UDC 629.5
DOI: 10.15587/2706-5448.2024.316781

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IMPROVEMENT OF THE PROCESS OF PREPARING CARGO TANKS OF CRUDE OIL TANKERS FOR CARGO OPERATIONS

The object of research is the process of inerting the cargo tank of an oil tanker. Issues related to improving the process of preparing cargo tanks of oil tankers for cargo operations are considered. It is noted that the efficiency of oil tanker operation, in addition to transport operations, is determined by the technologies used during the preparation of the vessel for receiving new cargo. One of such technologies is the inerting cargo tanks, which precedes any cargo operations. The study was aimed at improving the inert flue gas system by using a new technology for supplying jets of inert gas to the cargo tanks of an oil tanker. The main task of the research is to establish the degree of influence of the gas flow parameters (formed by the inert flue gas generator) at the entrance to the cargo tank on the nature of the change in air concentration in the entire volume of the tank. The final result of solving this scientific and applied problem is determined to be a reduction in the inerting time of cargo spaces of oil tankers. During the experiments, the supply of inert gas to the cargo hold was provided according to three technological schemes. The first contained only one jet source with an opening angle of 60°, which was located at the central point of the cargo tank bottom. The second contained four sources of inert gas jets, which were located crosswise on the tank bottom. The nozzles were installed diagonally in the centers of four identical rectangular zones of the tank bottom. Their opening angle to create a conical jet torch was 30°. The number of sources of inert gas jets of the third scheme was five. At the beginning of the inert gas supply process, four sources were used, which were located at the corners of the tank with an opening angle of 30°. When the initial value of the oxygen concentration in the air was reduced by thirty percent, the inert gas was supplied only from the fifth – the central jet source. It used a nozzle that creates a 90° cone opening angle of the jet torch. With the start of operation of the central nozzle, all angular sources of inert gas jets were turned off. It has been proven that this scheme ensures an improvement in the inerting process of an oil tanker, which is reflected in a reduction in the time required for its implementation.

Keywords: *cargo operations, inert flue gases, oxygen concentration, jet opening angle, oil tanker, inert gas system.*

Received date: 30.09.2024
Accepted date: 29.11.2024
Published date: 05.12.2024

How to cite
Kolegaev, M., Brazhnik, I. (2024). Improvement of the process of preparing cargo tanks of crude oil tankers for cargo operations. Technology Audit and Production Reserves, 6 (1 (80)), 00–00. https://doi.org/10.15587/2706-5448.2024.316781

1. Introduction

The efficiency of operation of vessels intended for transportation of crude oil and petroleum products, in addition to transport operations, is determined by the technologies used during the preparation of the vessel for receiving a new cargo. One such technology is the inerting cargo tanks, which precedes any cargo operations. There are a number of shortcomings in the technology of management and control of the inerting process of cargo tanks on tankers. First of all, these include: a long duration of the process; lack of technical means of intensification of the tank atmosphere replacement process; inconsistency of measurements of the tank atmosphere concentration at the outlet with the real values inside the cargo tank [1, 2]. The combination of these shortcomings cannot guarantee high efficiency of the inerting process of the tanker cargo spaces. For this reason, the inerting process of cargo tanks of an oil tanker takes a significant amount of time and affects the economy and environmental friendliness of the seagoing vessel [3, 4].

Reducing the time of the inerting process is in demand from an economic point of view, since for tankers with a deadweight of more than 50,000 tons, reducing the time from the standard 30 h to 20 h can provide annual fuel savings (used to ensure the operation of the inert gas generator) of up to 90–100 thousand US dollars [5, 6].

Modernization of the inert gas system of tankers involves conducting research work in two areas: constructive changes in the fuel preparation technology in the inert gas generation system [7, 8] and improvement of the inerting technology of cargo tanks [9, 10].

The basic principles of operation of the inert gas system on tankers are based on the combustion of diesel fuel in the inert flue gas generator, which is a separate device that is not connected to the vessel's fuel preparation circuit [11, 12]. The inert flue gas obtained during the operation of the generator, after a series of operations to clean it and reduce its temperature, is directed to the cargo tanks [13, 14].

According to the requirements of SOLAS [15, 16], the technical parameters by which inert gas must be supplied to the cargo tanks of oil tankers are determined by the following values:

1) the oxygen concentration in the inert gas must not exceed 5 %;

2) the oxygen concentration in the cargo tank is less than 8 %;

3) the temperature of inert gases is less than 65 °C [17].

The upward forced movement of the atmosphere in the cargo tank with its subsequent removal from the tank is caused by the action of force from the inert gas supplied to the cargo tank. This force is formed due to a change in the density of the multiphase mixture inside the tank, and is also a consequence of the interconnected processes of heat transfer and mass transfer through different concentrations of inert gas and tank atmosphere. The temperature stratification of the multiphase flow moving in a mixture with the tank atmosphere along the height of the cargo space is also one of the factors affecting the rate of replacement of the atmosphere inside the cargo tank [5, 18]. Under the condition of a temperature change from 20 °C to 50 °C, the air density changes by 10 % from 1.2 kg/m^3 to 1.09 kg/m^3 [4, 19, 20]. When determining the density of an inert gas, it is customary to take into account the content of its four main components: carbon dioxide CO_2, water vapor H_2O, nitric oxide NO_2 and oxygen O_2. According to the data of works [21, 22], the effect of temperature on the density of inert flue gases can be considered as the product of their density under normal conditions and the temperature correction according to the expression:

$$\rho_{IG} = \frac{G_{IG}}{V_{IG}} \cdot \frac{273}{273+T} = \frac{1+\alpha L_0}{22.4\left(m_{CO_2}+m_{H_2O}+m_{NO_2}+m_{O_2}\right)+} \cdot \frac{273}{273+T}, \quad (1)$$

where ρ_{IG} – density of inert flue gases, kg/m^3; G_{IG} – total amount of inert flue gases formed during combustion of 1 kg of fuel, kg; V_{IG} – volume of inert flue gases, m^3; T – temperature, °C; α – excess air coefficient; L_0 – theoretical amount of air required for combustion of 1 kg of fuel, kg/kg; $m_{CO_2}+m_{H_2O}+m_{NO_2}+m_{O_2}$, kmol/kg – molar content of carbon dioxide, water vapor, nitrogen oxide, oxygen in inert flue gases, respectively.

In works [23–25] it is shown that in the case of forced convection the flow field in a closed volume ceases to depend on the mechanisms of heat transfer and the current temperature field. This fact directly indicates the feasibility of using the supply of inert gas jets to the cargo spaces of the tanker. The main focus of research into the mechanism of using inert gas jets in a vessel's cargo tank should be to solve the problem of reducing the time of its inerting and reducing energy losses during its implementation [26, 27].

During inerting the cargo tank, the supply of inert gas jets should be coordinated with the air flow moving at low speeds inside the rigid walls of the cargo tank that limit it. The main change in the dynamic characteristics of the multiphase flow of gases and air will occur in the corner zones [28, 29]. For this reason, it is very important to supply inert gas jets precisely to the central part of the rising air flow. In this case, large-scale turbulent vortices in the middle of the cargo tank will lead to a reduction in its inerting time, which will contribute to reducing the vessel's parking time and, accordingly, the costs associated with it [30, 31].

A very important issue is the number of jet sources on the bottom of the cargo tank and the angle α of their flare. The smallest angles of opening will lead to the lengthening of the inert gas jet and, therefore, increase the area of turbulence of the air flow core along the height of the tank. Large angles will affect the intensification of the heat and mass transfer process, especially in the corner zones of the lower part of the cargo tank [32, 33].

The aim of research is to improve the inert flue gas system by using a new technology for supplying inert flue gas jets to the cargo tanks of an oil tanker.

2. Materials and Methods

The object of research is the process of inerting the cargo tank of an oil tanker. *The subject of the study* is the system for generating and supplying inert flue gas.

The main task of research is to establish the degree of influence of the parameters of the gas flow (formed by the inert flue gas generator) at the entrance to the cargo tank on the nature of the change in the oxygen concentration in the tank atmosphere. The final result of solving this scientific and applied task is determined to be a reduction in the inerting time of cargo spaces of oil tankers.

The research methods are the theory of statistics when processing the results of experimental measurements of the oxygen concentration in the entire volume of the cargo tank. As well as numerical approximation methods when constructing graphical dependences of oxygen concentration on the operating parameters of the inert gas supply process to the cargo tank.

At the stage of experimental study of the process of inerting the cargo tank by improving the inert gas supply, three technological schemes were used, which are shown in Fig. 1.

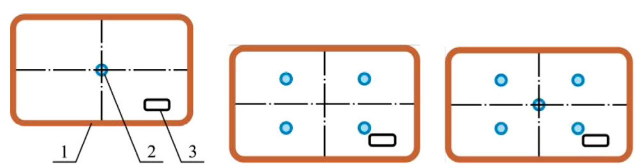

Fig. 1. Schemes of inert gas supply to the cargo tank: *a* – first, *b* – second, *c* – third scheme; 1 – cargo tank; 2 – gas supply nozzle (located on the bottom of the tank); 3 – outlet (located in the upper part of the tank)

During the experiments, three nozzles were used, identical in throughput, but with different angles of opening α of the inert gas jet torch cone equal to 30°, 60° and 90° (Fig. 2).

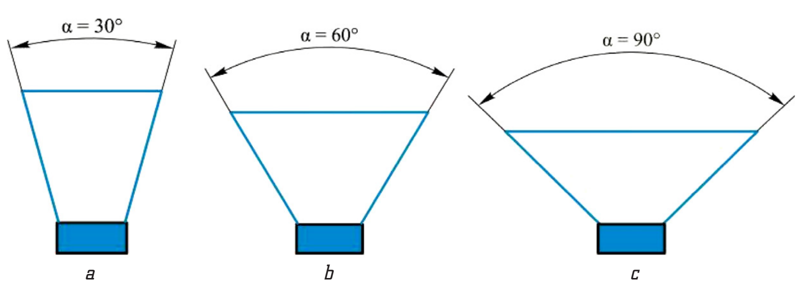

Fig. 2. Supply of inert gases to cargo tanks with different angles of flare opening: *a* – 30°, 60° and 90° first, *b* – second, *c* – third schemes

The first scheme (Fig. 1, *a*) contained only one jet source with an angle of opening α=60° (Fig. 2, *b*). It was located at the central point of the cargo tank bottom. The second scheme (Fig. 1, *b*) contained four sources of inert gas jets, which were located crosswise on the tank bottom. The nozzles were installed diagonally in the centers of four identical rectangular zones of the tank bottom. Their angle of opening to create a conical jet flare was α=30° (Fig. 2, *a*). This angle was used to exclude the mutual influence of inert gas jets on each other during their direction into the tank volume. The third scheme (Fig. 1, *c*) was combined. The number of jet sources was five. At the beginning of the inert gas supply process, four sources were used, which were located at the corners of the tank with an opening angle of α=30° (Fig. 2, *a*). When the initial value of the oxygen concentration in the air was reduced by thirty percent, the inert gas was supplied only from the fifth – the central jet source. It used a nozzle that creates an opening angle of the jet torch cone of α=90° (Fig. 2, *c*). With the start of the central nozzle, all corner sources of inert gas jet supply were turned off [34, 35].

3. Results and Discussion

For all three schemes of inert gas supply to the cargo tank, the dependence of the change in oxygen concentration on time during the inerting process was obtained. Measurements were carried out simultaneously at different heights in six cargo spaces.

The results of comparison with the standard technology are shown in Fig. 3. Due to the fact that during the experiments the main task was to choose the most effective inert gas supply scheme, *the duration of the gas analyzer operation was limited to a period of 5 hours.*

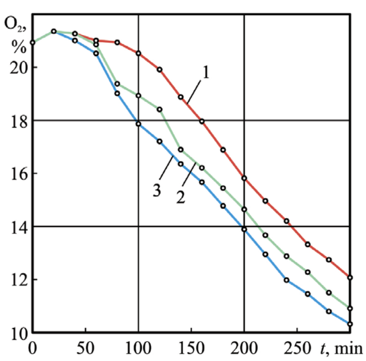

Fig. 3. Changes in oxygen concentration in the cargo hold of an oil tanker at different angles of the inert gas jet: 1 – 60° (standard scheme); 2 – 30°; 3 – 90°

As shown by the results shown in Fig. 3, the qualitative nature of the process of reducing the oxygen concentration inside the cargo hold in all four cases remained practically identical. This indicates that the influence of the angle of opening of the inert gas jet torch on the nature of the tank atmosphere replacement is not fundamental and that the process is influenced by the degree of stratification of the density of the multiphase flow of gases and air inside the cargo hold of the tanker. The results shown in Fig. 3 also indicate that the quality of the second technological scheme for supplying inert gas is better than the first scheme, but the greatest reduction in the time for inerting the cargo hold was achieved using the third technological scheme. Compared to the use of traditional inert gas supply, the changes for the better, all other things being equal, led to an additional decrease in oxygen concentration over the same period of inerting the cargo tank.

A comparison of the measurement results describing the entire process of changing the oxygen concentration in the cargo space of the tanker using the improved and standard inert gas supply technology is shown in Fig. 4.

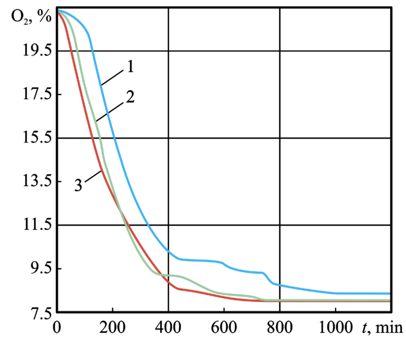

Fig. 4. Change in oxygen concentration in the cargo hold of an oil tanker with different inert gas supply: 1 – standard; 2 – improved; 3 – calculation

Fig. 4 also shows the data of theoretical calculations (solid line) of the inerting process of a cargo tank. The experimental data shown in Fig. 4 were obtained simultaneously when the inerting process of two identical cargo tanks was carried out. The gas supply was carried out according to the standard technological scheme (Fig. 1, *a*) and using the developed combined scheme (Fig. 1, *c*).

Analysis of the results shows that the use of improved inert gas supply led to a quantitative, but not qualitative, discrepancy in the changes in time of oxygen concentration inside the cargo hold. The obtained discrepancy between the two experimental curves indicates the achievement of the main aim of the research.

The use of an improved scheme for supplying inert gas to cargo tanks leads to the most important and basic result – a reduction in the time spent on inerting the cargo spaces of the tanker before cargo operations. The results shown in Fig. 4 demonstrate that at the beginning of the inerting process, the change in oxygen concentration occurs equally regardless of the method of supplying inert gas. A significant difference between the curves begins 80 min after the start of the inerting process of the cargo spaces. Depending on the method of inerting the tank, the final oxygen concentration inside its space differs – its value in the case of using the improved scheme becomes less than under the standard one. The steady-state value of the oxygen concentration in the cargo tank (equal to 8 %), in the case of improved inert gas supply, is observed approximately 740 min after the start of the inerting process of the cargo tanks. A similar concentration value under the condition of inerting according to the standard scheme is achieved over a longer period of time. Its steady-state value was observed approximately 1700 min after the start of the inerting process of the cargo spaces.

During the inerting process, the temperature inside the tanker's cargo space constantly increases. The process of temperature change T in time t along the height of the cargo tank H is shown in Fig. 5.

The given dependences correspond to four measuring points, which were located at different heights of the cargo tank: 0 (at the bottom of the tank), 0.25*H*, 0.5*H*, 1*H* (at the top of the tank).

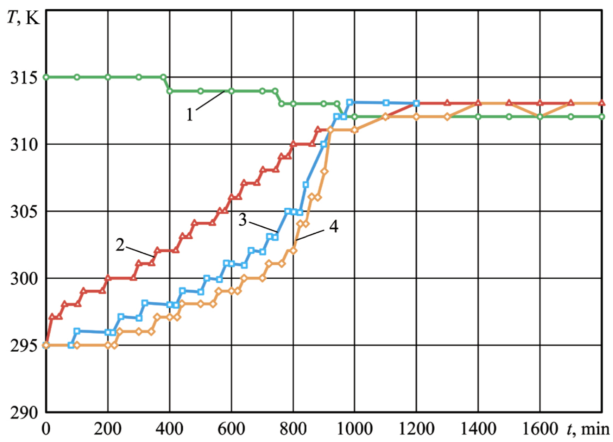

Fig. 5. Change in the temperature of the atmosphere of a cargo tank according to its height *H*: 1 – 0 (bottom); 2 – 0.25*H*; 3 – 0.5*H*; 4 – 1*H* (top)

By analogy with the process of changing the oxygen concentration inside the tank, stabilization of the temperature of the cargo space atmosphere is also observed. The results shown in Fig. 5 show that starting from a time equal to 960 min the temperature at all measuring levels ceases to change and acquires its stationary value.

When comparing the results of temperature measurements at the tank outlet according to the standard and improved inert gas supply schemes, it was found that temperature stabilization in the latter case also occurs earlier. The temperature gradient, which is –17 °C, in the case of using the improved inerting scheme was achieved in a time 38.2 % less, compared to the standard inerting scheme of the tanker's cargo spaces.

The technology of conducting research work was agreed with the department of technical operation and management of the shipping company that owns the vessel. All research was carried out in compliance with the requirements of MARPOL and SOLAS [36–38].

Further research should be aimed at developing methods for the technical implementation of the developed technology depending on the design of the tanker and the technical characteristics of the vessel's inert gas system.

Due to the identity of the technological implementation of the inerting systems of cargo spaces of oil tankers, the proposed improvements can be implemented on tankers of different tonnage. In addition, the use of the proposed solutions is possible on chemical tankers, as well as on vessels transporting liquefied petroleum and natural gases.

At the same time, the implementation of the proposed solutions may be limited by classification societies and charterers that supervise the transportation of cargo and the safety of transportation.

Reproduction of the improved technology of inerting cargo tanks is possible only during the dock repair of an oil tanker, which is due to the duration of its implementation and the need to carry out preliminary work on preparing the inert gas system. Also, during the practical use of the proposed technology, it is necessary to reconfigure the equipment that provides control and regulation of the inert gas generator performance, as well as measurement of the cargo tank atmosphere.

4. Conclusions

The paper shows that the currently used technology for inerting tanker cargo spaces is characterized by a long duration of this process. To solve this problem, it is proposed to improve the quality of the process of inerting tanker cargo spaces by using an improved supply of inert gas jets.

During inerting the tank, the supply of inert gas jets must be consistent with the structure of the air flow moving at low speeds inside the rigid walls of the cargo tank that limit it. For this purpose, a combined scheme for supplying inert gas to the cargo tank of the vessel was developed.

The proposed technology for supplying inert gas to the cargo tank provides an improvement in the process of inerting the oil tanker, which is reflected in the reduction of the time required for its implementation.

When using the proposed improved scheme for supplying inert gases to the cargo spaces of the vessel, the temperature inside the tank stabilizes earlier than when using the standard scheme. This is confirmed by the fact that the temperature gradient (which is –17 °C) was achieved in 38.2 % less time compared to the standard inerting scheme for the tanker's cargo spaces.

Conflict of interest

Authors declare that they have no conflict of interest in relation to this study, including financial, personal, authorship, or any other, that could affect the study and its results presented in this article.

Financing

The study was conducted without financial support.

Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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