INITIAL VERIFICATION OF AN APPLICATION FOR THE CALCULATION OF TECHNOLOGICAL PARAMETERS DURING PRODUCTION OF TRIMIX MIXTURE

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ABSTRACT

The paper presents the results of an engineering thesis carried out at the Department of Underwater Works Technology of the Naval Academy in Gdynia. The subject of the thesis was to improve calculations during the production of a trimix mixture based on a previously produced nitrox mixture. This was done by developing a dedicated computer application. The article describes the reasons for using artificial breathing mixes, an application developed as part of the thesis and the method of its initial verification along with the directions for further research activities.
Keywords: mechanical engineering, underwater works technology.

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INTRODUCTION

The safety of diving is inextricably linked with breathing compressed air. Providing the diver with breathing gas at a pressure corresponding to the current diving depth is the primary function of every underwater breathing equipment, regardless of its design. Man's natural breathing medium is air, which in the history of the Earth is its third atmosphere.

The most essential component of this atmosphere for man is oxygen, whose content per volume unit is 20.95%. [1]. The second component of the air in terms of its percentage share, in normobaric conditions inert for man, is nitrogen. Its content per volume unit is 78.09%. As a result, man's natural respiratory gas is in fact a mixture of nitrogen and oxygen, which contains other components in trace amounts: mainly argon (0.95%), then carbon dioxide (the value varies up to 0.03%), then hydrogen (0.01%) and trace amounts not exceeding in total 0.01% of helium, neon, krypton and xenon [1]. As the development of underwater technology shows, this natural breathing gas is not always and not in all conditions diver friendly.

In 1878, Paul Bert published the results of research related to breathing oxygen under conditions of increased and decreased pressure. One of his conclusions was that oxygen under increased pressure had a toxic effect on the central nervous system, which was manifested, among others, by the occurrence of convulsions [2]. Two decades later, another researcher identified a different form of oxygen toxicity. Lorrian Smith found severe pneumonia in a rat after four days of exposure to 73% oxygen [3]. Thus, the end of the 19th century yields two discoveries related to two forms of oxygen toxicity: the Bert effect related to the pressure of an oxygen exposure and the Smith effect, related to prolonged oxygen exposure. This is where the phenomenon appears, which Krzyżak describes as "an unusual paradox" – the gas, which is essential for life and in fact prevents death, is characterized by very significant toxicity at adequately high pressure and long exposure time [3]. On the other hand, the beginning of the 20th century brings new discoveries related to nitrogen effects, although the first reports on this phenomenon were made as early as 1835 by Junod, who, however, failed to interpret them properly [2].

In 1927 Damant observed in divers breathing air under pressure 7 ata serious personality changes, impaired memory resembling symptoms of alcohol intoxication, emotional disturbances and difficulties in following instructions [3]. However, Damant mistakenly indicated increased partial pressure of oxygen as their cause. It was not until 1935 that Albert Behnke undertook research as a result of which he stated that already from the depth of 20 metres divers breathing air may develop mental disorders characterised primarily by a state of euphoria and a slowdown in thinking processes and impaired neuromuscular coordination. As a cause, this time correctly, an increase in the partial pressure of nitrogen was indicated [3].

Thus, over the course of less than 60 years at the turn of the 20th century, researchers defined air as a gas that could be dangerous for divers. This eliminated air from deep diving and created the need for artificial breathing mixtures. The principle in this case is simple, the deeper we want to dive and the longer we want to stay at a given depth, the more gas with a lower oxygen and nitrogen content must be used for breathing. An additional condition is the necessity to use a gas with a lower density than air. As a result, a number of different artificially produced breathing mixes have been developed for diving. Of course, each of them also carries risks for the diver's body, for instance at great depths, in the form of high-pressure nervous syndrome [3]. The relationship between exposure pressure and the type of breathing mixturesused and the effects on the diver's body were given by A. Majchrzycka in her work [4], as shown in Fig. 1.

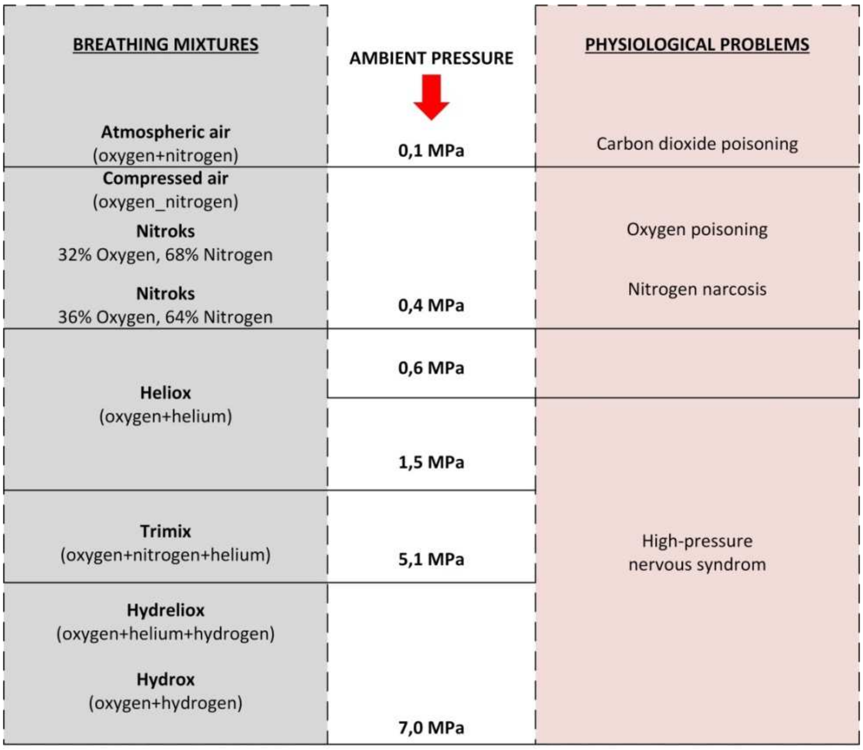

Fig. 1 Relationship between pressure, type of breathing medium used and the effects on the diver's body, based on [4].

In general, the choice of a particular type of breathing mixture for the execution of a dive depends on the following factors [5]:

- the metabolic demand of oxygen and the harmful effects on the diver's body of its excess or deficiency,
- degree of toxic effects of the other components of the mixture,
- effect of compressed gases on the human central nervous system,
- effect of gas viscosity and increased density on breathing resistance,
- degree of distortion of the voice spectrum in an atmosphere containing compressed light gases,
- thermal properties of gases,
- decompression conditions depending on solubility of gases in blood and tissue fluids,
- degree of fire hazard,
- cost and availability of components of the breathing mixture.

The most economical breathing mixes in the depth range above 50 m are nitrogen-helium-oxygen (trimix) and helium-oxygen (heliox) mixtures [6]. Of the above-mentioned artificial breathing mixes, the most technologically complex is the trimix, a three-component mixture. It can be produced using three methods. Method A (Fig. 2) consists in mixing pure component gases. Methods B and C comprise the production of trimix based on previously produced nitrox. In the first variant (B) nitrox is produced from pure gases and in the second (C) nitrox is produced from air and oxygen. The calculation methodology used when determining the individual technological pressures used during gas production by the pressure method is widely described in the literature, e.g. in the references: [5,6,7,8,9,10,11].

Although the calculations are not complicated, they can be tedious. For these reasons, within the framework of the engineering diploma thesis carried out at the Department of Underwater Works Technology of the Naval Academy in Gdynia, a task was implemented, which included streamlining of the calculation process. For this purpose, a special application was designed, which in a simple and clear way allows the user to calculate the data necessary for the production of a trimix mixture. The thesis was successfully defended in the spring of 2021.

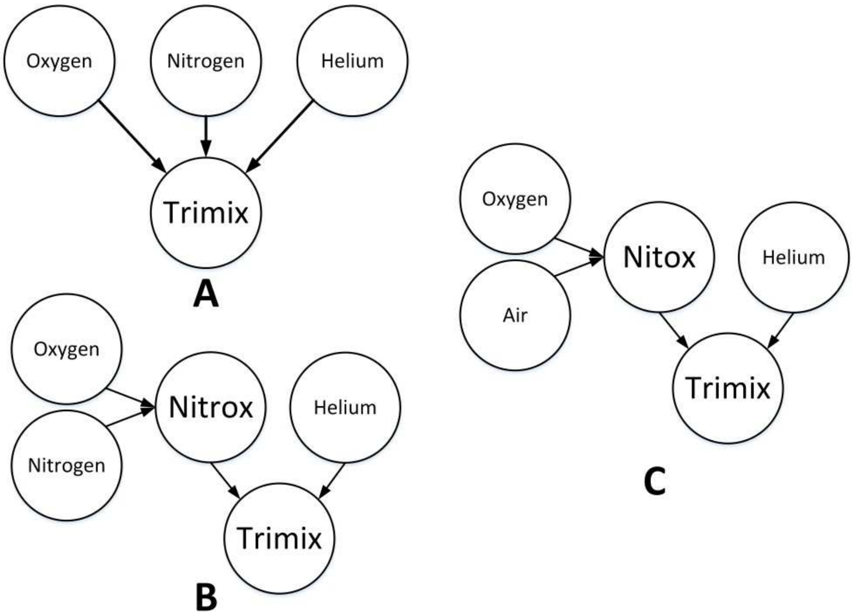

Fig. 2 Methods of producing a three-component mixture (discussion in the text).

APPLICATION FOR THE CALCULATION OF TECHNOLOGICAL PARAMETERS DURING PRODUCTION OF A TRIMIX MIXTURE

The application developed for calculating technological parameters during production of a trimix mixture is dedicated to gas production from a previously produced nitrox mixture. The "Input Data" section (Fig. 3) requires the user to enter the composition of the expected breathing mixture. The user then enters data on the parameters of the mixing vessel in which the mixture will be produced.

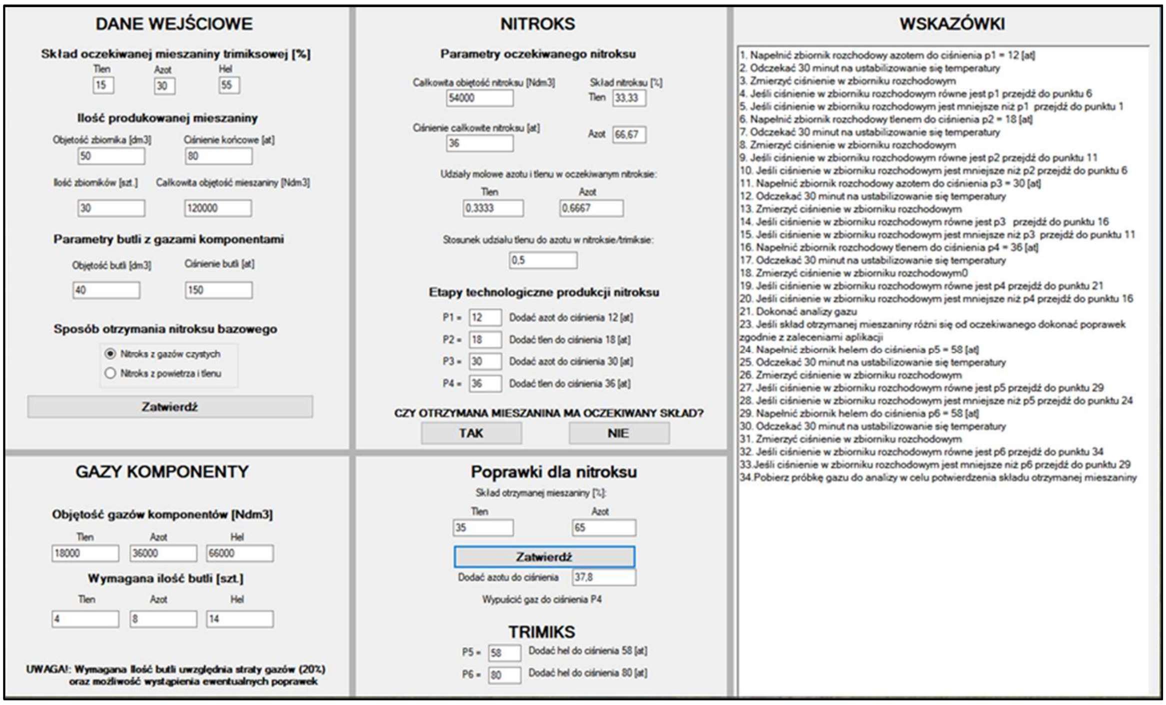

Fig. 3 Dialogue window of the application for calculation of technological parameters [7].

In addition, the user is required to enter information regarding the amount of mixture to be produced by specifying the number of cylinders, their volume and the final pressure in the production vessel. He then specifies the parameters of the component gas tanks for the production of the mixture and defines whether the expected mixture will be produced from nitrox made from pure gases, i.e. oxygen and nitrogen, or from air and oxygen. After pressing the 'Approve' button, the software calculates the quantity of component gases needed to produce the defined mixture volume and indicates the number of standard component gas cylinders to be reserved for its production. At this point, the application takes into account the losses of component gases to the dead spaces of the vessels and transfer lines, as well as a reserve for possible technological adjustments.

The next section independently calculates the composition and method of production of the base nitrox, listing information on the stages of filling the container with the necessary mixture components. After performing subsequent technological steps and checking the composition of the produced mixture, the user can obtain information on how to make corrections. Once the nitrox composition has been approved, the programme lists the technological pressures connected with related to the addition of helium, thus obtaining the produced trimix mixture. The addition of helium has been deliberately divided into two stages, which reduces the amount of gas added at a time to the reservoir, which has a direct effect on reducing the temperature variation (Joule-Thomson effect) during the individual stages of production and, consequently, allows the final pressure to reach a value closer to that expected.

The last part of the application's dialogue box lists a detailed list of subsequent technological steps depending on the way the trimix mixture is produced, from nitrox produced from pure gases or from air and oxygen.

INITIAL VERIFICATION OF THE APPLICATION FOR THE CALCULATION OF TECHNOLOGICAL PARAMETERS DURING PRODUCTION OF THE TRIMIX MIXTURE

Initial verification of the application was conducted in two stages. In the first stage, the application was validated by a group of testers with knowledge and diverse experience in the calculations necessary for the mixture production process and the methodology for producing breathing mixtures used diving. The testers then submitted their comments on the user interface, the clarity of the application and the possible need for improvements to make the application easier to use. This stage consisted primarily of verifying the functionalities of the application related to the way it communicates with the user.

In the second stage, also using testers, the correctness of the calculations performed by the programme was verified. Testers were given ten test tasks, of which five concerned the production of trimix based on nitrox produced from pure gases, and five from nitrox produced from air and oxygen. Naturally, the tasks had been calculated in advance using a different method, and the outcome of the test depended on the agreement between the calculations made using the application and the expected results calculated using a different method. One additional task was planned, which involved entering incorrect data into the application and verifying that the programme recognised this situation by returning an appropriate message to the user.

RESULTS OF THE INITIAL VERIFICATION

As a consequence of the first verification stage, it was possible to significantly improve the application's operation and add many useful functions. The first change introduced as a result of the tests was the addition to the panel concerning the quantity of the produced mixture of the possibility of calculating the production of the mixture in any number of output cylinders and not only in one, as it was designed in the initial version of the programme. The next addition was the window responsible for calculating the total volume of the mixture in normal conditions, which is the product of the number of cylinders, the volume of cylinders and the final pressure to which the expected mixture is to be produced. Another functionality added was the extension of the panel concerning the required quantity of component gases with the possibility of selecting the parameters of the component gas cylinders we intend to use in the production of the mixture. A further added feature in this panel was the calculation of the number of cylinders required to produce the expected mixture based on the calculations of the required quantities of component gases and the parameters of the component gas containers. Another change was the introduction of the possibility to make corrections based on measuring the amount of oxygen after the production of nitrox and the occurrence of deviations in the percentage composition of the resulting mixture from the expected nitrox.

As a result of the second stage of the initial verification, it was found that the results obtained both from the calculations performed in the traditional way and with the use of the verified programme were the same, which means that the application was developed correctly and the results of its calculations are consistent with the methodology of calculations during the production of the three-component mixture. Full verification and confirmation of this test result requires the use of the developed application in the actual production of the breathing mixture. In the case of incorrect input data, the application prevents the calculation from being carried out and gives an appropriate notice to enter the correct input data.

The tests carried out allow us to conclude that the developed application may be a useful tool when calculating and defining particular technological steps during the production of a three-component mixture on the basis of a two-component mixture produced earlier using the pressure method. In the analysed case, calculations concerned the production of trimix on the basis of previously produced nitrox from pure gases or from air and oxygen. Initial verification of the programme demonstrated its functionality and the correctness of calculations made with it. Further verification of the application requires conducting a wide range of experiments with the use of the software tested during actual production of breathing gas, which will allow full verification of the utility of the programme.

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