9. *Веников В. А.* Теория подобия и моделирования (применительно к задачам электроэнергетики): учеб. пособие для электроэнергетических спец. вузов / В. А. Веников, Г. В. Веников. — М.: Электротехника, 2013. — 440 с.
10. *Ивоботенко Б. Л.* Планирование эксперимента в электромеханике / Б. Л. Ивоботенко, Н. Ф. Ильинский, Н. П. Копылов. — М.: Энергия, 1975. — 184 с.
11. *Саушев А. В.* Планирование эксперимента в электромеханике : учебное пособие / А. В. Саушев . — СПб.: СПбГУВК, 2008. — 214 с.

REFERENCES

1. Karakaev A. B. Ustrojstva ventilyacii i kondicionirovaniya vozdukha / A. B. Karakaev, A. G. Ryabinin G. A. Ryabinin. — M.: Petrovskaya akademiya nauk i iskusstv, 1997. — 128 s.
2. Karakaev A. B. Specialnye odnofaznye asinkhronnye dvigateli dlya korabelnykh system avtomatiki / A. B. Karakaev. — SPb.: GMA im. adm. S. O. Makarova 1999. — 220 s.
3. Vol'dek A. I. Elektricheskie mashiny / A. I. Vol'dek. — M.: Elektroenergiya, 1978. — 832 s.
4. Karakaev A. B. Ustrojstva ventilyacii i kondicionirovaniya vozduha / A. B. Karakaev, A. G. Ryabinin, G. A. Ryabinin. — SPb.: SPbGUVK, 1997. — 238 s.
5. Voznesenskij V. A. Staticheskie metody planirovaniya eksperimenta v tekhniko-ekonomicheskih issledovaniyah / V. A. Voznesenskij. — M.: Finansy i statistika, 1981. — 263 s.
6. Adler YU. P. Planirovanie eksperimenta pri poiske optimal'nyh uslovij / YU. P. Adler, E. V. Markova, YU. V. Granovskij. — M.: Nauka, 1975. — 285 s.
7. Sautin S. N. Planirovanie eksperimenta v himii i himicheskoj tekhnologii / S. N. Sautin. — L.: Himiya, 1975. — 48 s.
8. Asaturyan V. N. Teoriya planirovaniya eksperimenta. / V. N. Asaturyan. — M.: Radio i svyaz', 1983. —148 s.
9. Venikov V. A. Teoriya podobiya i modelirovaniya (primenitel'no k zadacham elektroenergetiki): ucheb. posobie dlya elektroenergeticheskih spec. vuzov / V. A. Venikov, G. V. Venikov. — M.: Elektrotekhnika, 2013. — 440 s.
10. Ivobotenko B. L. Planirovanie eksperimenta v elektromekhanike / B. L. Ivobotenko, N. F. Il'inskij, N. P. Kopylov. — M.: Energiya, 1975. — 184 s.
11. Saushev A. V. Planirovanie eksperimenta v elektromekhanike : uchebnoe posobie / A. V. Saushev . — SPb.: SPbGUVK, 2008. — 214 s.

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COMPARATIVE ANALYSIS OF INERT GAS SYSTEMS WITH THE INERT GAS GENERATOR, WITHOUT IT AND INERT GAS SYSTEM WHICH UTILIZES NITROGEN GENERATOR

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The following article is about the analysis of different Inert Gas Systems, both used in marine practice and those that are not widely implemented. These systems are designed for supplying the cargo tanks of oil tankers and chemical tankers with inert gas in order to reduce the concentration of oxygen to the levels, at which the combustion is not possible. Because of this systems and their use on ships the amount of incidents connected to cargo operations is approaching zero. In this article those systems are analyzed, compared, including their advantages and disadvantages. One of the most important factors is gas supply, type of supply, as it is directly connected to cargo operations and their speed.

Keywords: N_2, inert gas, marine systems, IMO, IMO regulations, analysis of the systems.

СРАВНИТЕЛЬНЫЙ АНАЛИЗ СИСТЕМ ИНЕРТНОГО ГАЗА, ИСПОЛЬЗУЮЩИХ ГЕНЕРАТОР ИНЕРТНОГО ГАЗА, НЕ ИСПОЛЬЗУЮЩИХ ЕГО И СИСТЕМЫ ИНЕРТНОГО ГАЗА, ИСПОЛЬЗУЮЩЕЙ АЗОТ

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Данная статья направлена на сравнительный анализ различных систем инертного газа, как широко используемых в морской практике, так и систем еще не получивших широкого распространения. Эти системы предназначены для снабжения грузовых танков нефтеналивных судов и химовозов инертным газом с целью уменьшения содержания кислорода ниже значения, при котором возможно поддержание им горения. Благодаря введению этих систем и их использованию на судах количество инцидентов, связанных с грузовыми операциями устремилось к нулю, как результат использования данных систем повсеместно в связи с требованиями IMO. В этой статье рассмотрены системы инертного газа, их характеристики, достоинства и недостатки. Наиболее важными факторами при выборе являются подача газа, тип подачи, так как они напрямую влияют на грузовые операции и их продолжительность, из-за влияния на максимальную скорость погрузки/выгрузки.

Ключевые слова: N2, инертный газ, морские суда, IMO, требования IMO, сравнительный анализ.

Introduction

Since the beginning of the transportation of petroleum products, there have been a number of problems related to the protection of the environment, the protection of the ship 's crew, and the prevention of incidents on ships. As a result, this industry has strict standards and procedures associated with the above. All companies operating in this area are subject to the same rules. One of the main requirements is the reduction of sulfur emissions, the creation of emission control zones, the replacement of single-hulled tankers with double-hulled ones, and there is also a trend towards reducing CO_2 emissions to combat greenhouse gases that lead to global warming. The International Convention for the Protection of Life at Sea (SOLAS 1974) requires an inert gas system to be capable of supplying inert gas with an O 2 content of not more than 5% by volume. By maintaining a positive pressure in the tanks at all times with an atmosphere in them containing no more than 8% O_2 by volume, the tank atmosphere is non-flammable. The current SOLAS requirements, as amended on 1 January 2016, are such that all tankers over 8,000 dwt built on or after the date of the change must be equipped with an inert gas system if the ship is carrying flammable cargo.

Requirements and their origin

In 2006, a group was formed to investigate fires and explosions in cargo areas on oil tankers and chemical carriers, which presented their findings to the Maritime Safety Committee of the International Maritime Organization (IMO maritime Safety committee). The group conducted a study looking at 35 incidents over the past 25 years and the report included the following:

Table 1 – Analysis incidents Source -ICS OCIMF the use of inert gas for the carriage of flammable oil cargoes (2017)

Vessel	*8000 DWT or less*	*8000-20000 DWT*	*20000+ DWT*	*Oily cargo*	*Chemical cargo*	*Activity*
one	*x*			*x*		*Tank cleaning*
2	*x*			*x*		*Degassing*
3	*x*				*x*	*Loading*
four		*x*		*x*		*Tank cleaning*
5			*x*		*x*	*Degassing*
6		*x*			*x*	*Unloading*
7			*x*		*x*	*Tank cleaning*
eight			*x*	*x*		*Tank cleaning*
9			*x*		*x*	*Loading*
ten	*x*			*x*		*Tank cleaning*
eleven	*x*			*x*		*Ballast condition*
12		*x*		*x*		*Tank cleaning*
13			*x*	*x*		*Settling tank decanting*
fourteen	*x*			*x*		*Deck maintenance*
fifteen	*x*				*x*	*Tank cleaning*

And the following conclusions were made:

In most cases, the ship was tank cleaning, venting or gassing at the time of the incident;

In most cases, the correct procedures were not followed;

In several cases, the atmosphere in non-inert tanks was not observed.

In a large number of cases, ignition occurred in a cargo tank;

None of the incidents occurred during the use of inert gas.

These studies have led to the fact that the requirements have changed. Previously, the installation of inert gas systems was mandatory on ships of 20,000 dwt and above, and in accordance with the new rules, all ships of 8,000 dwt must also be equipped with an inert gas system.

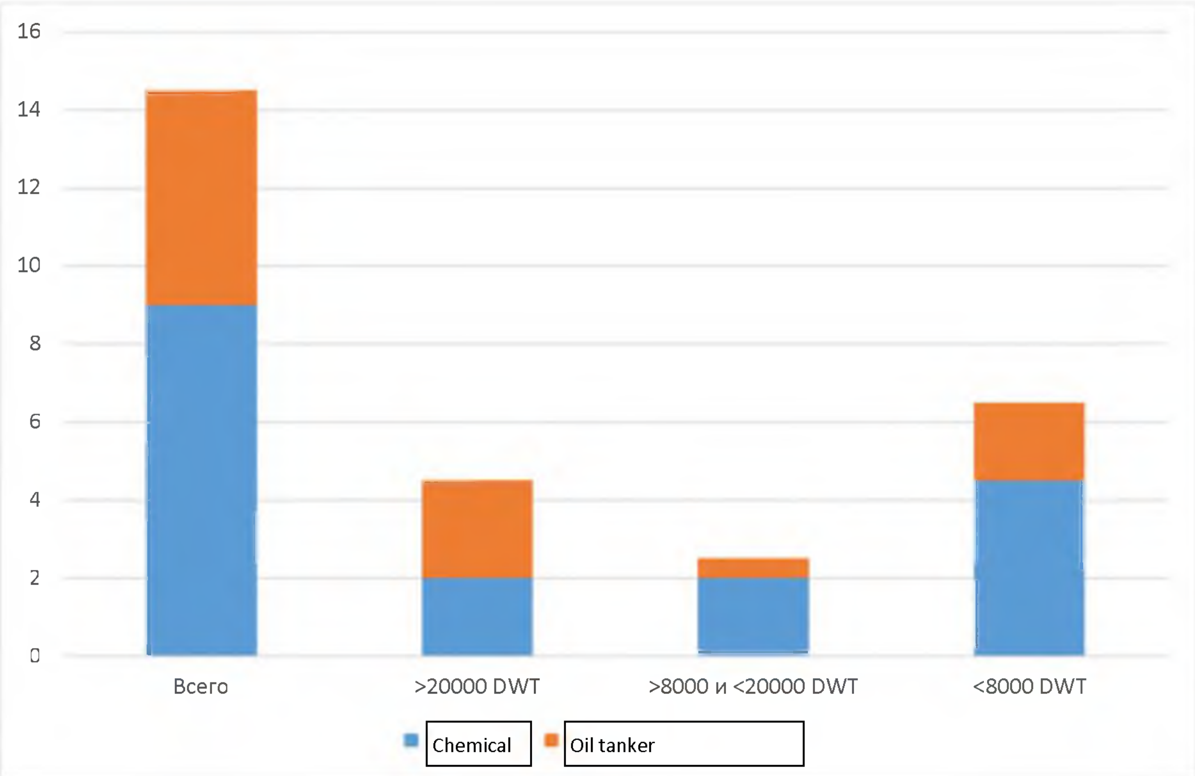

Table 2 Number of fires and explosions on chemical tankers and oil tankers 2004-2015 Source- ICS OCIMF the use of inert gas for the carriage of flammable oil cargo (2017)

Description of the method and materials of comparative analysis

There are various inert gas supply systems, among them the following inert gas production methods are mainly used

1) Exhaust gases from marine boilers, regardless of the type of boiler: main or auxiliary.

This is the best known and most commonly used method for producing an inert gas. Due to the fact that the system uses exhaust gases from boilers, it is possible to reduce fuel consumption.

In order for the boiler plant to be used as a source of inert gas, the following conditions must be met:

- The nozzles and equipment used to control the combustion process must be capable of consistently producing gases with an oxygen content equal to or less than 4 percent by volume;
- The boiler plant must be capable of producing enough gases to meet the requirements of the system;

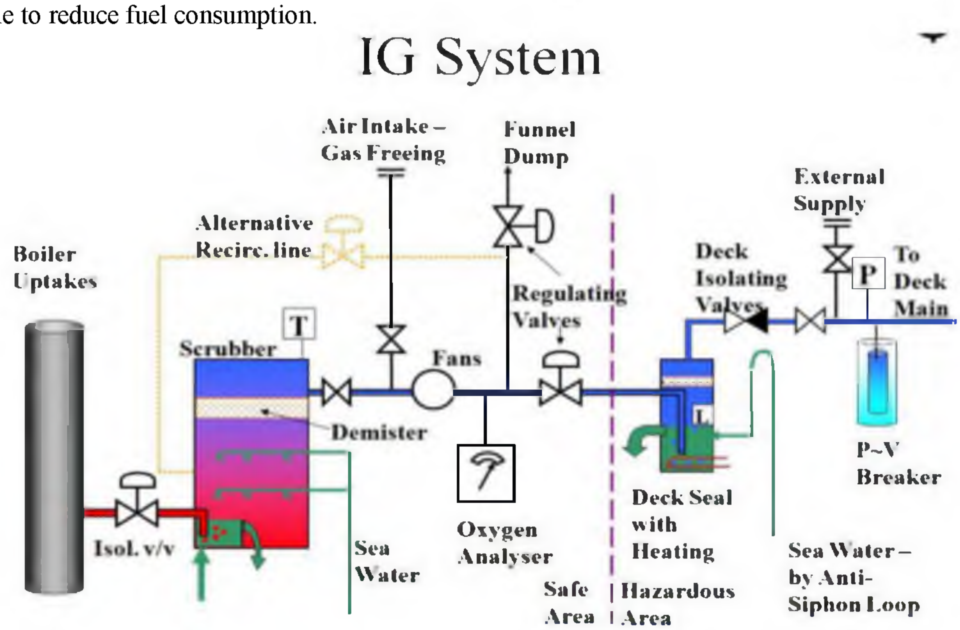

Figure 1 – Schematic diagram of an inert gas system Source- https://inameq.com/inert-gas-system/inert-gas-system

• The inert gas system using the boiler plant consists of the following parts: scrubber, demister, 2 inert gas blowers, deck water seal, pressure/vacuum fuse, ventilation and the required fixtures. The capacity (productivity) of this installation is 10500 m^3 / h.

This system is used in the following operations:

• oil product unloading;

• tank cleaning;

• knocking out inert gas in tanks during sea passage;

• release of tanks from gas (both cargo and ballast);

• inertia of the ballast tank during an emergency.

How the system works

The principle of operation of the system is as follows: there are two boiler plants in the engine room, one of which must be in reserve (during unloading, both work, since the unloading system of the considered system is linear, that is, by using pumps driven by steam turbines). Exhaust gases from these boiler plants obtained in the process of fuel combustion go to the inert gas line. This line has a pneumatic butterfly valve. The valves are connected to two fans, with an air supply and a soot blower. When the valve is dirty, it closes and is cleaned with a soot blower. Next to the valve is a closure for cleaning and inspecting the valves. The exhaust gas is transferred to the scrubber (water cleaning tower) where it is washed, cleaned and, most importantly, cooled. The gases enter the tower through the water in the lower section and are carried upwards through a series of nebulizers. These nebulizers cool the gas with cold seawater, condensing its pollutants, which in turn fall down and are then expelled into the seawater. The scrubber should always contain a small amount of water to avoid overheating the plant and its parts.

The purified inert gas exits the scrubber approximately 2 degrees Celsius warmer than the sea water. The gases also pass through a dryer before leaving the scrubber.

The hydrostatic lock serves to protect against possible overpressure. Its geometry (design) is determined by the pressure and vacuum with which it must be compensated.

The seawater pumps feeding the system shall be independent of the system which supplies water from the sea through the scrubber and deck seal seawater through the double circuit (reserve). Both the scrubber and the gate should never be without water. The trap feed pump must be running at all times, with the exception of dry dock repairs.

There are also two fans (air blowers), one of which is in reserve. Their function is to accelerate the gas and supply it to each of the cargo tanks. Before and after each fan there are fan isolation valves which prevent recirculation of gases through the fan when not in operation.

Each pair of valves is connected to a fan. These valves are equipped with remote control. If the fan stops, the inert gas distribution valve will automatically close.

Each fan can supply the equivalent of up to 125% inert gas, which is equivalent to the performance of the pumps. Each fan only starts if there is cooling water from the water tower, if the air inlet valve or one of the boilers is open, depending on the inert gas/air switch, and if both shut-off valves are open.

The gas coming out of the fan pipes must be at a certain temperature so that there is no danger of explosion, so thermostats are installed. As the gas exits these pipes, it enters a pressure control valve which, as its name suggests, regulates the pressure of the inert gas in the manifold cap by opening or closing it.

The main control valve controls the supply of inert gas to the tanks. If the control fails, the valve closes. The recirculation valve returns excess gas to the water tower. The system maintains a constant back pressure in the fans. The control is pneumatic, but with the possibility of manual.

Then, when the gas passes through the deck water seal, which in turn is a device with a large base, filled with a small amount of water and serves to prevent the return of gas, which is especially important in the event of a fire or explosion in the tank.

In other words, it is a liquid retained valve which, despite not resisting the passage of gases into the manifold, prevents back pressure up to 3500 mm of water column.

The gas then flows through a main line carrying pressure gauges connected to a control valve and control valves. At the beginning of the pipeline is a solenoid valve for the manifold. The pipeline has branches connected to each other so that the gas is distributed to each tank through a shut-off valve.

The main line has a pressure/vacuum valve that must open when the pressure or vacuum in the tank increases to prevent the tank from deforming or collapsing the structure.

In order for a tank to be considered inert, the oxygen content in it must be less than 5 percent by volume and the pressure must be positive (no air entered the tank)

2) Independent inert gas generator

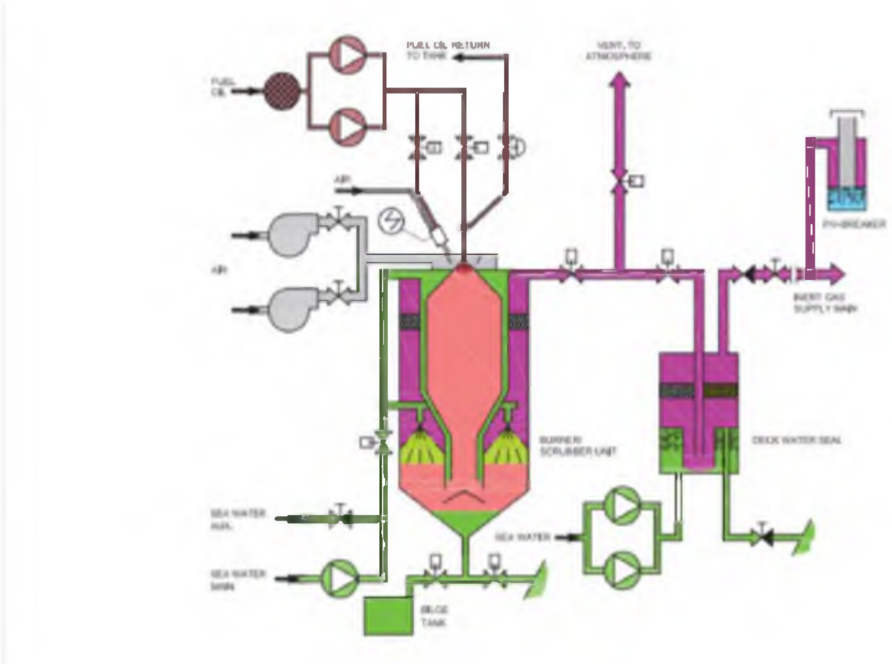

Figure 2 –Schematic diagram of the Warstilla inert gas system moss Source-https://cdn.wartsila.com/docs/default-source/product-files/inert-gas/wartsila-moss-generators-for-tankers.pdf

As an example, consider the WARTSILA inert gas generator . The capacity of this plant is up to 20000 m^3/h. Fuel - marine distillate ISO 8217 or heavy heated to a maximum of 20 cSt. Nominal fuel consumption - 0.075 kg/m^3 of gas. Electricity consumption is 0.015 kW per m^3 (excluding sea water pumps).

The principle of operation is the same as that of systems using exhaust gases from boiler plants, with the difference that the gases generated by the generator are supplied to the scrubber, and not the exhaust gases from the boiler plant.

Figure.3 – Schematic diagram of the nitrogen generator. Source-https://www.jinbomarine.com/psa-nitrogen-generator-system.html

The nitrogen generator is partly located in the engine room and partly in a similar location, the air composition is based on percentages of O2 and N2 calculated with an ambient temperature of 20 degrees Celsius, a relative humidity of 80 percent.

(*Source- Inert Gas Production: N_2 Plant Vs Conventional plant by M.C. Adrian and J.A. Gonzalez*) Hollow fiber membranes are used in the air separation system into nitrogen and oxygen. The separation principle is based on the selective permeability of nitrogen and oxygen. Each gas has a characteristic permeability rate. Nitrogen slowly permeates the membrane while oxygen, CO_2 and water permeate quickly. This allows the nitrogen to separate from the oxygen. Monitoring continues and control of product gases ensures that the product is at the correct level of purity. The design module model we have is a parallel tubular beam from the manufacturer GENERON.

Main components in the process line, 4 subsystems:

- Air supply;
- air preparation;
- Gas separation;
- Control system.

The characteristics of the system for the inert gas generator are as follows:

- 95% N_2-2250 m^3/h, 99% N_2-908 m^3/h, air requirement - 4325 m^3/h, mixture - N_2 and argon, dew point = -70 degrees Celsius after expansion at atmospheric pressure. Electricity consumption - 25 kW.
- The air supply to the generator is the most critical part of a membrane generator and properly designed filters are very important. The UNITOR filtration system includes:
- Water separator at the inlet to the filter system to remove condensate in the pipe after the compressor;
- Thick mesh filter and fine mesh filter providing coalescent filtration for oil and particulate recovery;
- Heater to ensure a constant temperature of the air supplied to the membranes;
- Activated carbon filter specially designed for oil vapor recovery unit;
- Submicron filter to trap possible dust particles from the activated carbon filter. This filter is the last membrane protection and has a high pressure differential alarm and shutdown;

Slow opening valve that eliminates pressure surges in the filtration system. This arrangement avoids possible drops that can be removed by the combined use of filters and dust from the activated carbon filter.

The membrane system consists of a set of parallel modules. The separation of nitrogen and oxygen takes place in membrane modules, where compressed air passes through the hollow fibers. The fastest gases (water, oxygen and carbon dioxide) penetrate the walls and are thrown out at a pressure close to atmospheric. The gaseous product (nitrogen) is maintained at the same pressure as the incoming air. The flow of oxygen is then directed to the safe area.

System Comparison

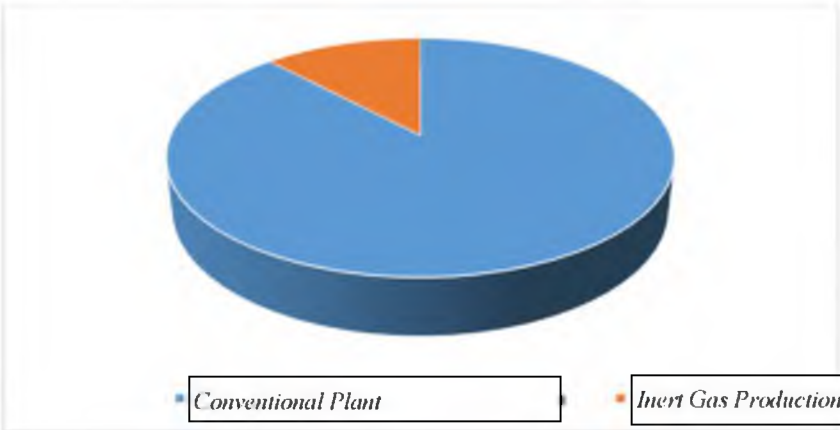

Table 3 - Comparative analysis systems Source - Inert Gas Production: N_2 Plant Vs Conventional Plant

The time required for the performance of two systems to match as a function of linear acceleration

Based on the chart, the same ship would require 88% more inertia time for a conventional inert gas system compared to a nitrogen generator, mainly due to the replacement of the gassing method with displacement rather than diffusion.

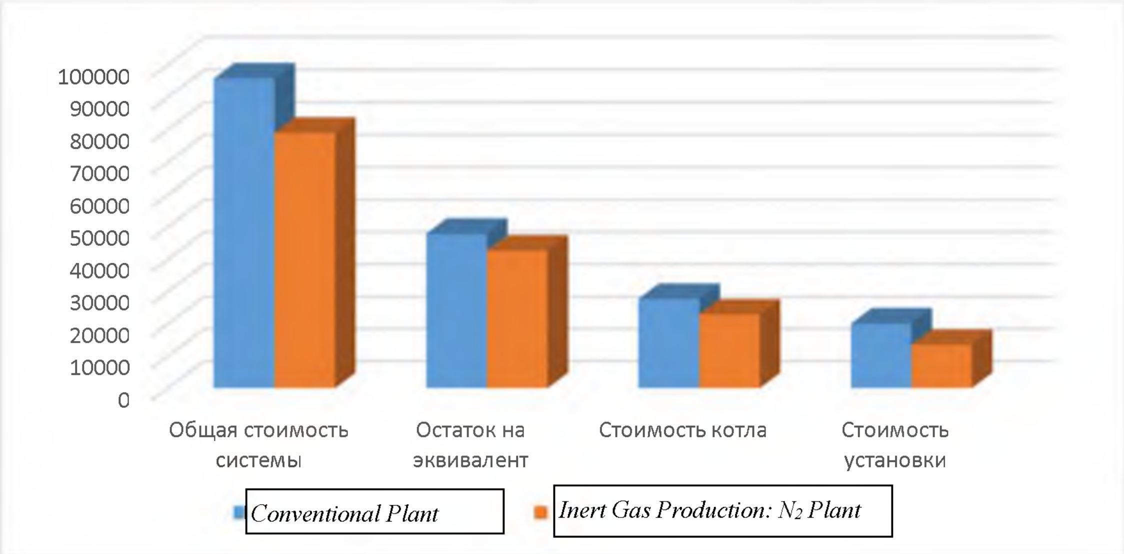

Table 4 – Cost per year fuel consumption comparison between conventional systems and N_2 system *Source- Inert Gas Production: N_2 Plant Vs Conventional plant*

There are more emissions from the conventional system than from the N_2 system, due to the fact that fuel is not consumed for this.

Regarding the comparison of an inert gas system using a boiler plant and an inert gas system using a generator, the study revealed the following:

- The consumption of fuel and electricity is greater in the second case, since the generator requires fuel and electricity, while the inert gas from the boiler plant is a secondary product of its work and thus does not require additional fuel costs;
- The inert gas generator requires a separate place in the engine room for both itself and for separately going to it mechanisms, such as a scrubber pump, more mechanisms affect the number of spare parts needed, working hours for system maintenance, and the system itself carries with it additional costs in the form of installation costs;
- The performance of an inert gas system with and without a generator is comparable and is therefore not taken into account;
- Regarding automation, an inert gas system using a generator would be preferable, since tank preparation type operations require the preparation of the entire steam system if there is no generator, while with a generator it is enough to start it separately, as a result, it is possible to make this system automatic (automated);
- An inert gas system using a generator also produces better quality inert gas than a boiler plant, which is why it is used on chemical tankers.

Conclusion

1. The nitrogen generator has a smaller capacity, but is more efficient, environmentally friendly, and safer.

2. Membrane nitrogen generator does not require fuel for its use.

3. Low installation and maintenance costs compared to an inert gas generator.

In conclusion, it should be noted that the inert gas system using a boiler plant is the most efficient in terms of fuel consumption, space consumption and electricity than other systems, but the operations associated with the use of this system require additional preparation time, and it only makes sense if the ship already has this boiler plant and uses it for other purposes, for example, unloading with steam turbopumps, if the unloading system is different, for example, using hydraulic pumps, then there is no need for two large steam boilers and alternatives in the form of a nitrogen generator and an inert gas generator are more favorable in cost, both installation and maintenance. Also, alternatives to this system produce higher quality inert gas, which is required on ships like chemical carriers carrying sensitive cargo, which is why the use of an inert gas system with a boiler unit is not suitable there. Also, the inert gas generator and the nitrogen generator are easier to automate in the future, which is also important in the future. As a result, it is important to use an inert gas system with a boiler plant in case the ship already has a powerful boiler plant used for any operations and does not carry sensitive cargo, that is, most oil tankers. If the ship does not have a powerful boiler plant, like small ships, or is a chemical tanker, then the choice is between an inert gas generator and a nitrogen generator.

References

1. ICS OCIMF the use of inert gas for the carriage of flammable oil cargoes (2017)
2. Inert Gas Production: N_2 Plant Vs Conventional Plant by MC Adrian and JA Gonzalez
3. https://www.jinbomarine.com/psa-nitrogen-generator-system.html
4. https://cdn.wartsila.com/docs/default-source/product-files/inert-gas/wartsila-moss-generators-for-tankers.pdf
5. https://inameq.com/inert-gas-system/inert-gas-system
6. Plahotnyuk A. N., Kreminsky B. O., Shkoda V. V., Kazaev A. A. Input filter capacitance of the converter feeding the inductor of a two-dimensional electric machine // Energy and resource-saving technologies and installations VRNA-20: Materials 6th All-Russian Scientific Conference, Krasnodar, November 19–21, 2020. – Krasnodar: Federal State State Military Educational Institution of Higher Education "Krasnodar Higher Military Aviation School for Pilots named after Hero of the Soviet Union A.K. Serov" of the Ministry of Defense of the Russian Federation, 2020. - P. 38-42.
7. Kashin Ya. M., Belov A. A., Shkoda V. V. [et al.] Generalized algorithm for selecting power supply installations for telecommunications facilities // Bulletin of the Adygei State University. Series 4: Natural-mathematical and technical sciences. - 2020. - No. 1 (256). - S. 54-61.
8. Khekert E. V., Vladetskaya E. A., Bratan S. M., Kharchenko A. O. Influence of external factors on the technological system of a high-precision machine tool in conditions of floating workshops // Marine Intelligent Technologies. - 2021. - T. 4. - No. 2 (53). - S. 33-37. – DOI 10.37220/MIT.2021.52.2.066.
9. Boran-Keshishyan A. L., Zamorenov M. V., Florya P. N. [et al.] Functioning of a technical system with an instantly replenished time reserve, taking into account prevention // Marine Intelligent Technologies. - 2021. - V. 1. - No. 4 (54). – S. 258-264. – DOI 10.37220/MIT.2021.54.4.061.