The Possibility of the Inert Gas Generator Environmental Operation Mode Utilization on Long Range 2 Oil Tankers During Discharge Operation

Mogućnost primjene ekološki prihvatljivog načina rada generatora inertnog plina na Long Range 2 tankerima tijekom iskrcaja

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Summary

Long Range 2 tankers are the largest ships used for the transportation of petroleum products. Although more than 400 Long Range 2 tankers are navigating the world's sea, many of the terminals, at which these ships discharge their cargo, do not utilize their discharging capacity to the full extent. This is due to the technological obsolescence of the terminal and the fact that these terminals are primarily designed to accommodate smaller tankers, such as Medium Range and Long Range 1 tankers. The reduced discharge capacity leads to longer ship stay in the port and increased air pollution due to the release of inert gas into the atmosphere since terminals unnecessarily insist on the continuous operation of the inert gas generator. This paper explains a possible solution to this problem by using environmentally friendly START/STOP operation mode of an inert gas generator using methods of analysis and synthesis, comparative methods and elements of the mathematical method. Environmentally friendly operation mode requires minimal modification of the software program and it is very easy to perform. This mode has a positive effect on reducing overall gas emissions and significant fuel savings.

Sažetak

Tankeri Long Range 2 najveći su brodovi koji se koriste za prijevoz naftnih derivata. Iako više od 400 tankera Long Range 2 plovi svjetskim morima, mnogi terminali na kojima ti brodovi iskrcavaju svoj teret ne koriste se u potpunosti svojim kapacitetom iskrcaja. Razlog je tomu tehnološka zastarjelost terminala i činjenica da su oni prvenstveno dizajnirani za prihvat manjih tankera, poput Medium Range i Long Range 1. Smanjeni kapacitet iskrcaja dovodi do dužeg zadržavanja broda u luci i povećanog zagađenja zraka zbog ispuštanja inertnog plina u atmosferu jer terminali nepotrebno inzistiraju na kontinuiranom radu generatora inertnog plina. U radu predstavlja se moguće rješenje ovog problema primjenom ekološki prihvatljivog načina rada START/STOP generatora inertnog plina korištenjem metodama analize i sinteze, usporednih metoda i elemenata matematičke metode. Ekološki prihvatljiv način rada zahtijeva minimalne izmjene softverskog programa i vrlo je jednostavan za primjenu. Ovaj način rada pozitivno utječe na smanjenje ukupnih emisija plina i značajnu uštedu goriva.

1. INTRODUCTION / *Uvod*

An important part of the transport chain of crude oil and derivatives from producers to final consumers are the terminals for their transshipment. These terminals can be divided into conventional and offshore terminals; the latter being mainly used for loading crude oil into larger tankers.

Conventional tanker terminals differ in their purpose and size. When designing and building them, the following must be taken into account: distance from populated areas, waterway from the open sea to berths, the impact of sea currents, sea depth, protection of berths from wind, configuration of the coast and surrounding terrain, increase of storage and

transshipment capacities and simplicity of pollution limitation in case of accidental discharge of cargo into the sea [3].

The number of berths in conventional tanker terminals varies from one to several dozen. Depending on their purpose and storage capacity, there are different numbers of storage tanks at the terminals. The capacity of tanks depends on the type of product they are designed for. There are terminals that are made only for transshipment of crude oil but are very rare. Most often the terminals are combined for transshipment and storage of crude oil with various derivatives. Terminals with a large number of berths and tank capacity are, in principle,

combined. Due to the harmful impact of oil and derivatives on people and the environment, transshipment terminals are located outside urban areas.

Tankers for the transport of petroleum products (product tankers) differ in their construction from crude oil tankers. Their main difference is in the size and construction of the cargo system, including cargo pipelines. Product tankers are more complex and have the ability to transport up to six different cargoes. They are smaller in size, and their largest size is LR2 (long range tanker) [5].

Table 1 shows the sizes of the product tankers.

Table 1 Product tankers sizes
Tablica 1. Veličine tankera za prijevoz naftnih derivata

PRODUCT TANKER CLASS	CAPACITY – dwt
HANDY	10 000 – 29 999
MEDIUM RANGE	30 000 – 54 999
PANAMAX	55 000 – 74 999
LONG RANGE 1	75 000 – 79 999
LONG RANGE 2	80 000 – 119 999

Source: Authors

It is important to note that the primary purpose of LR1 and LR2 tankers is to transport petroleum products, but they can also transport crude oil depending on the world's market demand. The cargo system of the LR 2 tanker is specially designed to enable efficient cleaning of cargo tanks. Cargo pumps are immersed in each tank. Cargo heaters are located on the deck and if it is necessary to heat the cargo this is done by slow circulation of the cargo through the heaters using cargo pumps. Owing to this, cargo tanks washing with SCANJET tank cleaning machines is very efficient and in most cases there is no need for manual inspection of cargo tanks. The tanks are also equipped with a super striping system that allows the tank to dry perfectly so that there is no need for the crew to enter the tank.

In this paper, the model of the tanker terminal for unloading of the petroleum products from LR2 tankers was used. Terminal has two berths, each with two cargo connections. Berths can accept tankers up to the maximum length of 250 m (LR2) and are characterized by: maximum tanker capacity (dwt) 120000 t, berth depth 13.0 m, minimum depth below the keel of the ship (UKC) 0.6 m, maximum draft of the ship 12.4 m (plus the value of high water) and the minimum parallel length of the ship's side on the waterline, measured from the center of the cargo unloading connections (cargo arms) - 30.0 m in the direction of the bow and stern. For tankers that do not meet these requirements the terminal will make a special risk assessment on the case by case basis.

During the tanker stay at the terminal, the ship's crew must follow the instructions prescribed by the terminal: use the minimum number of hydraulic units to drive the cargo pumps during unloading, minimize the use of engine room fans, minimize heating of fuel tanks, i.e. minimize steam boiler operation, reduce operation of unnecessary systems, reduce the load of the diesel generator and optimize the operation of the Inert Gas Generator (IGG) so that as little inert gas is released into the environment as possible. Therefore, it is crucial to develop an economical inert gas management system with the purpose of minimizing environmental pollution.

The development and modernization of tanker terminals does not follow an increase in the total tonnage of LR2 tankers.

The traditional way of using the inert gas system, during the unloading of these tankers at reduced capacity, is not a good solution because there is a big problem of environmental pollution. Therefore, it is necessary to find a new and better solution that can ensure a large reduction in gas emissions. To achieve this, the START/STOP mode of operation of the IGG during unloading would be more ecologically justified, which can be proven by applying the methods of analysis and synthesis, comparative methods and elements of the mathematical method.

2. MATERIALS AND METHODS / *Materijali i metode*

One feature of the LR 2 tanker is that inert gas is produced in a purpose built IGG. Cargo pumps can be driven either by the Norwegian manufacturer Frank Mohn (FRAMO) that utilizes hydraulic system or by electrically driven cargo pumps manufactured by the Dutch manufacturer MARFLEX. In this paper, the FRAMO hydraulic system and the Wartsilla Moss IGG are taken as examples.

2.1. Inerting of LR2 tanker cargo tanks / *Inertiranje tankova tereta na tankerima LR2*

Submersible centrifugal pumps driven by FRAMO (Frank Mohn Norwagien manufacturer of cargo systems used on most LR2 tankers) hydraulic units are used for unloading. During unloading, the cargo pumped out of the tanks is replaced by inert gas. The inert gas pressure in the tanks must be kept positive at all times, at least 100 mmWC. A feature of the LR2 tanker is that inert gas is produced in an IGG, installed only for this purpose.

Inerting of cargo tanks during unloading can be done in two ways: by inert gas from the tanker terminal or by inert gas produced in the ship's IGG. A small number of terminals have the infrastructure that allows inerting ship cargo tanks from the terminal tanks, so it is necessary to use inert gas produced on board. A Hamworthy Moss generator is commonly used to produce inert gas on the LR2 tanker.

A basic schematic diagram of the IGG is shown in Figure 1. The main parts of an IGG are burner, scrubber, demister and fans [7].

Inert gas is obtained by burning diesel fuel with low sulfur content (MGO <0.1% S) in the generator furnace. Two electric gear pumps are used to supply fuel. The pump supplies fuel to the ignition burner and the main burner. The air required to burn fuel is supplied by one of the two electric fans installed.

Exhaust gases flow through the combustion chamber towards its bottom where they come in contact with a large amount of seawater. Seawater cleans combustion gases from soot particles and other impurities. This process takes place in the part of the generator that is called purifier. Contaminated seawater from the purifier flows outside the ship by gravity.

An electric centrifugal pump is used to supply seawater. In addition to exhaust gas purification, seawater is also used to cool the combustion chamber. The combustion chamber has a mantle through which seawater flows and thus cools the inner walls of the combustion chamber.

After the purifier, the inert gas flows over the demister which prevents flowing of the water droplets with a stream of the inert gas and exits from the generator on the top of the tower. On the tower top there is a pipe which supplies inert gas to the deck.

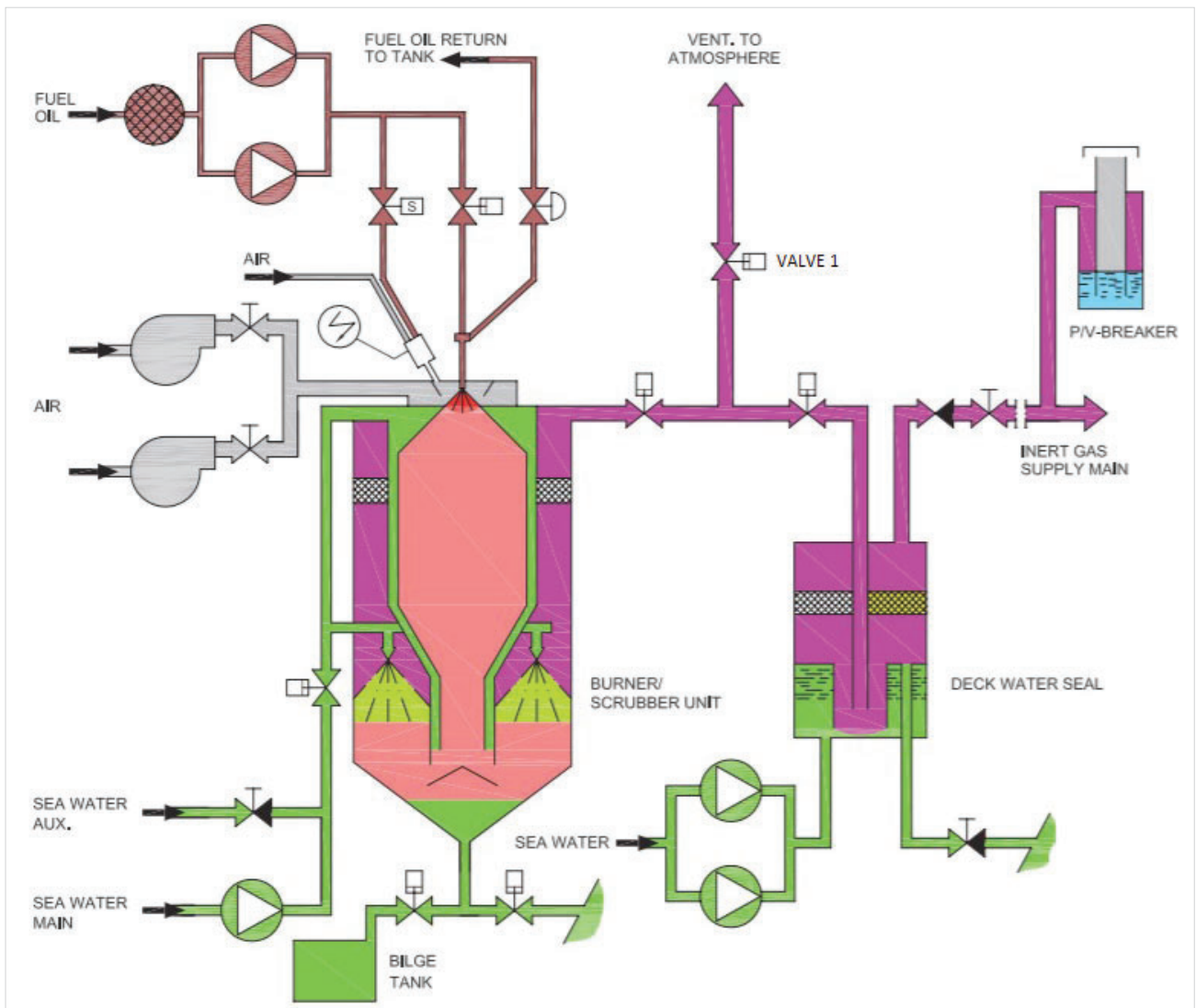IGG can operate in automatic and manual operation mode.

Figure 1 Working principle of Hamworthy Moss's IGG installation [7]
Slika 1. Princip rada instalacije IGG Hamworthy Moss [7]

During manual operation, the generator operates at a constant capacity. During automatic operation, the capacity of the IGG changes depending on the pressure in the deck pipeline.

Each time valve 1 is opened, the inert gas is released into the atmosphere, which represents a significant loss of energy and unnecessary environmental pollution. Energy loss is the combustion of fuel in an IGG to produce an inert gas that is released into the atmosphere under conditions of high pressure in the deck pipeline. This causes a great economic loss.

Environmental pollution caused by the emission of harmful gases from the combustion of hydrocarbons on ships has been recognized as a major problem in the recent years, so the International Maritime Organization (IMO) in 2011 has brought the resolution MEPC 304(72) which regulates that by 2050 greenhouse gas emissions from ships will be reduced by 50% compared to 2008 level [2]. One of the solutions that can help reduce greenhouse gas emissions to the environment is the application of the START/STOP mode of IGG operation.

2.2. Cargo tanks inerting by means of IGG / *Inertiranje tankova tereta IGG-om*

Equipment for the production of inert gas on tankers shall be designed with a capacity greater than at least 25% of the maximum unloading capacity. The capacity of the cargo pumps is designed for the nominal lifting height. If the lifting height is lower, the pump load may exceed its rated capacity. This is one of the reasons why inert gas production is designed with at least 25% reserve capacity. When LR2 tankers transport crude oil or heavy fuel (which is very rare), the unloading capacity is higher and generally amounts to 4000 to 8000 m3/h. When transporting oil derivatives, the unloading capacity is much smaller, ranging from 800 to 2500 m3/h and in some instances as low as 500 m3/h. The main reason is that the infrastructure at the tanker terminals is not adapted to that size of ships, but it was primarily intended for smaller ships such as medium range tanker (MR) and LR1 tankers.

Most tanker terminals request that the IGG operates continuously in automatic mode from the beginning to the end of the cargo unloading and that the inert gas pressure of 800 mmWG is kept constant in the cargo tanks. In conditions of reduced unloading capacity less than 40%, which corresponds to a flow of 3600 m3/h, the IGG releases a large part of the gases into the environment. The smaller the unloading capacity is, the higher the inert gas emissions into the environment are. This contributes to high environmental pollution and unnecessary fuel consumption.

Table 2 IGG Fuel consumption, NO_x and CO_2 emissions depending on unloading capacity
Tablica 2. Potrošnja goriva IGG-a, emisije NO_x i CO_2 ovisno o kapacitetu iskrcaja

Unloading capacity (% - m³/h)	IGG capacity (% - m³/h)	IGG fuel consumption (kg/h)	Unloading time (h)	NOx emission to environment (kg/unloading)	CO₂ emission to environment (t/unloading)	Unnecessary burnt fuel (kg)
100 - 9000	62 - 9000	664	14.9	0	0	0
90 - 8100	56 - 8100	660	16.6	0	0	0
80 - 7200	50 - 7200	535	18.6	0	0	0
70 - 6300	43 - 6300	465	21.3	0	0	0
60 - 5400	37 - 5400	398	24.9	0	0	0
50 - 4500	31 - 4500	332	30.0	0	0	0
40 - 3600	25 - 3600	267	37.3	0	0	0
30 - 2700	19 - 2700	199	49.7	147.9	10.84	3380
20 - 1800	12 - 1800	132	76.0	449.0	33.0	10260
10 - 900	6 - 900	66	149.0	1291	94.60	29500

Source: Authors

Table 2 ilustrates the data on fuel consumption, Nitrogen Oxides (NO_x) and Carbon Dioxide (CO_2) emissions depending on the unloading capacity. This table shows that the release of inert gas into the environment occurs when the unloading capacity is less than 40%. A factor of 3.206 t/t of light diesel fuel consumed was used to calculate CO_2 emissions to the environment [6], and a factor of 43.76 kg/t of fuel consumed was applied to NO_x emissions [4].

From a safety point of view, there is no justification for the continuous operation of an IGG. A possible solution to this problem is to apply the START/STOP mode of its operation.

3. CASE STUDY / *Studija slučaja*

The continuous operation mode of the IGG during loading is a standard practice regardless of the unloading capacity at the tanker terminals. This practice is fully justified during the unloading of MR and LR1 tankers as they are designed with lower discharging capacities, however, during the unloading of LR2 tankers at most terminals this practice is not justified from a safety, economic or environmental aspect. In the continuation of this paper, a possible solution to this problem is analysed.

3.1. IGG START/STOP operation mode during unloading / *START/STOP način rada IGG-a tijekom iskrcaja*

START/STOP mode contributes to reducing emissions of harmful gases into the environment and to reducing the environmental footprint. Therefore, this operational mode can be defined as an ecological or environmentally friendly mode.

An environmentally friendly mode of operation of the generator can be performed in two ways: manually with 50% fixed capacity, so that the person in charge of unloading turns on the generator when the inert gas pressure in cargo tanks is reduced to 400 mmWG, and turns off when the inert gas pressure reaches 1100 mmWG, or environmentally friendly automatic operation. To enable an environmentally friendly operation mode, it is necessary to make simple modification of the IGG operating software by defining the values of the inert gas pressure and capacity at which the generator will automatically turn on and off. The recommended value of the starting pressure is 400 mmWG, stopping 1100 mmWG (generator capacity varies from 25% to 50%, provided that the

generator is stopped and started at a capacity of 25%).

If the cargo tanks are loaded up to 98% of the maximum capacity, which in this example would be 134064 m³, while the empty space of the cargo tanks is 2736 m³, it is recommended to start with the application of environmentally friendly automatic operation after unloading a certain amount of cargo (which depends on the unloading capacity), in order to avoid frequent shutdowns of the IGG at the beginning of the unloading. The recommended time between stopping and restarting is about 30 min.

The time between stopping and starting the IGG in environmentally friendly automatic operation can be calculated by means of the equation (1):

$$p V = \dot{m} R T t \qquad (1)$$

where:
p – inert gas pressure, Nm^{-2}
V - inert gas volume, m^3
$\dot{m}$ – inert gas mass flow, kgs^{-1}
R - gas constant, $Jkg^{-1}K^{-1}$
T - inert gas temperature, K
t - time, s

From the equation (1) the time and mass flow can be calculated as follows:

$$t = \frac{p V}{\dot{m} R T} \qquad (2)$$

$$\dot{m} = \rho Q \qquad (3)$$

where:
ρ – inert gas density, kgm^{-3}
Q - flow volume – cargo unloading capacity, m^3h^{-1}

Time in minutes can be calculated as follows:

$$t = 60 \frac{p V}{\rho Q R T}, \quad \text{min} \qquad (4)$$

An average inert gas temperature during inerting process is 40°C or 313 K, density ρ is 1,044 kgm^{-3} and R is 282 $Jkg^{-1}K^{-1}$.

Given that the value of the product of three members in the denominator of the previous equation ($\rho R T$) of data in the real value of the inert gas approximately equals 100,000 Nm^{-2}, to calculate the time between the IGG start and stop in minutes the adapted equation was used:

$$t = 60 \, V \, \frac{p_1 - p_2}{Q}, \quad \text{min} \qquad (5)$$

where:
t – Time between IGG start and stop (min);
V – Volume of cargo tanks void space (empty space above cargo) after IGG stop (m³);

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p_1 – Inert gas pressure after IGG stop (bar) – defined as a constant of 0.11 bar;

p_2 – Inert gas pressure before start of IGG (bar) – defined as a constant of 0.04 bar;

Q – Unloading capacity (m³/h).

The following examples show the calculation of the environmentally friendly operation mode starting time.

Example 1: Cargo tanks loaded to the 98% of capacity, required unloading capacity 900 m³/h.

$$t = 2\ 736\ m^3 \times \frac{0.11\ bar - 0.04\ bar}{900\ m3} \times 60\ (min) = 13\ min$$

Example 2: Cargo tanks loaded to the 98% capacity, required unloading capacity 900 m³/h. The environmentally friendly mode of operation of the IGG starts after 3700 m³ of cargo has been unloaded:

$$t = 60\ (min) \times 6436\ m3 \times \frac{0.11\ bar - 0.04\ bar}{900\ m3} = 30\ min$$

Example 3: Cargo tanks loaded to 98% capacity, required unloading capacity 1800 m³/h:

$$t = 60\ (min) \times 2736\ m3 \times \frac{0.11\ bar - 0.04\ bar}{1800\ m3} = 6.5\ min$$

Example 4: Cargo tanks loaded to 98% capacity, required unloading capacity 1800 m³/h. Start with the environmentally friendly mode of operation of the IGG after 10000 m³ of cargo has been unloaded:

$$t = 60\ (min) \times 12736\ m3 \times \frac{0.11\ bar - 0.04\ bar}{1800\ m3} = 30\ min$$

Example 5: Cargo tanks loaded to 98% capacity, required unloading capac 2700 m³/h. Start with the environmentally friendly mode of operation of the IGG after 8100 m³ of cargo has been unloaded:

$$t = 60\ (min) \times 10836\ m3 \times \frac{0.11\ bar - 0.04\ bar}{2700\ m3} = 17\ min$$

Example 6: Cargo tanks loaded to 98% capacity, required unloading capacity 2700 m³/h. Start with the environmentally friendly mode of operation of the IGG after 16500 m³ of cargo has been unloaded:

$$t = 60\ (min) \times 19236\ m3 \times \frac{0.11\ bar - 0.04\ bar}{2700\ m3} = 30\ min$$

Examples 1, 3 and 5 show the calculation of the time in which the minimum of 30 minutes between stopping and restarting the IGG is not satisfied.

Based on the calculation of the initial start time of the ecological mode of operation of the IGG, values presented in Table 3 are obtained.

If the time delay of the application of the environmentally friendly operation mode is taken into account until the appropriate empty space in the cargo tanks is reached, the reduction of NO_x and CO_2 emissions at 10%, 20% and 30% of the unloading capacity can be calculated as per Table 4.

The calculation was made for continuous operation of the IGG at the minimum allowable capacity of 25%.

4. RESULTS / *Rezultati*

Figure 2 shows the dependence of CO_2 (t) emissions on the unloading capacity of the cargo during START/STOP operation mode of IGG.

Figure 3 shows the dependence of NO_x (kg) emissions on the unloading capacity of the cargo during START/STOP operation mode of IGG.

For a comparison of the GHG emissions to the environment, GHG emission for a new car with gasoline engine produced in 2018 can be used. This car emits 120.4 gr / km of CO_2 [1] and makes on average 20000 km per year.

If the LR2 tanker unloads its full cargo, with an unloading capacity of 900 m3/h, and if the IGG operates on continuous mode, LR2 releases the amount of pollution equivalent to 38 cars in a year or 2237 cars, just during the ship's stay at the terminal for one cargo unloading of 149 hours.

Table 3 Calculation of the initial time of the IGG START/STOP operation mode
Tablica 3. Izračun početnog vremena načina rada IGG-a START/STOP

V – Void space volume at beginning of START/STOP operation (m³)	IG STOP-START Pressure difference $p_1 - p_2$ 0.11 – 0.04	Q – required unloading capacity (m³/h)	T – calculated time between IGG stop and start (h)	Initial time of START/STOP operation mode after start of cargo unloading (h)
2736	0.07	900	13	
6436	0.07	900	30	4.1
2736	0.07	1800	6.5	
12736	0.07	1800	30	5.5
2736	0.07	2700	4	
19236	0.07	2700	30	6.1

Source: Authors

Table 4 Calculation of NO_x and CO_2 emission reductions in the IGG START/STOP operation mode [Authors]
Tablica 4. Izračun smanjenja emisija NO_x i CO_2 u načinu rada IGG-a START/STOP [Autori]

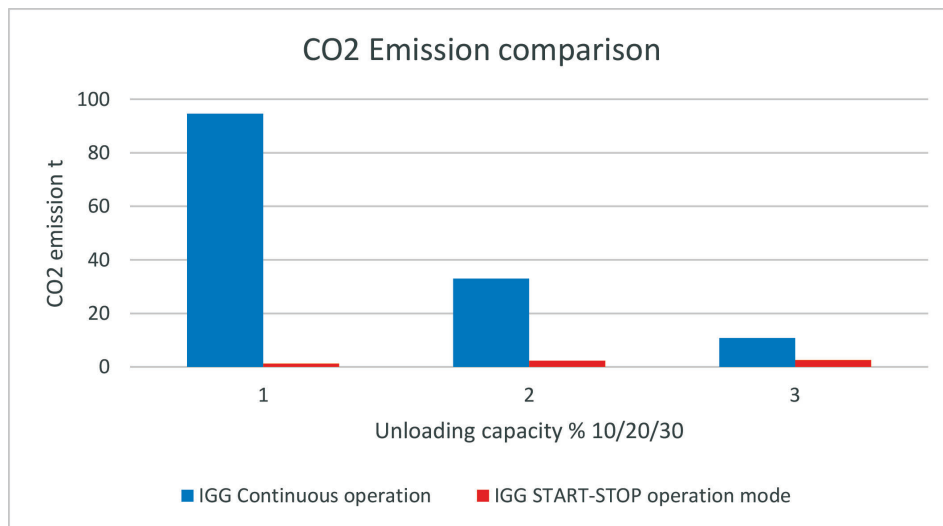| Unloading capacity Q (% - m³/h)	IGG continuous operation CO_2 emissions (t)	IGG START/STOP operation mode - CO_2 emisssions (t)	TOTAL REDUCTION OF CO_2 EMISSIONS (t)	IGG continuous operation NO_x emissions (kg)	IGG START/STOP operation mode NO_x emissions (kg)	TOTAL REDUCTION OF NO_x EMISSION (kg)
10 – 900	94.6	2.6	92.0	1291.0	36.0	1255.0
20 – 1800	33.0	2.4	30.6	449.0	32.5	416.5
30 – 2700	10.8	1.3	9.5	147.9	18.0	129.9

Source: Authors

Figure 2 Graphic comparison of CO_2 IGG emissions
Slika 2. Grafička usporedba emisija CO_2 iz IGG-a
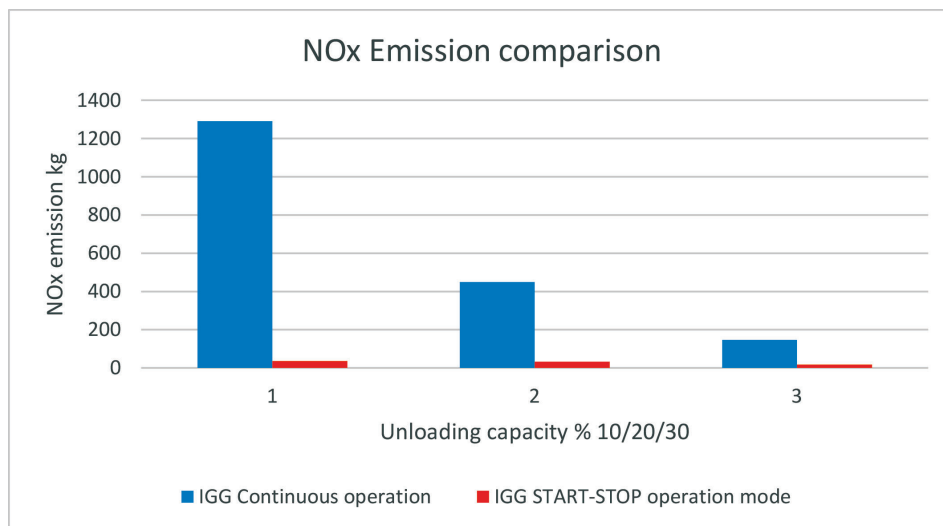
Source: Authors

Figure 3 Graphic comparison of NO_x IGG emissions
Slika 3. Grafička usporedba emisija NO_x iz IGG-a

Source: Authors

5. CONCLUSION / *Zaključak*

Due to the growing number of LR2 tankers on the market in recent years, an increasing amount of petroleum products are transported by this type of ship instead of MR and LR1 ships. The reason for this is the change in direction of the sea transport of petroleum products and the increase in the amount of derivatives that are transported over long distances. Transporting oil products on LR2 tankers is significantly more economical per ton-mile compared to smaller ships. Since the development and modernization of tanker terminals is not aligned with an increase in the total tonnage of LR2 tankers, there is a problem of environmental pollution due to the release of inert gas during unloading of tankers with reduced capacity. Therefore, the traditional way of using an inert gas system during unloading at reduced capacity is not a good solution. A much better solution can be achieved by START/STOP operation mode of the IGG during unloading which ensures a large reduction in emissions of harmful gases into the environment and thus is ecologically justified as presented by the methods of analysis and synthesis, comparative method and mathematical method elements.

REFERENCES / *Literatura*

[1] EU Comission – Regulacion EC 443/2009, Reducing CO2 emissions from passanger cars before 2020, released 23 April 2009. https://ec.europa.eu/clima/policies/transport/vehicles/cars_en [accessed 1/7/2020]

[2] IMO GHG Emissions: Second GHG study 2009. http://www.imo.org/en/Our-Work/Environment/Pollution Prevention/AirPollution/Pages/GHG-Emissions.aspx [accessed 19/7/2020]

[3] Oil Companies International Marine Forum (OCIMF): Manning at Conventional Marine Terminals, 1 June 2008. https://www.ocimf.org/publications/information-papers/manning-at-conventional-marine-terminals [accessed 15/7/2020]

[4] SSB Statistics Norway: Emission to air 1990-2018, 1 November 2018. https://www.ssb.no/en/natur-og-miljo/statistikker/klimagassn/aar/2019-11-01 [accessed 26/7/2020]

[5] US Energy Information Administration. https://www.eia.gov/todayinenergy/detail.php?id=17991 [accessed 15/4/2020]

[6] Verifavia Shipping Emissions. https://www.verifavia-shipping.com/shipping-carbon-emissions-verification/faq-which-emission-factors-shall-be-used-110.php [accessed 26/7/2020]

[7] Wartsila Moss Inert Gas System for Tankers, 2013. https://www.wartsila.com/marine/build/gas-solutions/inert-gas/wartsila-moss-inert-gas-generators-for-tankers [accessed 15/7/2020]

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