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Inert Gas Production: N_2 Plant Vs Conventional Plant

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ABSTRACT

The modern oil tanker industry has been subject to many changes over the last 50 years. Both continuous and scrupulous improvements have led the industry to show more responsible and secure technologies.

It is more so now obligatory for vessels that have inert gas production systems. These systems maintain oil tankers with an inert atmosphere. In other words, vessels do not have enough oxygen to sustain combustion. While under operation, the inert gas is pumped to tanks or cargo tanks. The inert gas is produced either by an inert gas generator or is released by a clean exhaust from the vessel's boiler.

Accidents related to the loading and unloading processes have been almost completely eliminated as a result of the obligatory use of these systems on all vessels.

In this article a descriptive study of the two most used methods is carried out taking two model types of opposing plants used in the Merchant Marine, as far as possible, similar transport vessels of refined products derived from oil that possess different systems of the generation of Inert gas, for example, a state-of-the-art asphalt plant with N_2 generating plant.

The most characteristic data of their inert gas generation plants have been taken by comparing them, on the one hand, with vessels with a conventional inert gas generation plant, most of which are characterized by being large vessels with low speed, trips with more than eight days on average and with very few maneuvers during the week and on the other hand, vessels of medium length IMO II type and over 100 meters in length, low speed, travelling similar paths and with a greater maneuverability index.

The selection of the inert gas generation system depends mainly on two operating factors: The load capacity and the type of load. These factors depend not just on the calculation necessary for the maximum load / discharge speeds, the maximum capacity of inert gas generators, limitations of the load type, number and power of electric generators, The impact on maintenance cost, required safety levels depending on the adopted generation plant, etc.

1. Introduction

Since the beginning of crude oil transportation, one of the main concerns, in both cases the companies that make up the oil industry as well as for the states and international organizations, this is to avoid possible accidents that do environmental damage in the transport phase by sea, from extraction sites to the processing and consumption centers. As a result, the oil industry has very strict environmental protection standards and procedures. All oil companies are governed by the same rules.

Maritime crude oil and refined products transportation are currently carried out by tankers built under the most demanding naval engineering standards, all of which are equipped with

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state-of-the-art technology to

ensure transport safety and therefore, protect the environment. Taking this into regard, both IMO (International Maritime Organization) and the European Union have adopted legislation to accelerate the replacement of single hull oil tankers with double hull oil tankers.

The European Union has also had a series of laws adopted which are aimed at controlling vessels with increased maritime safety and protection of the environment. In this way, vessels that do not comply with the set rules for 2004 will not be able to sail in European waters. This, however, the International Maritime Organization has already adopted standards for the same purpose, which affect other countries rather than those of the European Union. From the end of the 19th century, oil has been the world's most important source of energy, as well as serving as the basis for an almost infinite number of by-products, and can consequently also make an environmental impact, both in terms of the Atmosphere (greenhouse gases and others) and the generation of solid waste (such as plastics) or liquids (such as oils).

In this way, there is an advanced technological development for the reduction of CO_2 emissions in order to reduce the greenhouse effect, which produces global warming.

One of the crude oil transportation problems is the danger of explosions on the high seas as well as hydrocarbon pollution, which are a type of pollutant that importantly affect water quality. Oil spills are becoming more and more frequent in the oceans, leaving traces of long-term pollution effects. The formation of an impermeable film of water in spill zones affects not only birds, but also aquatic mammals rapidly and directly.

Contamination by crude or refined oil (fuel, petrol, and other products obtained by fractional distillation and the chemical processing of crude oil) is generated accidentally or deliberately from different sources.

A large proportion of the sea pollution is due to the waste from millions of vessels that cruise the seas on a daily basis. It is likely that the most important waste of all is oil. It is estimated that about one thousand five hundred million tons per year are transported across the seas and during the process of loading and unloading, 0.1% of that oil is lost. The insertion of the Inert Gas system has improved these problems to a certain extent.

2. Background: the Origins of Inertization in Tanker Vessels.

In the late evening of February 4, 1932, the Bidwell Tanker weighing 10,950 Tons was cleaning its tanks at the Marcus Hook Refinery on the Delaware River. It had brought Texan crude oil to the refinery and was about to return with petrol. When at 00:20, it exploded. The first explosion was then followed by three more consecutive bursts over a period of 25 minutes.

The explosions were heard over 20 miles away. 19 crew members were killed and the Captain's wife was rescued from the cold water by a crew member.

Tanker explosions were nothing new. The first known conversion of a wooden sailboat to carry wholesale oil was the Charles Vessel. In 1869, The Charles Vessel was equipped with 59 separate tanks. Three years later it caught fire and was lost. The tanker's owners knew they should be concerned, however, its twin called "Vorwarts" only lasted four years before it exploded in Savona and had to be sunk.

Shipping companies knew that safer tankers could be made with inert gas systems for cargo tanks. The technology was already in use in refineries and could easily be adapted to oil tankers. Basically, the process consists of directing a portion of the exhaust gas from the boiler to a water purifier, which is quite simply a large shower that cools the gas and extracts most of the sulfur, and then is pumped into the tanks.

If the system was being properly used and functioning, the oxygen content in the tank atmosphere would be less than 5%. Normally, air is 21% O_2. Below a 10% oxygen level would not help combustion without taking into account the amount of hydrocarbon vapor in the gas.

C.S. Petrol knew that the system would not have prevented the first explosion at Bidwell's.

At that time, it was necessary for a person to enter a tank so that it could be cleaned, which required the entrance of fresh air for cleaning. However, the inert gas would have made it much more difficult for the fire to spread to the other tanks, and would most probably be possible to prevent the explosions that would occur.

Therefore, the company of that Tanker reacted quickly, in the later months of 1933, all of the Company's Tankers were equipped with inert gas (IGS) systems. This included the Bidwell tanker which had survived.

The Bidwell tanker was later torpedoed in 1942 while sailing loaded just thirty miles east of Cape Vigilance by the German U-boat, U-160. The torpedo struck the tanker, spilling onto the deck and killing the 2nd officer. Fortunately, the fire did not spread to intact tanks. The crew was able to take control of the fire and the vessel arrived safely to harbour. The Bidwell oil tanker ended up being scrapped in 1965 after being in service for forty-five years.

Further on, more tests were being performed on the use of inert gas and it was found that it produced corrosion in the tanks. They observed that corrosion is a process due to the oxidation of the steel in the cargo tanks. That is to say that those vessels carrying a clean product had a life of twelve years, however, those carrying unclean cargoes lasted twenty to twenty-five years.

The American company Sun Oil had observed during a four year period that their vessels had passed the sixteen-year review without having to replace any steel and in which lasted about twenty years with minor partial repair work. The vessel Sun Sabine passed the special of twenty year examination without renewals to the cargo spaces, this vessel had two and a half years in service of clean products and more than seven years' service of unclean product. As a result, it was not only a significant economic saving, but the vessel's safety was unbeatable.

Extraordinarily, neither oil tankers owners nor oil suppliers took any apparent notice of Sun Oil's success with the inert gas system for almost thirty years.

Tabla 1. Explosions of vessels without inert gas systems.

YEAR	VESSEL	M^3	SYNOPSIS
1872	Charles	---	Conversion from sail/ 59 tanks/ lost to fire
1888	Fergusons	---	Converted to steam/ lost in Rouen
1890	Vorwarts	---	Exploded in Savona
1891	Lux	16	Exploded, 16 dead
1892	Petrolea	---	Exploded near Burdeos
1902	Nerite	---	Lost
1902	Bakunin	---	Loaded in Callao, A fire started and was repaired
1907	Silverlip	5	Explosions in Tank nº4, it sank. 5 dead.
1910	Manhatten	---	On 23/09/1910 it left NY to Argelia loaded. Nothing was known of its whereabouts
1911	Chesapeake	---	Expedition 40.2N,48.4W to Argelia, it was abandoned
1912	Spondilus	---	13/01/1912 Exploded
1914	Kometa	15	16/04/1914 Several tanks Exploded. 15 dead
1915	Dakotah	---	03/10/1915 Exploded
1917	Sebastian	---	17/05/1917 fully loaded vessel, Exploded
1922	Coylet	---	08/02/1922 fully loaded vessel, Exploded and sank.
1926	Volga	---	12/01/1926 set on fire
1926	Phoenix	2	Cleaning of a tank, exploded in Boston
1928	Chuky	---	15/02/1928 fully loaded vessel, Exploded and was lost.
1932	Bidwell	18	Cleaning of a tank, last load of crude oil
1933	C.S. Petrol	3	14/07/1933 exploded and sunk
1934	La Crecenta	29	Sunk. 29 dead

Source: Jack Devanney Center for Tankvessel Excellence, his own elaboration.

There was no attempt to use tankers with an inert gas system during World War II, even though the United States Navy was aware of the value of inertisation. Nearly every American aircraft carrier was using inert gases (nitrogen). Several authorities claim that this was a major factor during the war in the Pacific.

In fact, it is not known for sure if the tanks had been using inert gases on vessels they might have saved lives during the Second World War. After the war, oil tanker explosions continued.

One of the most dramatic explosions which had innumerable casualties was that of the Japanese tanker Stanvac. During the cleaning of the tanks, an explosion occurred whilst in the Arabian Sea in 1958. The explosion destroyed the entire deck of central tanks, killing 19 crew members.

Stanvac was a company made up of a joint venture between Esso and Mobil. In the 1960's. The company BP, which had experienced very quick tank corrosion on its vessels carrying high sulfur content from the Middle East, was interested in inerting as a method of corrosion management. BP visited the American company Sun Oil, inspecting some vessels as well as the inert system, and developed its own variant in conjunction with the Sun Oil design.

Due to initial problems, equipment malfunction, the long periods in which tanks were exposed to normal air as well as measurement difficulties, they found that the O_2 content in the tanks was 5.4% when the tanks were inert, but 8.2% by the time the repair / inspection had been included, implying that the tanks were not inert for approximately 18% of the time.

Figure 1: The Stevanc Tanker Japan.

Source: Jack Devanney Center for Tankvessel Excellence

The overall results roughly agreed with BP laboratory tests which showed 0.014 inches in air loss and 0.005 in years in 9%.

In other words, while the tanks were inerted at an O_2 average of 5.4%, the loss of prices were at 1/12 times less than those of the control vessels. From 1963, BP introduced the inert gas system throughout the entire shipping company.

Tabla 2.Explosions of vessels without inert gas systems.

date	vessel	deaths	Vol(m³)	Synopsis
25/09/1948	Esso Salta	?	0	Explosion, sunk
20/04/1951	Esso Greensboro	44	7000	Fog in the Persian Gulf , Exploded
20/04/1951	Esso Suez	2	0	Fog in the Persian Gulf , Exploded
19/10/1958	Stanvac japan	19	0	Cleaning of the tanks in Saudi Arabia, exploded, cause unknown
25/03/1960	Mobil Astral	4	0	Explosion after loading in Puerto La Cruz, cause unknown
08/07/1960	Esso Portsmouth	0	0	Unloading, a fire started and it exploded.
06/12/1960	Sinclair Petrolore	?	60.000	Unloading type OBO, was sunk in Brazil
14/12/1960	World Harmony	52	0	Collision in Bosporus, three vessels, cause unknown
14/12/1960	Petar Zoranic	52	20.000	Collision in Bosporus, three vessels, cause unknown
14/12/1960	Tarsus	52	0	Collision in Bosporus, three vessels, cause unknown

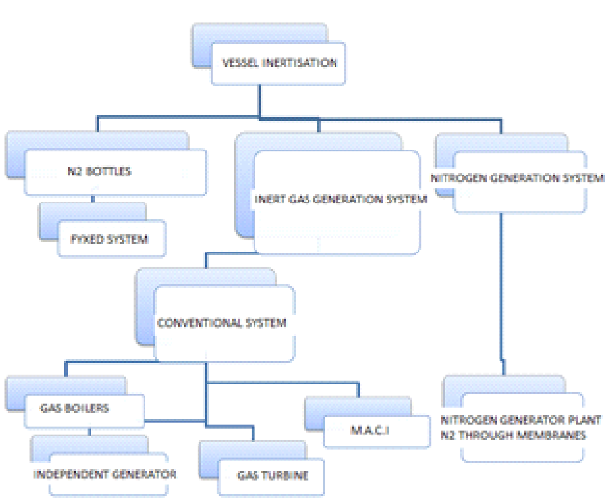
Source: Jack Devanney Center for Tankvessel Excellence, his own elaboration.

Throughout the 60's, both companies Sun Oil and BP were the only ones interested in the process of inertisation.

3. Material and Method

Existing techniques of inerting and gas replacement methods inside a vessel's cargo tanks can be divided mainly into three fully different processes, in which current inerting techniques are based on oil and chemical tankers.

Figure 2: Inertisation Scheme.



Source: Field work, my own design

3.1. *Convetional Inert Gas System*

The following are the types of inert gas generation methods: Potential sources of inert gas in vessels for this type of system may be:

a) The exhaust of vessel's boilers, whether main or auxiliary.

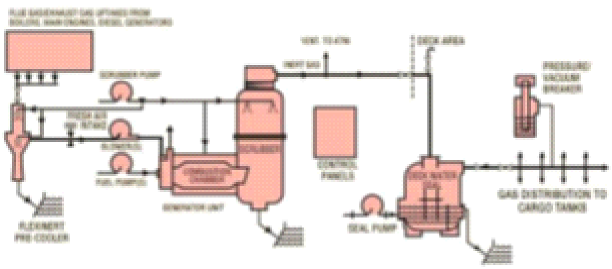
They are the best known and most widely used source on vessels. In general, no extra fuel is consumed due to the fact that it takes advantage of the exhaust gases from the boilers.

In order for a boiler installation can be used as an inert gas source, it must fulfill the following two requirements:
1. Burners and combustion control equipment are capable of stably producing gases with an oxygen content equal to or less than 4%.
2. Boilers are capable of producing sufficient quantities of gases to satisfy the system requirements.

b) An independent inert gas generator.

In case the vessel does not want the boilers to start because it is not economical, similar to that in navigation, which is to say that it is used as an auxiliary element. It is used to fill the cargo tanks, when the vessel is fully loaded, the Inert gas needs are small. It is also used as the only source of inert gas is this Inert Gas Generator which is sufficient to supply the mentioned gas during the discharge and cleaning operation, however, this is not the case for this project.

Figure 3: scheme of inertisation.



Source: Jose Luis Lopez, project of technical naval engineering.

The main components of conventional inert gas installations are as follows:

- A washing tower or "Scrubber"
- A cooling water pump
- A sealed water pump
- Two fans
- A hydraulic seal on deck
- Valves, instruments, and controllers suitable for the correct distribution and control of gases to each of the cargo tanks.

A completely separate generator is established by the burner, the combustion control devices and by the elements of cooling and cleaning the gas.

c) Groups "A self-sustainable autonomous gas generator turbine".

The reasons they are used is for saving energy. Exhaust gases from gas turbines contain a percentage of oxygen that exceeds the highest limit allowed and enough to maintain a second combustion through an independent generator. The initial cost is high, but sometimes it is considered to make amends for the main reason of electrical balance and energy savings. There are some facilities like this, but few on board vessels.

d) Groups "A self-sustainable autonomous Diesel engine".

They are similarly used as to the previous one. Exhaust gases from diesel engines usually have an insufficient oxygen content in the overload condition to withstand a second combustion.

Under fully loaded conditions they can maintain this combustion with difficulty, but only in partial loads, they contain such a high percentage which makes them unusable as a source of inert gas.

Process Description

There are two boilers, one on each side, always leaving in reserve. From the exhaust of these boilers the gas produced in combustion is taken through the inert gas line.

A pneumatic butterfly valve is attached to the pipe connection. These valves are connected to both fans, with the air intake and the soot blower. When this valve is expected to be dirty, it is closed and cleaned with this soot blower, which is nothing more than a stream of cleaning air. Next to the valve is an inspection cover for cleaning and checking the condition of the valves.

This gas (which is the inert gas we use) is carried to the "Scrubber" or wash tower where the gas is cleaned and most importantly, where the gas is cooled. The gases enter the tower through the water stored in the lower section and brought up through a series of sprinklers. These sprinklers or diffusers pour water, cooling the gas, agglomerating the solids it carries and condensing its contaminants. These pollutants fall in the lower part and which are then discharged into the sea. The washing tower must maintain a small amount of water, avoiding resurging gas and appliance overheating.

Exiting the washing tower clean inert gas is at about 2 °c which is more than sea water. And also before leaving the tower, the gas passes through a dehumidifier.

The hydrostatic lock or "pot-seal" serves as protection against possible overpressures or large gaps. Its geometry is defined by the pressure and vacuum which must be counteracted.

Pumps feeding sea water are totally independent of the system, which sucks up the sea and provides water for both the Scrubber and the cover seal through a double circuit (reserve). Both the Scrubber and the cover seal should never run out of water. The pump feeding the seal must run almost always continuously (unless in dry dock).

There are also two fans (one is a reserve) which sole function is to boost the gas, then take it to every one of the tanks. Before and after each fan, there are fan isolation valves, which prevent the recirculation of gases through a fan which is not in service.

Each pair of valves is connected with its fan. These valves must be remotely controlled from the central control chamber. In the event that a fan stops, this inert gas distribution valve will automatically close.

Each fan can supply an equivalent of up to 125% of inert gas, which is the capacity of the loading pumps. Each fan will only start if the cooling water from the tower is flowing, if the air intake valve or one of the boilers is open that depending on the inert gas / air selector, and if both isolation valves are open.

The gas coming out of the fan's pipes must be at a certain temperature so that there is no danger of explosion, so that is why thermostats are installed. When the gas leaves these pipes it comes across a regulating pressure valve, which as its name indicates, regulates the pressure of the inert gas in the cover manifold, opening or closing.

The main control valve, adjusts the supply to the tanks. If the control fails, the valve closes. The recirculation valve returns excess gas to the tower. The system maintains a constant back pressure in the fans. The control is pneumatic although with a manual presence. If the valve fails it is opened.

Then, this gas passes through the cover seal, which is a device with a large base, it is filled with a small amount of water and serves to prevent a recoil of gas especially in case of fire or tank explosion.

In other words, it is a liquid retention valve which, although it does not offer resistance to the passage of the gas to the collector, it prevents return with counter pressures of up to 3,500 mm with a water column.

The gas then flows through the main line, carrying pressure transmitters connected to the regulating valve and suitable check valves. Also, at the beginning of this pipe, there is a solenoid valve for the collector. This pipe has branches which are joined so that the gas is distributed to each tank through a shut-off valve.

This main line has, a pressure / vacuum valve attached, the reason for this is to open it when the pressure or the vacuum in the tanks increases to protect it from deforming or collapsing the structure.

The deck seal pipe comes with a check valve connected to the side of the vessel, which also has a separate steam system. The outlets have butterfly valves. There are shut-off valves before and after the pumps with check valves included. Thermometers and pressure switches are installed next to the pumps.

For a tank to be considered inert, it must be properly inerted and subjected to positive pressure (so that air is not allowed to enter the tank).

3.2. Specifications of the Generator Unit of N_2

The design of the installation is based on the following principles:

- IMO Regulations.
- Rules of the Classification Society.

The nitrogen generator is partly installed in the engine room and the rest in a similar space, its air capacity is based on the percentages of O_2 in N_2 calculated with an ambient temperature of 20 ° C , relative humidity of 80% and atmospheric pressure. Voltage tolerance: -15% / + 10%.

Hollow fiber membranes are used in the system for the separation of the air 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 penetrates slowly through the membrane while oxygen, CO_2 and water permeate rapidly. This allows the nitrogen to separate from the oxygen. The monitoring continues and the gas control of the product guarantees its correct purity level. The model of the design module we have is a parallel tubular beam from the manufacturer GENERON.

The main components in the process line, four subsystems are formed:

- The air feed,
- The pre-treatment of air
- The separation of the Product Gas
- The control system

Which the system's performance is:

- Capacity: 2250 Nm 3 / hr @ 95% N_2
- Capacity: 908 Nm3 / hr @ 99% N_2
- Discharge pressure in the high pressure line: 10 bar
- Discharge pressure in the low pressure line: 0,2 bar
- Air supply demand: 4325 Nm3 / h
- Temperature discharge N_2: not more than 55 ° C
- Composition of purged gas: N_2 + Argon
- Dew point: -70 ° C after the expansion at atmospheric pressure
- Ambient temperature: between 3°C and 45°C
- Air supply temperature from the compressors: maximum 45°C
- Air temperature in membranes: maximum 55°C
- Required air flow of feed: maximum 5060 m3 / h
- Required air pressure supply: 13 bars before entering the membranes.
- Power supply: 3 x 440V / 60Hz
- Power consumption: 25 kW (maximum heater load)
- Noise level: ¡85 db (A) at 1 meter distance.

Description of the Entire Process

The air supply to the nitrogen generator is the most critical part of the membrane generator. Properly designed filters are of extreme importance to avoid membrane contamination, resulting in performance loss over time.The on-board filtration system belonging to the Unitor company incorporates:

A) Water separator (MS-11) at the inlet of the filter system to remove condensed water in the pipe after the compressor. The water separator has an automatic drain trap with high water level alarm and "Shutdown" .

B) A thick mesh filter (F-13) and a fine filter (F-14) offering coalescing filtration for the extraction of oil and particles.

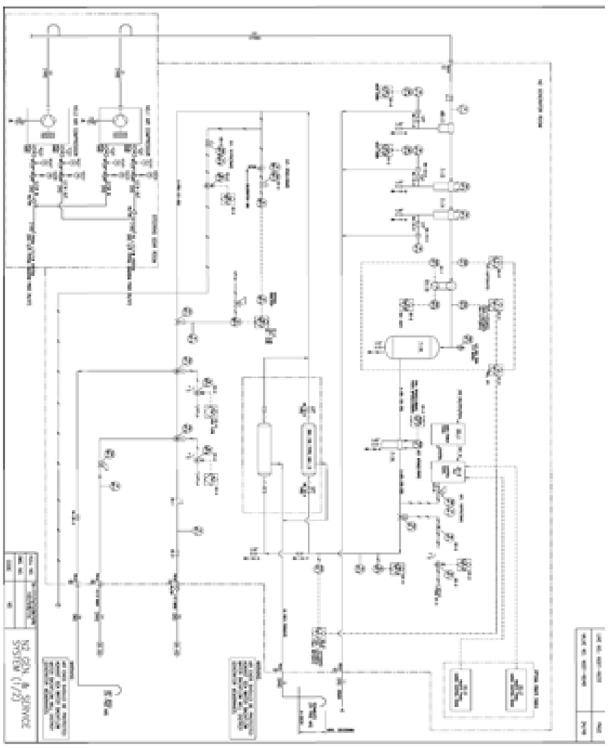
C) Heater (EH-15) to provide constant temperature for the air feed in the membranes.

D) An activated carbon bed filter (F-16) specially designed for the plant to catch the oil vapors.

E) A sub-micron filter (F-19) to trap possible dust particles from the active carbon filter. This filter is the last protection of the membranes and has a high pressure differential alarm and shutdown.

F) A slow opening valve (FSV 19 - 1) which eliminates the pressure shock in the filter system. This arrangement avoids possible droplets that can be expelled by the combined use of filters and dust from the active carbon filter.

Figure 4: General scheme of the N_2 system B/Q TINERFE.



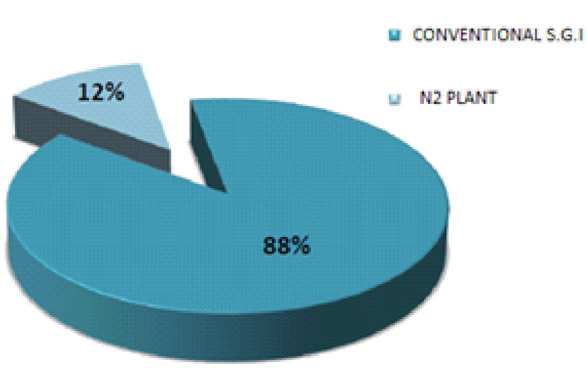
Source:B/Q TINERFE PLANS.

The membrane system consists of a set of parallel modules (MM-19). The separation of nitrogen and oxygen occurs in the membrane modules, where compressed air flows through the hollow fibers. The fastest gases (water, oxygen and carbon dioxide) impregnate through the walls and are vented to the outside at nearly atmospheric pressure.

- The gas product (nitrogen) is maintained at the same pressure as the incoming air.
- The enriched oxygen flow is directed to be then expelled into a safe area.

3.3. The Comparison of both Systems

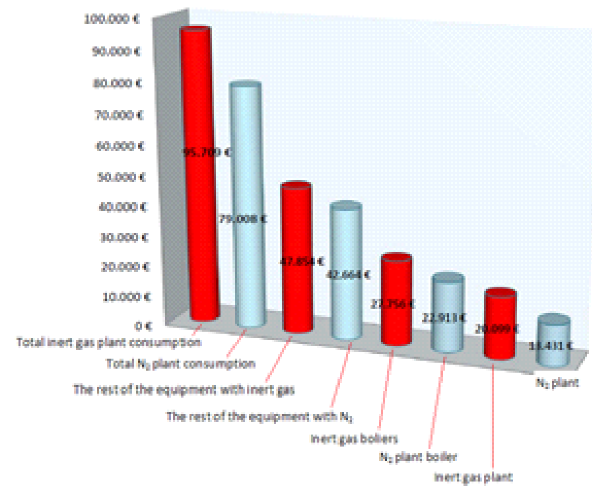
Figure 5: Time needed to match the capacity of the two systems in function of linear velocity.



Source: Field work, my own design.

As we can see represented in figure 1, for a same vessel it would require an 88% higher inert time for the Conventional Inert Gas System compared to the N_2 Generation Plant, mainly due to the replacement of gas method for displacement and not by dilution of the same.

Figure 6: The comparison of annual fuel consumption costs between inert gas plant and N_2 generation plant for one year.

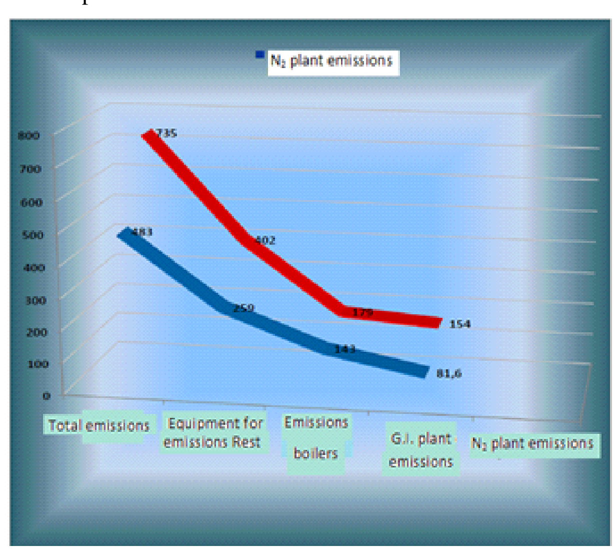


Source: Field work, my own design.

Once the calculations for the consumption of both systems on the same vessel have been carried out, the costs are compared in the following graphs.

It should be taken into account that there has been no increase of approximately 5% in the cost of installing inert gas inherent to the water supply devices to the deck and boiler seals. They have been omitted in the first calculations, giving an increase of 5% to the final result.

Figure 7: Annual emission comparison between inert gas plant and N_2 generation plant.



Source: Field work, my own design.

Obviously, the contamination with a conventional plant is superior with respect to a nitrogen plant, which in the majority of the cases only a boiler is used.

This data is limited to the start-up while moored in port, being a reference for obtaining the estimated total consumption of the vessel and the emissions of harmful gases regulated by regulation. The consumption data which is calculated is that referring to being moored in port for unloading. The consumption of the inert gas generation system and boilers will be more important (only one boiler is used during operations), since they are the equipment used with relevant consumption during the unloading operations.

Once the calculations were made, the total consumption was calculated during the unloading operations, resulting in an expense of 176 tons of low sulfur diesel, of which 24% corresponds to the inert gas generation plant and 25% to the boiler

4. Conclusions

1.- The production of nitrogen on board vessels in a nitrogen generating plant, avoiding the most complex means and with the specific drawbacks of corrosion, higher cost, complexity in maintenance, low production of inert gases in the same space as well as others, has achieved greater efficiency and better results in the inertisation of cargo spaces, also in the maintenance of tank walls and in safety / environment. Bringing the security of the process to an approximation of 100%.

2.- This nitrogen production system by non-cryogenic "membranes" is an advance in the maritime sector dedicated to the transportation of flammable products derived from fossil fuels, mainly due to the low cost of production of the gas after air separation and how the facilities of production of nitrogen have been simplified, due to a very basic procedure of installation and operation.

3.- The system's high efficiency is its low installation and maintenance costs, as well as the increasing global demand for safety during shipping and maritime vessel operations, this has led to companies specializing in the elaboration or manufacture of these types of membranes by investing their resources in R + D + I to continue the development of new polymer components which are able to permeate more "fast gases" to this end, in order to reduce the limitations that still exist in their application.

4.- The amortization of these types of installations are linked to the maintenance of the installation, therefore, the importance of maintenance and the conditioning of the compressed air that feeds the membranes, as, this will depend on the durability and performance of the membranes and furthermore its cost of amortization.

5.- The advantage of the permeate in the generation plant for the combustion of the boiler of auxiliary services is a good option to take into account.

The consumption of fuel will have a decrease in the boiler because the combustion with enriched oxygen causes an increase of the flame's temperature and therefore the combustion time is reduced to reach the steam pressure in the boiler. With the studies done we take into regard and speak of fuel savings that move in percentages from 25% to 35%, depending on the type of fuel used.

It should be kept in mind, that even the most optimistic forecasts in the market, are focused on the fact that the price of fuel with low sulphur levels will increase during the next few years, the savings would be much higher.

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