 650 000 USD.
- Effective Power management, it is assumed running extensively at low load, can easily increase the SFOC by 5% (about 1 324 mt / 609 040 USD of fuel savings per annum). It is assumed that equipment cost is 80 000 USD.
- Operating the cooling water pumps at variable speed would optimise the flow according to the actual need. It is expected up to 1% (about 265 mt / 121 900 USD of fuel savings per annum) assumed that equipment cost is 70 000 USD.
- The exhaust gas scrubber, known as the open loop scrubber, reduces the sulphur oxide content of the exhaust gases by 90 to 95 per cent. Estimated cost for installation of Exhaust Gas Scrubber is approx. 1 000 000 USD.

Table 9. Additional *"green profile"* VLCC project economical effect calculation * saving over fifteen years VLCC trading.

Additional *"green profile"* for VLCC project	Spent money, USD for 10 year period	Saved money, USD for 10 year period
Hull coating	1 138 850	9 629 487*
Vessel trim	25 000	6 090 400
Variable speed electric power generation	650 000	6 090 400
Power management	80 000	6 090 400
Cooling water pumps, speed control	70 000	1 219 000
Exhaust Gas Scrubber	1 000 000	0
Total	**2 963 850**	**29 119 687**

Table 9 indicates that saving over ten years VLCC trading is 26 155 837 USD. Moreover, research has shown that "VLCC" project is the most environmental friendly.

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