



## ANALYSIS OF SPECIFIC FUEL CONSUMPTION BY SHIP INERT GAS GENERATOR: NITROGEN VS COMBUSTION-TYPE

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**Abstract** : The paper compares two methods of generating inert gas on ships. The advantages and disadvantages of two inert gas generators are considered: membrane nitrogen generator and combustion-type generator. Based on the analysis of electricity and fuel consumption of both systems, it was shown that the membrane nitrogen generator outperforms the combustion-type inert gas generator. Specific fuel consumption for a nitrogen generator (at 5 % of oxygen on inert gas) is more than two times less compared with a combustion-type one: 34.8 kg/nm<sup>3</sup> vs 78.5 kg/nm<sup>3</sup>. However, when the required oxygen content in the inert gas decreases, the membrane nitrogen generator will be inherent in higher electricity consumption, requiring further analysis of its feasibility compared to the combustion-type one.

**Key words** : Combustion, comparison, consumption, cost, energy, fuel, inert gas generator, membrane nitrogen generator, ship.

### 1. INTRODUCTION

Inert gas generation (IGG) systems are critically important for ensuring fire safety on tankers transporting petroleum products. The inert gas system operates on a typical product tanker for approximately 750 hours per year [1]. In modern practice, two main types of such systems are predominantly used: the traditional inert gas generator (combustion-type IGG), which operates based on fuel combustion, and membrane installations for nitrogen production. Given the increasing demands for energy efficiency in maritime transport, especially in the context of implementing the IMO Energy Efficiency Design Index (EEDI) for new vessels, a detailed analysis of both systems in terms of energy consumption is warranted [2].

### 2. PRINCIPLE OF OPERATION AND ENERGY EFFICIENCY

Combustion-type IGG operates by burning fuel in a special chamber, after which the flue gases are cooled, purified, and delivered to the cargo tanks [3]. The composition of such gas predominantly includes CO<sub>2</sub>, N<sub>2</sub>, water vapors, and Sulphur impurities, which necessitate purification that contributes to additional power consumption. The overall efficiency coefficient of such systems ranges from 15% to 30% [4].

Membrane nitrogen generators function on the principle of separating compressed air through a polymer membrane, allowing for the extraction of nitrogen with a purity of up to 99.9% [5]. These systems consume electrical energy to operate compressors and are considered not to produce harmful emissions, achieving efficiencies of up to 70% [6].

However, the above statement is not entirely accurate, as ship fuel is burned to operate the compressors on board the vessel. Moreover, it is not entirely clear how to compare the efficiency of combustion-type IGG and the nitrogen generator based on the data from [4] and [6]. Therefore, it is more appropriate to compare the fuel consumption of the two systems rather than the abstract concept of efficiency, which can be calculated differently for these systems.

### 3. ANALYSIS

The Nitrogen Generator model NCI type approved by DNV (produced by Air Products AS) was chosen for analysis. The operational principle is based on membrane separation. This PRISM® Nitrogen system, based on PRISM® membranes, allows for continuous on-site production of pure and dry nitrogen from air that can cover various purposes. The main characteristics of the two operation modes are presented in Table 1.

Nitrogen generation is based on the following processes. Compressed air is fed to the Filter & Control



Unit and passes through a filter-package which will protect the membranes from harmful particles and oil and water condensate. The air then passes through a heater (electric or heat exchanger type), which will raise the air temperature by min. 5°C to approx. 50°C.

Table 1. Performance data of membrane nitrogen generator

Data	Mode 1	Mode 2
Capacity – Nitrogen Flow, nm <sup>3</sup> /h	925	110
N <sub>2</sub> purity (N <sub>2</sub> +Argon), vol %	95.4	99.9
N <sub>2</sub> Dew Point (at atm. Pressure), °C	-60	-60
Outlet Pressure, kPa	21	700
Outlet Temperature (max), °C	50	50

The heated air is now fed from the Filter & Control Unit to each Membrane Bank and then to each individual membrane separator. The nitrogen product exiting the membrane modules is collected in a manifold and fed back to the Filter & Control Unit. The Filter & Control Unit is equipped with an oxygen analyzer that will continuously monitor the oxygen content in the nitrogen product. Should the oxygen content, for some reason, rise above the design value, an alarm will be initiated. If the nitrogen consumption is lower than the design, the backpressure in the distribution lines will build up and give a lower product flow. A lower flow in the tum will result in higher nitrogen purity, i.e. less oxygen in the product.

The electricity consumed in the production of nitrogen using the Nitrogen Generator, which is discussed in the paper, is used for the operation of the:

- compressor (the predominant part),
- electric heater for heating the airflow before the membranes,
- powering the control system (a small amount).

The Nitrogen Generator discussed has a water-cooled marine screw compressor DSDX 305 (KAESER compressor) installed. Their main characteristics are the following: max. working pressure 14 bar, min. working pressure 5,5 bar, free air delivery 1162 m<sup>3</sup>/h, shaft power 152 kW.

Electricity on board a vessel is produced by burning marine fuel either in the main engine using a shaft generator or in auxiliary engines with electric generators.

The hour fuel consumption for the electricity production for the operation of the Nitrogen Generator:

$$M_{Fuel}^{El} = g_F \cdot (P_c + P_h), \quad (1)$$

where  $P_c$  and  $P_h$  are the electrical power of the compressor and heater; correspondently, kW;  $g_F$  is the specific fuel consumption of a diesel generator, kg/kWh (taken 0.185 kg/kWh [7]).

It was calculated that the compressor power when compressing 1162 m<sup>3</sup>/h of air to 9 bar (working pressure according to the manometer for mode 1) and with an efficiency of 0.75 is 138 kW. The power of the electric heater for this amount of air when heated by 10 K, considering the heat capacity and density of compressed air according to [8], is 36.2 kW.

For comparison, the Alfa Laval Smit Combustion inert gas system was chosen, which consumes the MDO (DMB or DMC) as fuel. The special burners of the Ultramizing system ensure inert gas production with low NOx emissions and no soot. Quality is further assured by sprayer systems that avoid creating salt crystals through water evaporation.

The energy during inert gas production in a Combustion-type IGG is consumed for the operation of the:

- scrubber pumps,
- gas blower after the generator,
- power supply for the control system (a small amount).

Similar to eq. (1), the hour fuel consumption for the electricity production for the operation of the Combustion-type IGG:

$$M_{Fuel}^{El} = g_F \cdot (P_{SP} + P_{GB}), \quad (2)$$

where  $P_{SP}$  and  $P_{GB}$  are the electrical power of the scrubber pumps and gas blower; correspondently, kW.

For scrubbers in a Combustion-type IGG system, typical power consumption is no more than 7 kW/1000 nm<sup>3</sup> of gas being cleaned. The calculated compressor power when compressing 925 m<sup>3</sup>/h of inert gas from a pressure of 0.15 bar after the Combustion-type IGG to 0.5 bar (for supply to cargo tanks) with an efficiency of 0.75 is 10.7 kW.

Fuel consumption for producing 1000 nm<sup>3</sup> of inert gas depends on many factors (fuel type, oxygen content in the inert gas, and others). According to the analysis of information provided by various manufacturers of Combustion-type IGG, the specific fuel consumption is 0.075...0.084 kg of MDO per 1 m<sup>3</sup> of inert gas.

All this data is needed later to compare fuel consumption per unit of inert gas the IGGs produce.

#### 4. RESULTS AND DISSCUTIONS

Table 2 provides information for comparing the combustion-type and the membrane nitrogen inert gas generators.

Table 2. Comparison of the Nitrogen IGG and Combustion-type IGG.

Characteristic	Nitrogen IGG	Combustion-type IGG
Operating principle	Air separation through the membrane	Fuel combustion
Oxygen content in inert gas	≈ 0.5...5%, but performance drops and energy consumption increases with lower O <sub>2</sub>	≈ 2...4%, even less without loss of performance
Inert gas purity	High	Low (soot, sulphur oxides even after cleaning)
Initial capital investment	Relatively high (per IG unit)	Relatively low (per IG unit)
Fire safety	High	Fire risk due to fuel
Compactness	High	Low
Sensitivity to air quality	High (requires pre-filtration)	Low
Maintenance complexity	Frequent maintenance costs for membrane and filter replacement	Simple, but requires combustion process monitoring

Information on the components of the total energy consumption of IGGs and the calculated specific fuel consumption for the production of a unit of inert gas are presented in Table 3.

Table 3. Comparison of energy characteristics for Nitrogen IGG and Combustion-type IGG

Characteristic	Nitrogen IGG	Combustion-type IGG
Capacity, nm <sup>3</sup> /h	925	
Fuel consumption for combustion in IGG, kg	-	69.4
Electric power consumed by the compressors, kW	137.6	10.7

Power consumed by a heater, kW	36.2	-
Power consumed by scrubber, kW	-	7.0
Fuel consumption for electricity production (auxiliary engine-driven generator), kg	32.2	3.3
Total fuel consumption, kg	32.2	72.6
Specific fuel consumption, kg/nm <sup>3</sup> of IG	34.8	78.5

As can be seen from the results presented in Table 3, in terms of energy consumption, the membrane nitrogen IGG wins over the Combustion-type IGG.

## 5. CONCLUSIONS

Membrane nitrogen inert gas generators, despite a higher installation cost, demonstrate a significant advantage in terms of energy saving, environmental safety, and ease of operation. In the medium and long term, they have lower operating costs, faster payback, and fully comply with modern environmental standards.

A disadvantage of the membrane nitrogen inert gas generators is that their productivity is relatively low. In this regard, they may lose to traditional combustion-type inert gas generators, especially when it is necessary to service large tankers. This issue can be partially resolved by using buffer tanks.

The results of the calculations show that specific fuel consumption for membrane nitrogen IGG is more than two times less compared with combustion-type IGG: 34.8 kg/nm<sup>3</sup> vs 78.5 kg/nm<sup>3</sup>. This indicates the greater efficiency of the membrane nitrogen IGG when used on most merchant vessels. However, in cases where the oxygen content in the inert gas is required to be below 4...5 %, the combustion-type IGG may be more energy efficient than the membrane nitrogen IGG (during operation in mode 2 – Table 1). The issue of the energy feasibility of using one or another method of inert gas production depending on the oxygen content will be considered in my further research.

## 6. CREDIT authors statement

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