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Breathing Gas Quality and Monitoring in Dive Centres of the Maltese Islands

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Abstract

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This study aimed to examine the current practices of filling, blending, and storing SCUBA breathing gases by diving centres across the Maltese Islands. The research objectives were to determine the state of compliance with local breathing gas standards, understand the gas monitoring practices in diving centres, and identify areas for improvement in gas filling procedures and quality monitoring.

A mixed-methods approach was adopted, involving a structured questionnaire distributed to 42 dive centres, of which 78.6% participated. The questionnaire covered aspects such as equipment ownership, gas blending, quality monitoring, and awareness of regulatory requirements. Additionally, random air samples were collected and analysed to assess the quality of breathing gases.

The findings revealed that while most dive centres are engaged in gas filling and blending activities, there are opportunities for improvement in areas such as gas logging practices and testing frequencies. The study also highlighted a discrepancy between the dive centres' perceived and actual knowledge of relevant standards. Random air sample analysis identified a few instances of parameter exceedance, underscoring the need for more frequent testing and adherence to industry best practices.

The study provides valuable insights into the diving industry across the Maltese Islands, suggesting the need for enhanced awareness of local regulatory requirements, proactive measures to address gas quality issues, and a re-evaluation of air purity testing schedules. The recommendations include further research into equipment maintenance practices and gas blending techniques to continually improve safety standards and protect the well-being of divers.

Keywords
SCUBA, air, oxygen, helium, nitrox, trimix

Declaration of Authenticity

Student Name and Surname: Arthur Gauci

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Programme : BSc. Diving Safety Management

Research Title : Breathing Gas Quality and Monitoring in Dive Centres of the Maltese Islands

Declaration:

I hereby declare that this research study is based on the outcome of my own research. I, as the author, declare that this research study is my own composition which has not been previously produced for any other qualification.

The research study was conducted under the supervision of Guy Thomas.

Date

Student's Signature

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Contents

1. Introduction

1.1 Research Background

Self-Contained Underwater Breathing Apparatus, commonly known as the SCUBA unit, is used in recreational and technical diving. The SCUBA unit consists of a high-pressure compressed gas cylinder, filled with air or other breathable gas, and a valve to which the regulator is connected. The purpose of the regulator is to reduce the pressure of the gas in the cylinder to a breathable level. The regulator will typically have two stages. The first stage will reduce the gas pressure in the cylinder to a set level above ambient pressure, while the second stage will give air on demand hence, the second stage is also known as the demand valve. Attached to the first stage is a submersible pressure gauge that shows the pressure in the cylinder, a redundant demand valve or second stage, and inflator hoses, used for buoyancy compensators and dry suits.

Rebreathers are a different kind of underwater breathing apparatus which recycle exhaled air, enabling the user to breathe underwater for a longer time. They work by eliminating carbon dioxide from exhaled air and renewing the oxygen in the gas, which is breathed again. Thus, a rebreather would include a cylinder holding pure oxygen and another cylinder containing the breathing gas for the intended depth, known as diluent gas. The gas renewal is achieved through a process involving chemical scrubbers and gas mixers within the rebreather system. Subsequently, rebreathers also find use in activities like science diving, rescue operations, military tasks and other scenarios demanding extended periods of underwater breathing.

The advancement of diving techniques to extend the limits, has demanded the adoption of a wider range of breathing gases. This evolution has enabled divers to explore deeper depths and stay underwater for longer periods, enhancing the overall diving experience. The use of specialised breathing gases such as nitrox and trimix, has opened up new possibilities for divers to explore the underwater world effectively and minimise the risks. This shift in diving practices reflects the ongoing pursuit of innovation and improvement within the diving community (Heine, 2000).

As diving becomes more complex, ensuring the quality of SCUBA breathing gases supplied to divers, is increasingly important, as it has a direct effect on their health and safety. This has led to the development of standards for gas quality, which are typically outlined by international and European norms, and which include specifications for the levels of oxygen, carbon dioxide, carbon monoxide, oil, water vapour and other potential contaminants within the breathing gas. These standards are designed to mitigate safety concerns and short-term or long-term health risks, that the gas mixtures may pose to divers.

Furthermore, the integrity and maintenance of SCUBA cylinders become critical factors because they can impact the quality of the gas they hold. During this study, a review of the role that cylinders have in ensuring the purity of the breathing gas remains untainted, will be conducted. This examination will include an assessment of the standards applied in the maintenance, inspections, and tests required to keep the cylinders in service. The goal is to identify best practices for cylinder maintenance and handling, to ensure divers have access to safe, uncontaminated breathing gases.

Monitoring of gas quality in dive centres across the Maltese Islands involves audits conducted by Government-appointed bodies and industry self-regulation mechanisms. During inspections, documents are audited to ensure they meet regulatory standards. Additionally, dive centres are expected to conduct the required tests and maintain their gas production and storage equipment in optimal condition, to minimise contamination risks.

1.2 Research Aims, Objectives and Hypothesis or Questions

The use of breathing gases in diving operations is a critical component that directly impacts divers' safety. Adherence to established local standards and regulations for handling breathing gases is of the utmost importance. This research aims to examine the current practices of filling, blending and storing SCUBA breathing gases by diving centres across the Maltese Islands. By evaluating these practices against applicable local norms, this study seeks to not only ascertain the level of compliance but also to identify potential areas for procedural enhancements and quality control improvements.

Objective 1: Compliance with local breathing gas standards

The first objective of this research is to determine the state of compliance with local breathing gas standards and regulations. This encompasses a comprehensive review of the statutory framework governing the handling of breathing gases across the Maltese Islands. By conducting systematic audits and visits to various diving centres, this research will examine adherence levels to these standards during the filling and storage of SCUBA breathing gases. The outcome will offer insights into the current regulatory landscapes' effectiveness and the industry's commitment to maintaining these standards.

Objective 2: Gas Monitoring practices in diving centres

The second objective focuses on understanding the type and frequency of monitoring conducted concerning gas quality and filling procedures. This entails an in-depth investigation into the protocols that diving centres adopt to ensure the purity and safety of the breathing gases provided to divers. The frequency of these quality checks is crucial for maintaining consistent safety standards. The research will evaluate whether current monitoring practices are sufficient and in line with the best practices recommended by industry experts and regulatory bodies.

Objective 3: Improvements in gas filling procedures and quality monitoring

This study ultimately aims at identifying areas for improvement in the filling procedures and quality monitoring of breathing gases. By collating data from the objectives, the research will pinpoint deficiencies and recommend strategies for enhancement. This could involve suggesting technological upgrades, training programs for personnel, or modifications to existing protocols. The goal is to elevate the standard of safety for divers while ensuring that diving centres can feasibly implement these improvements.

In order to meet the objectives stated above, the central research questions were designed:

1. Do all dive centres perform compressed air fills and how many of these centres blend gases like, Nitrox, Trimix and Heliox
2. Awareness of local regulatory and standard quality requirements in air filling and gas blending.
3. Method of monitoring gas quality and records kept of gas filling and blending

This research is poised to offer a valuable contribution to the diving industry across the Maltese Islands, by ensuring that the handling of breathing gases meets or exceeds the required standards. Through a meticulous examination of current practices and a focus on continuous improvement, it is anticipated that this study will lead to heightened safety measures for both recreational and technical divers. The findings will also serve as a benchmark for regulatory bodies to refine policies and for diving centres to elevate their operational procedures, thereby fostering a culture of excellence within the Maltese Islands diving community.

1.3 Research Methods, Material and Structure

The proposed study will adopt a mixed methods research design, incorporating both qualitative and quantitative elements to comprehensively address the research objectives. The initial phase of the investigation will involve administering a structured questionnaire to dive centres within the Maltese Islands. This questionnaire aims to clarify the specifics of gas-filling practices. These include the types of gases dispensed, equipment maintenance, awareness and adherence to applicable regulations, and the standard operating procedures employed during the gas-filling process. Meetings or calls will be conducted if necessary, with the respective gas blenders to resolve ambiguities arising from the data given or to gain factual insights into their operational protocols. In furtherance of data validation, the study includes a component of random air samples that will be evaluated at consenting dive centres that are participating in the study. This step is designed to corroborate the questionnaire findings, providing a robust empirical basis for the study's conclusions.

The target population for this research comprises of dive centres that are affiliated with the Professional Dive School Association (PDSA) and other dive centres located across the Maltese Islands. The PDSA's current membership at the time of this study included 42 dive centres, all of which were invited to participate in the study (PDSA, 2017). By engaging with these members, the research aims to capture a representative understanding of gas-filling practices within the community of diving professionals. The findings are expected to contribute valuable insights into the operational standards and safety protocols employed by these entities, potentially informing future regulatory measures and industry guidelines.

2. Literature Review

The Maltese Islands are highly regarded for their pristine waters and the splendid legacy found beneath the waves, enticing divers around the world with their unique offerings. While the abundance of sea life captivates many, the quest to visit ever-deeper shipwrecks is entrancing (VisitMalta, 2021). Diving across the Maltese islands is popular with locals and visitors keen to explore and enjoy the islands underwater attractions. With the safety of each diver a priority the quality of the gas breathed is of the utmost importance, in ensuring the health and safety of divers.

This review is a crucial element of a dissertation aimed at examining and scrutinising the existing methods and standard procedures of monitoring and maintaining breathing gas quality within diving facilities across the Maltese Islands. It merges the findings from diverse scholarly articles, technical documentation, and protocol from the diving industry to deliver comprehensive insight into the European norms (EN) standards and the various challenges encountered in securing high-quality breathing gas. It also delves into the progress made in technology and the legislative measures that oversee this essential facet of diving safety. By integrating information from systematic studies and seasoned professionals, the goal of this review is to pinpoint shortcomings in the current system and propose enhancements. These would serve to enrich the diving experiences while reinforcing diver safety, thus fostering the dive sector's enduring development across the Maltese Islands.

2.1 Scuba Air Quality: How do we analyse the air we are breathing?

In a two-part article, Mr. Francios Burman, explains the importance of air testing and the reasoning behind established contaminant thresholds given in most recognised air quality standards. He starts by explaining that, in SCUBA diving, ensuring the purity of breathing gas is paramount for both health and safety. Analytical methods to test for contaminants in SCUBA cylinders vary from basic field-testing devices to advanced laboratory equipment. Field testing, which is sufficient for operational monitoring, includes single-use detector tubes and electronic sensors that can detect carbon dioxide (CO_2), carbon monoxide (CO), water vapour and oil vapour content. While most contaminants can be field-tested, oil vapour content is typically measured in laboratories through gravimetric or spectroscopic techniques due to the complexity of its’ detection in the field. Detector tubes or equivalent methods for oil content, offer a simple pass/fail result or discrete values such as 0.1, 0.5, or 1.0 mg/m^3, aiding in swift assessments.

Frequent testing is encouraged as it is crucial in maintaining compressor and filter efficiency and preventing environmental pollutants from compromising the air supply. However, in cases requiring high accuracy, such as forensic or accident investigations, sophisticated laboratory analyses are used.

It is important to be familiar with additional potential toxic substances that could contaminate SCUBA cylinders during filling, including environmental hazards from various sources. The safe limits for contaminants like oil, methane (CH_4), and moisture (H_2O) are not only health-related but also consider the risks of fire and damage to equipment.

In conclusion, while none of the testing methods is inexpensive, the trade-off between convenience, cost and accuracy must be carefully balanced against the imperatives of health and safety. Diving operators must carefully select the appropriate testing method and frequency to ensure the air quality meets the established safe limits for a secure diving experience (Burman, 2013).

2.1.1 Scuba Air Quality: What Do the Limits Really Mean?

The knowledge base regarding air quality has been historically shaped by the practices of commercial and military divers. These standards emerged from practical experience, aiming for achievable targets, and learning from incidents. Over the last five decades, medical research has sought to understand the effects of prevalent air contaminants on divers. Concurrently, occupational health and safety protocols, particularly Hazard Identification and Risk Assessment (HIRA), have been employed to address the risks posed by toxic substances entering divers' breathing apparatus (Burman, 2013).

Carbon dioxide (CO2) is a ubiquitous gas, commonly found in the atmosphere as well as being produced by various processes including combustion in vehicles and cooking, respiration in animals and humans, microbial decomposition of organic materials, and during the conversion of carbon monoxide (CO) to CO2 in compressor filters. While CO2 is non-toxic, exposure to elevated levels can have significant effects on human health. It acts as a respiratory stimulant, causing an increase in breathing rate and depth. This can pose a risk, particularly in patients with high arterial oxygen tension (PaO2), who may experience oxygen-induced seizures if PaCO2 levels rise. Symptoms of CO2 exposure range from minor perceptual changes and discomfort to dizziness, stupor, and in extreme cases, unconsciousness, or death. Despite its potential health risks, CO2 does not pose a threat in terms of fire safety and is not a concern for equipment operation. It is crucial to monitor and manage CO2 concentrations in environments where humans are present to ensure safety and prevent adverse health effects.

Carbon monoxide (CO) is a colourless and odourless gas commonly found in the environment and is a byproduct of various combustion processes including those occurring in internal combustion engines, furnaces and gas burners. It is also present in cigarette smoke and can be produced by overheated compressor oils. In terms of human safety, CO is particularly dangerous as it binds to haemoglobin with a greater affinity than oxygen, significantly reducing the bloods' oxygen-carrying capacity. This can lead to tissue hypoxia, a condition where the body is deprived of adequate oxygen supply and can be fatal at high concentrations or prolonged exposure. Moreover, the toxicity of CO is exacerbated under increased chamber pressure, which can magnify its environmental levels. Despite its severe impact on human health, CO does not pose direct concerns for fire safety or equipment as it does not contribute to flammability or equipment deterioration under normal conditions. It is crucial to maintain vigilant monitoring and control of CO levels in environments where it may accumulate to ensure safety and health standards are upheld.

Moisture, or H2O, is present in various environments and processes, including ambient air, laundry drying and combustion. Some moisture in breathing air is beneficial for human comfort and helps prevent dehydration. High moisture levels in breathing gas, can compromise equipment such as regulators which are susceptible to malfunction due to freezing when excessive moisture undergoes adiabatic cooling during pressure reduction. This can lead to over-pressurization and potential damage to downstream piping and equipment. Moreover, high moisture levels accelerate corrosion and oxidation in air storage vessels and diminish the efficiency of filtration systems by saturating elements and chemicals, causing increased pressure drops. Managing moisture levels is therefore essential for ensuring human safety and maintaining the integrity and performance of equipment.

Condensed oil primarily originates from compressor lubrication processes but can also enter the system through external sources such as motor vehicle emissions entering via the compressor intake and contamination in air pipes. It is crucial for human safety to consider that while the body can eliminate larger oil particles, smaller ones may persist in the respiratory system, potentially causing inflammation or damage to the alveoli depending on their nature and concentration. From a fire safety perspective, condensed oils pose a significant risk regardless of their type. However, when it comes to equipment functionality, standard controls maintain oil levels well below the threshold of concern. The maximum permissible concentration is 5 mg/m^3 or 6 ppm, maintaining these levels ensures both human and equipment safety and mitigates fire hazards.

Volatile hydrocarbons and volatile organic compounds (VOCs) such as toluene, xylene, benzene, ethane, styrene and acetone pose significant health and safety risks. These contaminants are often present in the ambient environment due to their widespread use in building materials, plastics, industrial chemicals, and cleaning products, as well as from emissions related to heating and combustion. Overheating compressors have also been identified as a potential source of VOCs. Exposure to these substances can lead to serious health issues including carcinogenic effects, neurological impairment, narcotic symptoms, damage to internal organs and general distress. Early signs of exposure may manifest as fatigue, headaches, confusion, numbness, cardiac irritation and depression. Additionally, these compounds present considerable fire safety hazards due to their low ignition temperatures and flashpoints. However, at the expected levels of exposure in typical environments and breathing gases in SCUBA cylinders, there is no significant concern regarding damage to equipment. The presence of VOCs does not directly indicate condensed oil but does indicate the presence of the gases that oil mist emits, hence the importance of monitoring and managing the presence of these contaminants which will also ensure human safety and mitigate fire risks.

Particles in the ambient environment, such as micro-particles of dust and pollens, along with breakdown products from compressors, piping systems, and filtration media, can compromise human and fire safety, as well as damage equipment. Post-construction debris in pipes also contributes to these risks. Particles under 10 μm are particularly hazardous to human health, potentially causing shortness of breath and exacerbating conditions like asthma and bronchitis. Additionally, they may lower the body's resistance to infections. From a fire safety perspective, high concentrations of particulates can function as fuel for ignition, posing a serious threat. In terms of equipment, larger particles can lead to malfunctions in pressure regulators by preventing valves from sealing properly and causing erosion to valve seats, discs and seals. It is essential to monitor and control particulate levels to ensure the safety and proper functioning of systems and protect human health.

Odours in the ambient environment, particularly those stemming from cleaning agents used on air supply systems, are considered a matter of comfort rather than safety. However, it is important to note that when odours are associated with volatile, toxic, or otherwise harmful substances, they may signal potential health risks. In such cases, the presence of these odours necessitates immediate attention to identify and mitigate the source of the contaminants to ensure human safety. With regards to fire safety, odours themselves do not typically pose a direct risk. Nonetheless, any contaminants that have inherent fire risks, such as oils or volatile organic compounds (VOCs), should be evaluated and addressed as detailed in their respective sections. As for equipment, odours do not present any concerns. It is crucial to maintain vigilance in monitoring odour sources as part of an overall strategy to safeguard human health (Burman, 2013).

2.2 European Norm (EN) standards

SCUBA diving necessitates the use of high-quality breathing air to ensure the safety and well-being of divers. The importance of adhering to stringent standards for SCUBA breathing air cannot be overstated, as the underwater environment poses unique challenges and risks to human physiology. For this purpose, European Norm (EN) standards have been developed to regulate the quality of breathing air used in underwater diving and other activities. These standards are critical in providing guidelines for the acceptable levels of contaminants, moisture, and oxygen content, ensuring that divers are supplied with air that is both safe and conducive to the physiological demands of diving.

2.2.1 EN 12021:2014

This standard has been prepared by Technical Committee CEN/TC 79 and outlines specifications for respiratory protective devices. This standard, which supersedes EN 12021:1998, has been adopted as a national standard by member countries and is to replace any conflicting national standards by October 2014. It has been developed under the mandate of the European Commission and the European Free Trade Association to align with essential requirements of relevant EU Directives. The standard specifies the requirements for breathing air used in SCUBA diving. It includes limits for contaminants such as carbon monoxide, carbon dioxide, oil, water vapour and other impurities. The standard also outlines the procedures for testing and monitoring the quality of breathing air and the maintenance of equipment used to produce and store breathing gases. In this standard there is stated, the quality requirements of compressed gas for mixing or to be used in respiratory protective devices, hyperbaric and hypobaric operations. The application of compressed gases to normal atmospheric pressure, as well as to hyperbaric and hypobaric pressures, is discussed. This EN Standard is not intended for compressed gases used in aerospace or medical applications.

Breathing gases for SCUBA diving, fall under this standard and are subject to these stringent quality and safety specifications to ensure the well-being of divers. The standard sets the permissible composition of the breathing gas, including the proportion of oxygen and other gases. They also set maximum thresholds for potential contaminants such as carbon monoxide, carbon dioxide, oil, and water vapour to minimise health risks.

Below is an extract from chapter 6.2 in SM EN 12021:2014. Table 1 gives us the acceptable value levels for the components listed in the first column whilst Table 2 states the water content limits. These would be the variables measured in a typical air test for breathing air.

Table 1 — Composition of breathing air

Component	Concentration at 1 013 mbar and 20 °C
Oxygen	(21 ± 1) %
Carbon dioxide	≤ 500 ml m^{-3} (ppm)
Carbon monoxide	≤ 5 ml m^{-3} (ppm)
Oil	≤ 0,5 mg m^{-3}

Compressed breathing air shall have a dew point sufficiently low to prevent condensation and freezing. Where the apparatus is used and stored at a known temperature the pressure dew point shall be at least 5 °C below the likely lowest temperature.

Where the conditions of usage and storage of any compressed air supply is not known the pressure dew point shall not exceed −11 °C.

Table 2 — Water content of high pressure breathing air

Nominal maximum supply pressure bar	**Maximum water content of air at atmospheric pressure and 20 °C** mg m^{-3}
40 to 200	≤ 50
> 200	≤ 35

The water content of the air supplied by the compressor for filling 200 bar or 300 bar cylinders should not exceed 25 mg m^{-3}.

(CEN, 2014)

List of tables

The standard includes comparable tables for the different gases and impurities in addition to the previously shown Tables 1 and 2. The tables in the standard are stated as follows:

Table 3 — Water content for supplied breathing air up to 40 bars.

Table 4 — Composition of oxygen-compatible air

Table 5 — Composition of nitrogen-depleted air and oxygen-enriched air

Table 6 — Composition of breathing oxygen

Table 7 — Composition of oxygen and nitrogen gas mixtures

Table 8 — Composition of oxygen and helium gas mixtures

Table 9 — Composition of oxygen, helium, and nitrogen gas mixtures

Table 10 — Composition of helium

Section 6.3.1 of the standard specifies that when mixing gases from Table 4 to Table 10, the resulting mixture must be evaluated for oxygen content to ensure compliance with the relevant values. Similarly, when blending gases from Table 8 or Table 9 for diving breathing gases, the mixture must be evaluated for helium content. Only the ratios of mixing need to be confirmed post-mixing, focusing on oxygen and, if applicable, helium content. This ensures the correct gas mixture is achieved.

Section 6.3.2 of the standard presents Table 4, which outlines the specifications for oxygen-compatible air, required for the blending of breathing gases for SCUBA diving. When reviewing the Table 4, it becomes evident that the primary distinction between standard breathing air and oxygen-compatible air, lies in the more rigorous standards for water content and oil permissible levels. These stringent requirements are essential to ensure the safety of those involved in blending, the divers breathing the gas and the functionality of breathing apparatus. It is imperative for those involved in the preparation and maintenance of SCUBA equipment, to be acquainted with these specifications to prevent equipment failure and to safeguard their well-being and the divers breathing the gas.

Table 4 — Composition of oxygen compatible air

Component	Concentration at 1 013 mbar and 20 °C
Oxygen	(21 ± 1) %
Water	≤ 25 mg m^{-3}
Carbon dioxide	≤ 500 ml m^{-3} (ppm)
Carbon monoxide	≤ 5 ml m^{-3} (ppm)
Oil	≤ 0,1 mg m^{-3}

(CEN, 2014)

The standard sets specific criteria for various gas compositions used in diving applications, amongst others. It also outlines the parameters for nitrogen-depleted air and oxygen-enriched air. Additionally, the standard specifies the quality and purity requirements for breathing oxygen, ensuring that it meets the safety standards necessary for human consumption. The document also addresses the composition and purity levels for both oxygen and nitrogen gas mixtures as well as oxygen and helium gas mixtures. Furthermore, it encompasses the standards for complex mixtures involving oxygen, helium, and nitrogen, which are used for technical diving. The standard includes guidelines on the permissible levels of contaminants in helium and the detection of odours that may indicate contamination or impurities in the gases. The standard also lists the designations for the various breathing gases, to facilitate clear communication. The quality specifications and prescribed methods for evaluating these gases are also listed. However, the standard fails to set frequencies for air purity testing on breathing air compressors.

2.2.2 EN ISO 18119:2018+AM1:2021

SCUBA cylinders are a fundamental piece of diving equipment, serving as the lifeline for divers by storing the breathing gases. The integrity and performance of these cylinders is non-negotiable due to the potentially hazardous extreme pressures they contain. Over the years, SCUBA cylinders have been subject to various international standards aimed at regulating their testing and inspection. One of the most recent and comprehensive standards is EN ISO 18119:2018+ AM1:2021, which outlines the testing and inspection of SCUBA cylinders.

Testing and inspection are critical components in the lifecycle of a SCUBA cylinder. The introduction of this standard brought about a unified approach to the testing and inspection of scuba cylinders. Periodic hydrostatic testing, visual inspections, and non-destructive testing are common practices to ensure the structural integrity of the cylinders over time. Researchers have emphasised the importance of regular inspections to detect signs of wear, corrosion or damage that could compromise contained gas quality and safety.

The standard sets forth rigorous testing methods for SCUBA cylinders, including pressure tests to verify the strength and elasticity of the material. It also provides guidelines for visual inspections and establishes criteria for rejecting or accepting cylinders based on their condition. Cleaning and drying procedures are also outlined to avoid compromising the purity of the gases they will contain. This standard has been instrumental in harmonizing testing procedures across different regions and enhancing global safety practices.

As shown in the following Annex A, which was extracted from EN ISO 18119:2018, where the testing periods for SCUBA cylinders are outlined, it is stated in note ‘c’ that annual inspections, with hydrostatic tests every five years, must be conducted unless a specific procedure, involving a report with a risk assessment is conducted. Such a procedure will allow a local authority, to change the test frequency, to conduct an inspection every two and a half years and a test every five years. In the case of the Maltese Islands, no such exercise was done therefore, locally the requirement is for annual visual inspections and a hydrostatic test every five years.

Annex A
(informative)

Periodic inspection and test periods

The information shown in Table A.1 includes intervals as outlined in the UN *Model Regulations*[23].

Table A.1 — Intervals for periodic inspections and tests

Gas type	Examples	UN recommended period years
Compressed gases	Ar, N_2, He, etc.	10[a]
	H_2[b]	10[a]
	Air, O_2	10[a]
	Self-contained breathing air, O_2, etc.	[c]
	Gases for underwater breathing apparatus	[c]
	CO[d]	5[e]
Liquefied gases	Refrigerants, CO_2	10[a]
Corrosive gases	[f]	5
Toxic/very toxic gases that are non-corrosive	Sulfuryl fluoride (SO_2F_2), Arsine (AsH_3), Phosphine (PH_3), etc.	5
Gas mixtures	All mixtures	5 years or 10 years according to dangerous properties. Generally toxic or corrosive mixtures have a 5-year interval while other mixtures have a 10-year interval.

These test periods may be used provided the dryness of the product and that of the filled cylinder are such that there is no freestanding water. This condition shall be proven and documented within a quality system of the filler. If this condition cannot be fulfilled, alternative or more frequent testing may be appropriate.

NOTE At all times, certain requirements can necessitate a shorter time interval, e.g. the dew point of the gas, polymerization reactions and decomposition reactions, cylinder design specifications, change of gas service, etc.

[a] Some transport regulations (e.g. ADR) allow the interval between periodic inspections and tests to be extended up to 15 years under specific conditions.

[b] Particular attention shall be paid to the tensile strength and surface condition of such cylinders. Cylinders not in conformance with the special hydrogen requirements shall be withdrawn from hydrogen service. See ISO 11621 for possible additional testing.

[c] Local regulations specify the interval of periodic inspection and testing. In the absence of any regulations, an annual internal inspection should be carried out with a periodic inspection carried out every five years. However, if a risk assessment and the specific use of a cylinder indicate that there is a low risk of internal degradation, then the interval for carrying out an internal examination may be increased to a maximum of 2,5 years.

[d] This product requires very dry gas. See ISO 11114-1.

[e] The interval between periodic inspections and tests may be extended to 10 years for seamless aluminium-alloy cylinders, when the alloy of the cylinder has been subjected to a stress corrosion test as specified in ISO 7866.

[f] Corrosiveness is with reference to human tissue (see ISO 13338) and NOT cylinder material as indicated in Annex C.

(CEN, 2018)

The safety implications of SCUBA cylinder failures are severe, ranging from personal injury to loss of life. The implementation of this standard aims to mitigate these risks by providing a framework for operators and users to maintain high safety levels. The standard's impact on safety is comprehensive, it assists filling stations, dive operators, and individual divers in understanding their responsibilities regarding cylinder handling and maintenance.

SCUBA cylinders are an essential component of diving equipment that must be manufactured and maintained with utmost precision and care. The literature review highlights the critical role that standards play in ensuring the safety and reliability of these cylinders. EN ISO 18119:2018+AM1:2021 represents a significant advancement in standardizing practices related to SCUBA cylinders. By setting clear guidelines for testing and inspection, this standard helps prevent accidents and enhances the overall safety of the diving community.

2.2.3 EN 144-1-2-3

To ensure the safety and interoperability of scuba diving equipment, standards such as the EN 144-1-2-3 were developed.

EN 144-1:2018 is a European Standard, part one of a series of 3, that specifies requirements for the design and performance of cylinder valves which are critical components for controlling the flow of breathing gas to the diver. This standard particularly addresses the thread of the valve which connects to the cylinder.

The standard outlines several key requirements for cylinder valves, including:

- Cylinder and valve interface threads namely 17E and 25E taper threads, M18x1,5 and M25x2 Parallel threads and the standards they should meet.
- The standard includes material strength requirements and testing procedures to verify the strength, durability, and performance of the valve under various conditions.
- Markings on the valve should include the standard requirements it meets, i.e. 144-1/2, manufacturer logo or name, the manufacture date, and the thread.
- On delivery, information supplied by the manufacturer shall point up where and how the valves are to be used.

(CEN, 2018)

The standard EN 144-2:2018 specifies essential criteria for outlet connections, for SCUBA cylinders it then refers to EN ISO 12209 Gas cylinders — Outlet connections for gas cylinder valves for compressed breathable air (CEN, 2018) (ISO, 2013). This standard is commonly known by divers as the regulator DIN fitting connection.

Furthermore, the standard EN 144-3:2003 describes the specifications for outlet connections used with diving gases, including Nitrox and oxygen. Per the 'Scope' section within the standard, it is a requirement that a valve be installed on cylinders if they contain more than 22% oxygen (CEN, 2003). This standard is commonly referred to as the M26 x 2 nitrox regulator fitting.

These standards play a vital role in ensuring the safety and reliability of SCUBA diving cylinder valves. By setting out clear requirements for design, materials, markings, and testing, the standard protects divers and supports manufacturers in producing high-quality products. For divers, using equipment that complies with EN 144 assures safety and quality. It also ensures compatibility with other equipment that meets European standards, making it easier to assemble a complete and reliable set of SCUBA gear.

2.3 Maltese recreational diving services regulations

The ‘SUBSIDIARY LEGISLATION 409.13 Recreational Diving Services Regulations of Malta’ establishes the licensing and requirements for service providers in the field of recreational SCUBA diving. These regulations apply to any individual or entity offering recreational diving services to the public and any person employed by them. The regulations define various terms related to diving, such as breathing gas, client, dive leader, dive site, diving equipment, diving instructor and more. They also outline the process for applying for a license, the qualifications required for directors of diving, diving instructors, and dive leaders, and the general safety and operational requirements for dive centres.

Article 2, Section 1 of the legislative text specifies the meanings of the terms ‘breathing gas’ as well as ‘diving equipment.’ The definition provided for diving equipment might encompass both a breathing air compressor and related apparatus that deliver breathing gases.

Article 12, Section 2 mandates that the holder of the license is responsible for the routine and meticulous upkeep of all the facilities, SCUBA gear and additional equipment, as well as any land or maritime transport vehicles, used for the provision of snorkelling and diving services to patrons. Moving forward to Section 3, it is imperative to maintain a methodically updated log of service for all apparatus and facilities, wherein each piece is itemised. This record must detail the maintenance operations performed in adherence to the guidelines set out by the equipment manufacturers.

Article 23, Section 2 explicitly requires that all dive gear must comply with both EU safety regulations and the specifications set out by the manufacturer. Additionally, Section 3 of that article calls for a systematic schedule to be in place for the upkeep of the diving apparatus (RECREATIONAL DIVING SERVICES REGULATIONS, 2012).

Although the legislation cites numerous EN standards, it only indirectly refers to EN 12021, the standard relevant to SCUBA divers' breathing gas. Furthermore, it mandates that maintenance plans should be developed and implemented in line with standards and manufacturer’s guidelines, but it does not stipulate a specific interval for evaluating the purity of air from compressors.

2.4 Breathing gas standards and the frequency of tests

The Health and Safety Executive (HSE) of the United Kingdom, in an article titled ‘Diver’s breathing gas standard and the frequency of examination and tests’ set the standard requirements for air quality and testing (HSE, 2018). As stated in the title the document specifies procedures and refers to the standard for a diver's breathing gas ensuring that it is free from harmful contaminants and meets specific compositional requirements. In This article a review of the HSE literature will be done, , focusing on the recommended frequency of examination and tests to uphold these vital safety measures.

The HSE standards for diver's breathing gas, are designed to minimise the risk of hyperbaric illnesses, oxygen toxicity, and other health hazards associated with breathing contaminated gas. The standards specify the permissible levels of oxygen, carbon dioxide, carbon monoxide, oil, and water vapour, among other potential contaminants. The composition of breathing gases must be carefully controlled and monitored to ensure that they fall within the safe limits established by the HSE.

To maintain compliance with HSE standards, regular examination and testing of breathing gases are required. The frequency of these tests is determined by several factors, including the type of diving operation, the equipment used, and the potential exposure to contaminants.

1. Pre-Use Checks: Before each diving operation, a pre-use check of the breathing gas supply system should be conducted. This includes a visual inspection of cylinders, regulators, and hoses for any signs of damage or wear.

2. Continuous Monitoring: During diving operations, continuous monitoring of the breathing gas is recommended to detect any deviations from the acceptable composition in real time. This often involves the use of electronic sensors and alarms that can alert dive supervisors to potential issues immediately.

3. Periodic Testing: In addition to continuous monitoring, periodic laboratory testing of gas samples is required. The HSE recommends that these tests be conducted at intervals not exceeding three months for diving operations where the quality of supplied gas could be affected by the method of supply or by contamination from the working environment.

4. Post-Dive Analysis: After certain high-risk or extended diving operations, a post-dive analysis of the breathing gas may be necessary to ensure that any contaminants did not exceed allowable limits during the dive.

5. Record Keeping: Detailed records of all examinations, tests, and any corrective actions taken must be maintained as part of the diving operation's safety documentation. These records are crucial for demonstrating compliance and for investigating any incidents that may occur (HSE, 2018).

The literature underscores the importance of adhering to standards for diver’s breathing gas to ensure diver safety. Regular examination and testing are essential components of a comprehensive safety program. By conducting pre-use checks, continuous monitoring during dives, periodic laboratory testing, and post-dive analysis, when necessary, dive operators can help protect divers from the risks associated with breathing contaminated gas. Maintaining detailed records also supports ongoing safety efforts and regulatory compliance.

3. Methodology

According to John W. Creswell, a prominent figure in the field of research methodology, research is defined as a process of steps used to collect and analyse information to increase our understanding of a topic or issue. It consists of three main components: a question, data collection, and data analysis. His definition encapsulates both qualitative and quantitative research methodologies, providing a structured framework that guides scholars through the conception, development and implementation of their research projects (John W. Creswell, 2018). In this research, a systematic approach will be undertaken which aims to enhance our grasp of breathing gas standards within the diving centres across the Maltese Islands.

Primary data refers to the specific information gathered directly for a particular study, utilizing the most appropriate methods for that research question. The collection of primary data enriches the current body of knowledge. Subsequently, this newly acquired information becomes available to other scholars, thus transforming it into secondary data for their use. This kind of data can be amassed through various approaches, including conducting experiments and quasi-experimental designs, distributing surveys, conducting interviews, and engaging in observation, among other techniques (Hox & Boeije, 2005). For this study, an online questionnaire was chosen as a tool to collect primary data. This allowed the research to reach a larger number of participants and evaluate their answers through a bigger sample which makes the results more accurate. Hox and Boeije explain how the use of structured questionnaires requires gathering a large quantity of variables from a big and respective sample of participants. This study is to assess the breathing gas standards and monitoring in the dive centres of the Maltese islands. Questionnaires were distributed to all the dive centres by the end of June 2023 and responses were gathered up to 10th March 2024.

3.1 Outline

The questionnaire consists of a set of questions related to breathing gas quality and monitoring, equipment and standards. A combination of open and closed-ended questions was employed. Predominantly, closed-ended questions served to maintain the relevance of the responses to the subject matter. These queries result in very restricted yet remarkably consistent answers, and though the data they yield is limited in scope, it is straightforward to assess and interpret. Nevertheless, to give the participants the freedom to express their opinions without the risk of the researcher's bias influencing the interpretation, a small number of open-ended questions were also included at the conclusion (Reja, et al., 2003).

The questionnaire, with the assistance of the PDSA, was disseminated to the respondents through an email. Within the questionnaire, the anonymity of the respondents was rigorously maintained. Throughout the study, the researcher maintained a high degree of professionalism. Moreover, before progressing to the questionnaire a consent form outlining the study's procedures was presented. In line with data protection guidelines, all the research data was securely disposed of after its contribution to the study was concluded. Copies of both the consent form given to participants and the questionnaire used can be found in Appendix 1 : Dissertation Survey Questionnaire,' which contains the full questionnaire as published.

Part of the data-gathering process involved testing random air samples from consenting participants, which were performed to assess the air quality and identify any potential contaminants. Primarily, the exercise was conducted in this manner to achieve an accurate depiction of the standard breathing gas supplied to SCUBA divers. The testing involved the use of scientifically validated sampling techniques and equipment to ensure that the results were accurate and dependable. The sampling process was conducted using a DE-OX test unit with serial number: 90102121. The certificate of conformity of this unit can be found in Appendix 2 : Air testing unit certificate of compliance.' The air testing process was conducted according to the procedures developed in consultation with the manufacturer of the testing unit, the steps followed for the air purity test are listed in Appendix 3 : Air purity test procedure.'

The initial response to the distributed questionnaire was insufficient, which needed a strategic adjustment to procure a significant sample size. This compelled a change in approach to a subsequent direct method which meant visiting dive centres in person and asking for their participation. This method ranged from making unscheduled appearances at their facilities to engaging with them during encounters. This direct strategy proved to be highly effective, as the dive centres showed commendable cooperation, with none declining to participate in the study.

The air sampling was conducted on a random sample from the cylinders filled and prepared for divers. While this provided insight into the air quality, more precise air purity tests, such as lab analysis, coupled with more extensive sampling in different periods, is beneficial to fully understand the air quality characteristics.

3.2 Research approach

Quantitatively, the study necessitates the rigorous analysis of breathing gases, equipment and monitoring methods used in the local dive centres. This entails precise measurements of potential contaminants and quality-related questions, to assess compliance with European standards. This data is critical for establishing a baseline understanding of gas quality across different dive centres. When assessing the questionnaire, it becomes clear that quantitative questions are crucial for achieving detailed data collection. These precise questions allow for the numerical representation of variables, which supports objective evaluation and comparison of responses. The questions asked were focused on the type of gas filling performed, gas quality monitoring regimes, together with equipment maintenance, since this contributes to the quality of the breathing gases. Unambiguous questions were presented to ensure the accuracy of the responses. Consideration was given to the response range to adequately reflect all possible feedback from the participants. Integrating quantitative questions judiciously can enhance the interpretative value of the survey findings (John W. Creswell, 2018).

Qualitative questions are essential in surveys for gathering detailed data that delves into participant perspectives and drivers. These questions foster open-ended conversations that bring to light intricate viewpoints and emotions, as opposed to quantitative questions that quantify data. Deriving significance from qualitative responses requires deciphering themes and developing patterns through a thoughtful analysis approach. They are an indispensable tool for a well-rounded survey interpretation, providing a depth of understanding beyond the reach of quantitative metrics alone (Reja, et al., 2003).

The mixed methods approach utilised in this study, provides insights into the human factors and perceptions, the dive centre expertise, and quality standards that are integral to the study which cannot be captured through numerical data alone. By integrating these methodologies, the research can offer a more comprehensive analysis that not only identifies potential gaps in gas quality and monitoring but also understands the contextual factors that contribute to these issues. This holistic perspective is essential for developing effective recommendations for policy and practice that are informed by both empirical evidence and practical realities within the dive industry across the Maltese Islands (McKim, 2017).

3.3 Data Analysis

A thorough data analysis strategy will be implemented to fully comprehend the breathing gas quality data from dive centres across the Maltese Islands. Descriptive statistics will outline the fundamental aspects of the sample data, deriving insights into the general trends and variability of the gas quality measures. By using visualisations and charts generated by Google Forms (Google, 2024), significant differences in breathing gas attributes among dive centres can be assessed for statistical substantiation. For the analysis of open-ended questionnaire components, content analysis will facilitate extracting prevalent themes, shedding light on the perceptions and outlooks concerning gas quality and control processes. Additionally, cross-tabulation will unearth potential links between the framework of dive operations and the breathing gas standards they maintain, potentially guiding additional scrutiny or directive implementations.

3.4 Ethical considerations

In the process of examining breathing gas quality and monitoring practices in dive centres across the Maltese Islands, it was important to consider a range of ethical considerations to ensure the integrity of the research and the safety and privacy of all participants. Firstly, informed consent was obtained from all dive centres involved in the study. This involved clearly explaining the purpose, methods, potential impacts, and any associated risks of the research to the participants before any data collection occurred. Fundamentally, the participation was voluntary, and the dive centres had a right to withdraw at any point, without repercussion.

Confidentiality is another significant concern. Data was handled with the utmost care to protect the identity and privacy of the individuals and organizations involved. Sensitive information regarding business practices was anonymised to prevent any potential harm or competitive disadvantage that could result from disclosure.

Furthermore, it was necessary to address any potential conflicts of interest and maintain transparency about affiliations or funding sources. The findings were reported honestly and without bias, regardless of whether they supported the initial hypothesis. The research also adheres to all local laws and regulations about the diving tourism industry.

Finally, considering the potential implications of the research on health and safety, it was essential to ensure that the dissemination of results does not lead to unwarranted alarm or misunderstanding. The goal is to contribute positively to the diving industry's standards and practices across the Maltese Islands, enhancing safety outcomes for recreational divers and professionals alike while upholding the highest ethical standards throughout the research process.

4. Results, Analysis and Discussion

The survey was divided into five sections. The first two sections included details of the dive centres and the consent form. The third section focused on equipment, such as compressors, cylinders and maintenance routines. This section aimed to answer the research question, 'Do all dive centres fill breathing gases?' The fourth section was about blending gases like Nitrox, Trimix, and Heliox. It aimed at finding out what percentage of dive centres blend gases. The final set of questions was about quality and monitoring, aimed at answering research questions about the 'Method of monitoring gas quality and records kept of gas filling and blending' and assess the 'Awareness of local regulatory and standard quality requirements in air filling and gas blending.'

In the survey, there were 33 questions in total. The first four questions were related to the details of the dive centre: dive centre name, contact name and e-mail and also included the consent form. However, for data protection purposes, this information will not be included in the preserved data.

Out of the 42 dive centres that were invited to participate in the survey, 33 responded. This indicates an elevated level of engagement within the industry. Unfortunately, a few dive centres were not available at the time of the survey, resulting in their inability to participate. Despite this, the overall response rate of 78.6% demonstrates the willingness of dive centres to contribute to this research initiative, which will increase the survey's validity and robustness. The findings of this study, will help to improve the quality of breathing gases, ultimately benefiting the local diving industry.

Augmenting and complementing the survey, a random air sample was collected from the respondents. The air sample will provide valuable data for analysing the quality of breathing gas provided by the local dive centres. Analysing the composition of the air sample, gives a better understanding of the quality of gas that divers are breathing during their activities. The results of this air sample analysis will provide valuable insights for both the dive centres and the diving community, ultimately contributing to a safer diving experience.

4.1 Do all dive centres fill breathing gases?

Figure 1 shows the data pertaining to the most direct survey question asked, relating to the first research question: ‘Do all dive centres fill breathing gases?’. This question was designed to provide an unambiguous quantification of the circumstances affecting this subject.

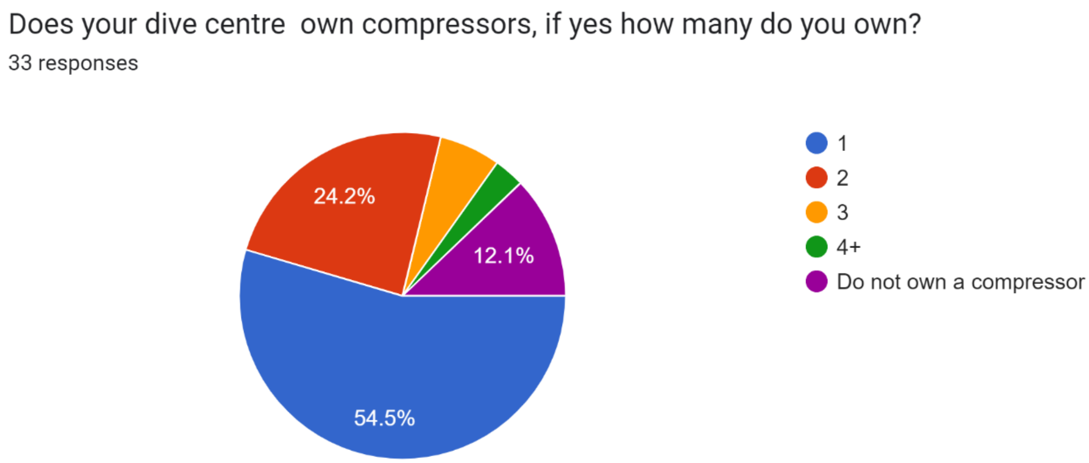

Figure 1. Breathing air compressor ownership

Four, dive centres amounting to 12.1% of the participants in the survey answered that they do not own a compressor and therefore do not have gas-filling facilities in their dive centres. It is worth noting that there is one dive centre that possesses a compressor but for reasons mentioned subsequently, does not make use of it. This data is supported by ensuing data presented in Figure 4, 5, 6 and 7 of this analysis.

The survey question in Figure 2 was asked to gain a deeper insight into breathing gas filling.

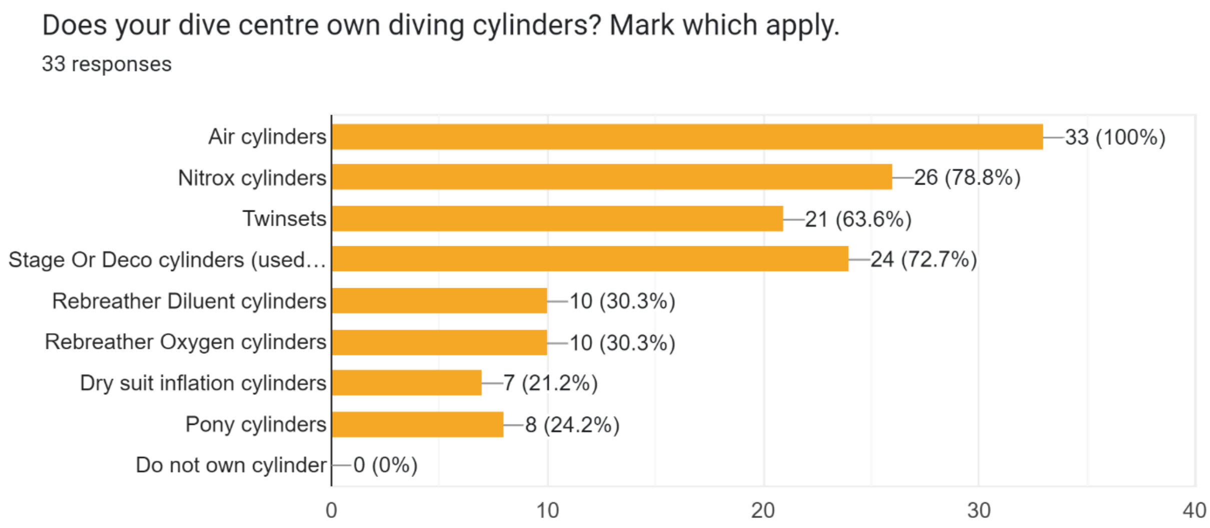

Figure 2. Cylinder ownership

All the survey participants stated that they own their diving cylinders. Therefore, the dive centres without gas filling facilities need to make other arrangements to fill their cylinders. Further enquiries revealed that these participants rely on fellow dive centres, with filling facilities, to meet their breathing gas-filling needs. The reasons given for the scope of such arrangements were, the prohibitive cost of running a compressor, stated by four respondents, whilst one of the participants stated that they were waiting for permits and equipment.

Such gas filling arrangements relieve the burden of gas filling facilities' operation, maintenance and gas quality monitoring that the dive centres use. However, it does not remove their responsibility towards their customers for the breathing gas quality provided (RECREATIONAL DIVING SERVICES REGULATIONS, 2012). The dive centres receiving such services should consider independently verifying the gas purity to ensure that the gas fills meet the necessary quality standards for the safety and satisfaction of its clients. Furthermore, this reliance on other centres for breathing gas filling may pose logistical challenges and potential delays for these dive centres. It is important for such dive centres to establish strong relationships with other centres to ensure that their cylinder filling needs are consistently met to the required quality standards.

Nevertheless, cylinder ownership places the burden of maintaining the cylinder on the dive centre that owns it. Responsibility for ensuring that the maintenance is carried out, will also be shared with the dive centre filling the gases, in cases where the filling facility dive centre is not the owner of the cylinders being filled (RECREATIONAL DIVING SERVICES REGULATIONS, 2012). Dive centres and all those involved in filling breathing gas cylinders must understand that proper maintenance of the cylinders is also crucial for ensuring the quality of the breathing gas and for maintaining general safety, particularly due to the high pressures involved. Carrying out the relevant tests and inspections on the cylinder contributes to the quality of the breathing gas it contains and the safety of staff and divers handling the cylinders.

The interval of cylinder inspections and tests is noted clearly in the EN standards and should not be misinterpreted. Consequently, all dive centres must be familiar with the applicable standard, Gas cylinders - Seamless steel and seamless aluminium-alloy gas cylinders and tubes - Periodic inspection and testing MSA EN ISO 18119:2018 (CEN, 2018). The significance of regular maintenance to ensure the safe and effective use of their cylinders, cannot be overstated since this also has an impact on the quality of the breathing gas.

Noteworthy in Figure 2, is the variety of uses of the cylinders owned. All the dive centres participating stated that they owned air cylinders, whilst 78.8 % declared owning oxygen-enriched air nitrox cylinders. Furthermore, 72.7% of the respondents also stated ownership of stage or deco cylinders which can also be used or considered as a nitrox cylinder. Figure 2 also shows that several dive centres use blended breathing gases along with air for their SCUBA diving needs, indicating the wide spread use of these gases.

4.1.1 Gas blending, dive centres blending gases like Nitrox, Trimix, and Heliox

The survey questions in Figure 3 and Figure 4 are about gas blending and intended to add detail to the first research question: 'Do all dive centres fill breathing gases?'.

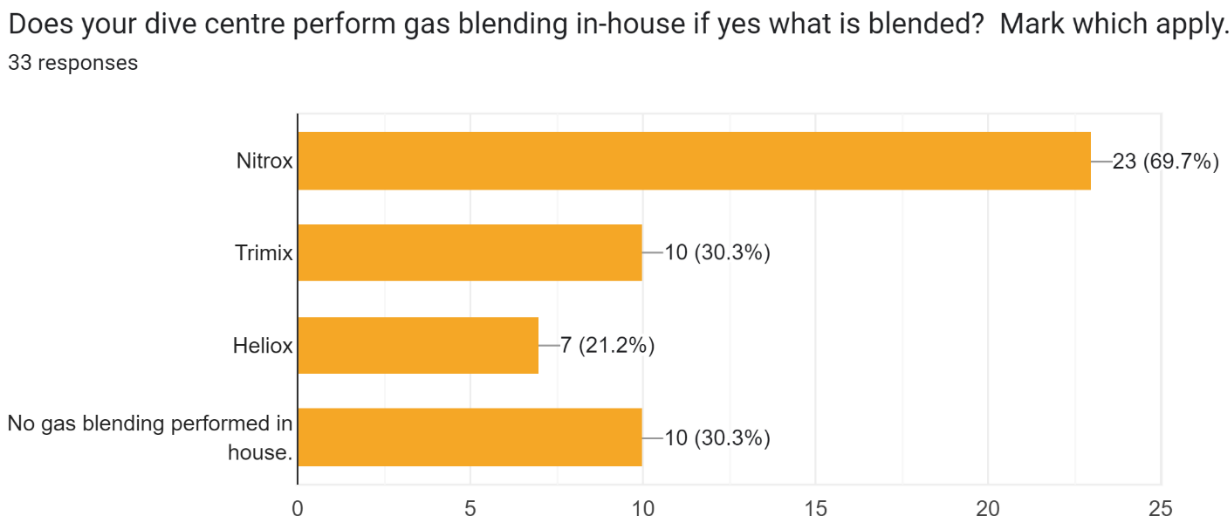

Figure 3. Gas blending facilities

Figure 3 shows that most dive centres filling compressed air breathing gas, also have the capability and equipment to mix breathing gases in addition to air. Data from the questions in Figure 1 and Figure 3, show that the majority of dive centres with compressors also engage in blending other breathing gases. Figure 1 shows 87.9% fill gases in house whilst in Figure 3 it can be deduced that 69.7% of dive centres have gas blending facilities, meaning that 79.3% of the dive centres that fill gases also blend gas mixes. The result indicates that a considerable proportion of dive centres, equipped with compressors, are involved in blending other breathing gases. This suggests that dive centres across the Maltese Islands with a compressor, increasingly seek to complement it with the capability to blend a variety of breathing gases, highlighting the evolution to more technical diving activities within dive centres.

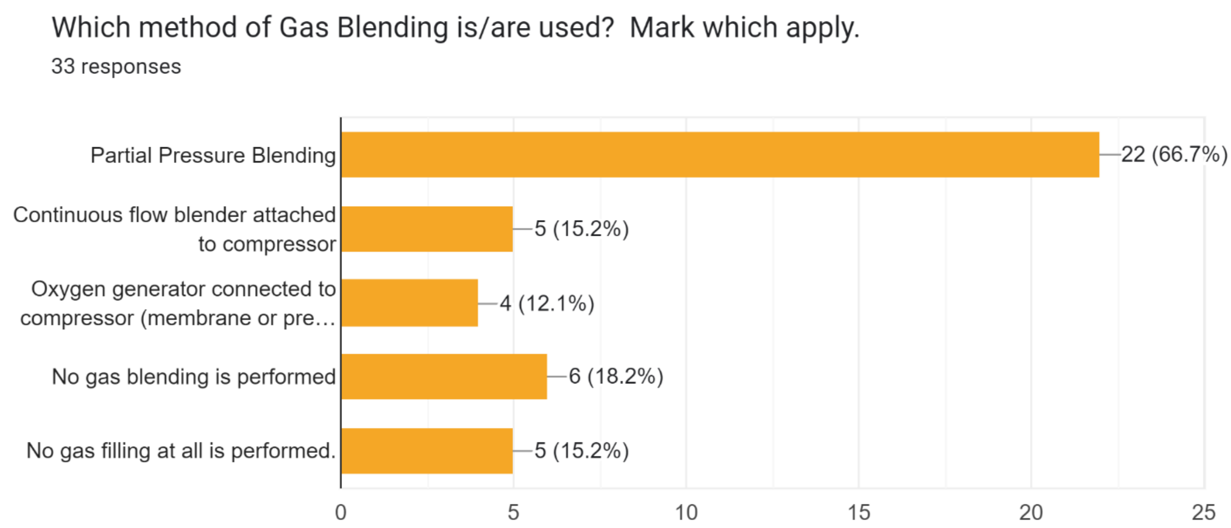

Figure 4. Gas blending

Further to inquiring about gas blending facilities in Figure 3, dive centres were also asked about the method of gas blending they use. Figure 4 shows an overview of the various methods used in gas blending production. The most commonly used method is partial pressure blending, where gases are proportionally filled in the cylinder to achieve the desired gas blend. This method is preferred due to its cost-effectiveness and the limitations of other methods. However, it requires extra caution when handling pure oxygen. Other methods such as an oxygen generator attached to a compressor and continuous flow blending are usually limited to a maximum mix of around 40% oxygen, which may suffice for recreational diving but falls short for technical diving that requires higher percentage mixes, sometimes up to 100% oxygen.

Blending breathing gases for SCUBA diving, warrants extra care to ensure the safety of the gas blenders and the divers breathing the gases. A thorough understanding of the blending process and gas quality is extremely important. Gas blenders must be familiar with the standard EN 12021:2014 'Respiratory equipment - Compressed gases for breathing apparatus,' which outlines the quality requirements for diving breathing gases (CEN, 2014). Training in gas blending is necessary for those blending the breathing gases, this training is available through most technical diving training organisations. The gas blender courses include hands-on sessions. Participants learn about different blending methods together with the pros and cons of each. They refine their enriched air and trimix blending skills, learn to identify oxygen handling hazards and apply risk management techniques. Typically, the training will cover oxygen equipment cleaning procedures and explain oxygen service prerequisites (PADI, 2024).

4.2 Method of monitoring gas quality and records kept of gas filling and blending

When filling and blending breathing gases for diving, oxygen content is a key parameter monitored during the process. The incorrect oxygen content can be extremely dangerous in diving and it is crucial for diver safety as too much oxygen is toxic, whilst too little may not be adequate to support life. Oxygen levels are typically measured using an oxygen analyser, which provides an accurate reading of the percentage of oxygen gas in the blend. In addition to oxygen content, other parameters such as moisture content (H2O), carbon dioxide (CO2), carbon monoxide (CO) pressure, and volatile organic compounds (VOC), may also be monitored to ensure the gas meets the necessary gas purity standards for safe diving (CEN, 2014). By monitoring these parameters during the gas filling or blending process, divers can have added confidence in the quality and safety of the breathing gases they rely on during their underwater expeditions.

Figure 5, Figure 6 and Figure 7 aim to address the research question regarding the method of gas quality monitoring. The survey question in Figure 5 enquires about the parameters monitored.

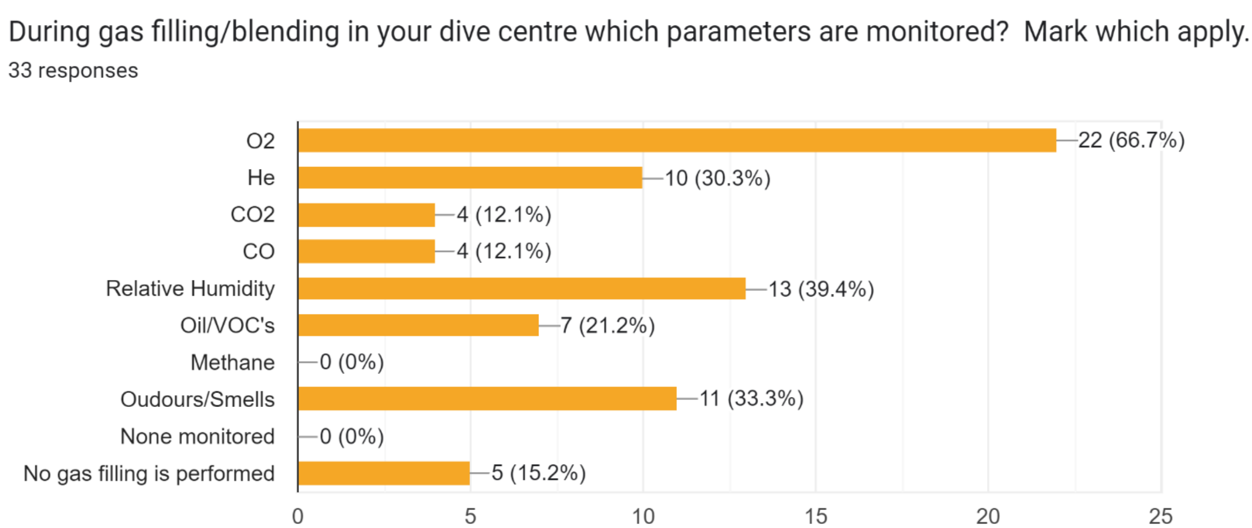

Figure 5. Breathing gas composition monitoring

The bar chart presented in Figure 5 shows the responses to the question regarding the gas parameters monitored. It is worth mentioning that none of the participating dive centres indicated that they do not monitor the breathing gases. This suggests that the centres responsible for filling gases are ensuring some level of checking on the breathing gases they fill, but impurity parameter monitoring is low. Therefore, there is room for improvement in this aspect, especially in monitoring the impurities that can taint the quality of the breathing gases. By consistently monitoring the breathing gases, dive centres can mitigate potential risks and uphold exact standards of safety.

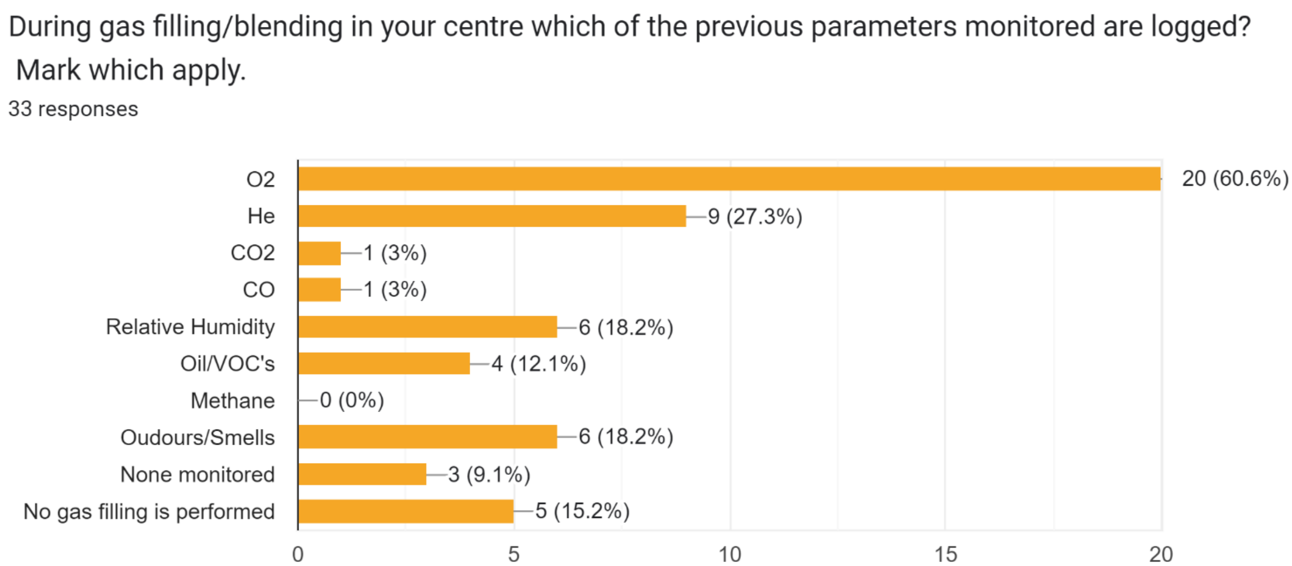

Figure 6. Monitoring and logging breathing gas composition

The comparison between Figure 6 and Figure 5 reveals that the logged breathing gas composition is lower than the percentages indicated in the latter figure referenced.

In addition to monitoring the logging of such data can help identify trends thus possibly serving as an early warning for issues that may arise in the gas filling process. This highlights the need for dive centres to understand the significance of monitoring and logging the breathing gas composition. Ensuring the safety and well-being of divers using these gases requires a greater effort in this aspect.

Capturing data related to the levels of oxygen, carbon dioxide, and other gases present in the breathing gas, provides real-time information to support personnel upholding the air purity standards. By continuously monitoring the gas composition, this system helps to prevent potential health issues or emergencies that may arise from inhaling gas with improper levels of oxygen or excessive amounts of other gases. The data collected from this monitoring can also be used for analysis and improvement of breathing gas systems, contributing to the overall safety and efficiency of the equipment.

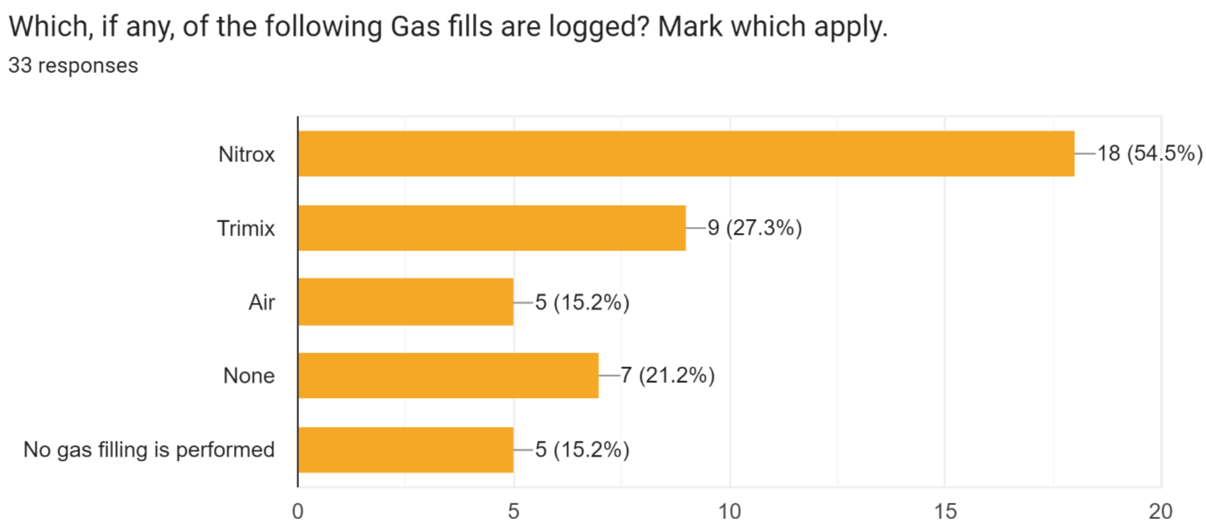

Figure 7. Breathing gas fill logging

The question in Figure 7 relates to the logs of the breathing gas as a finished product in the cylinders and asks if breathing gas fill logs are kept. Analysis of the breathing gas oxygen content is required and specifically mentioned in EN 12021:2014 (CEN, 2014).

Gas logs are used to monitor the content of the breathing gas mixture used during a dive, encompassing the oxygen percentage as well as inert gases like nitrogen and helium. These logs are crucial in ensuring dive safety, as incorrect gas mixtures can pose severe health risks. This is fundamental to adhere to, and the prevalent gas logging practices in dive centres across the Maltese Islands are poor as shown in Figure 8. Moreover, a detailed log of gas fills could help identify root causes of problems should an issue arise, encouraging the practice of recording all breathing gas fills for divers could greatly enhance their safety and should be promoted.

The gases used in blending are a major factor in the outcome of the breathing gas quality. The question in Figure 8 is enquiring about the knowledge of the helium gas quality by the dive centres who purchase helium for gas blending.

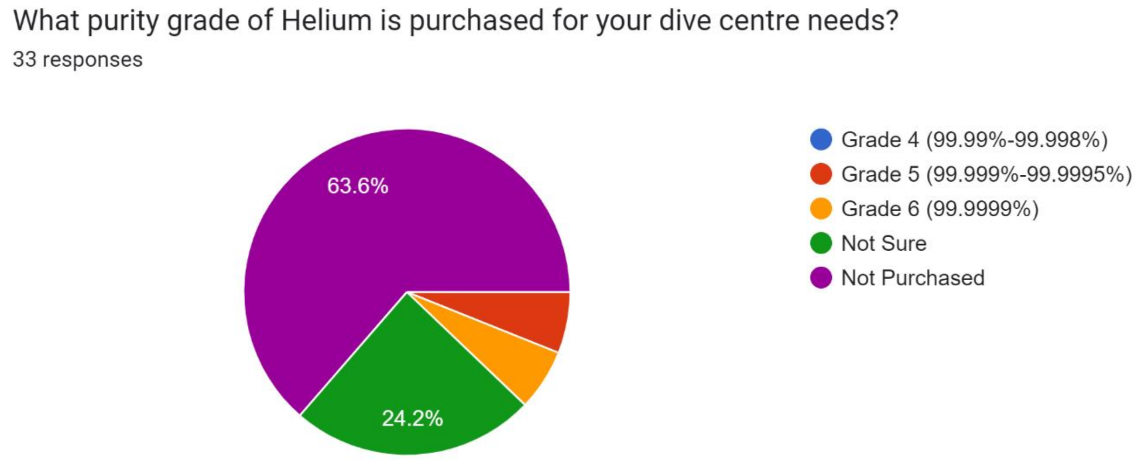

Figure 8. Helium quality

The chart shows that a small group of participants use grade 5 and grade 6 helium, while 24.2% stated that they are not sure of the helium used. The importance of using grade 5 helium or better with a purity level of at least 99.999 per cent for diving applications cannot be overstated. This grade of helium ensures that potential contaminants are not more than 30 ppm, making it suitable for use at depth without affecting human physiology. It is crucial to understand that all helium gases, whether used for balloons or diving, are produced as pure helium, with the only difference being the specific impurities that are analysed during the verification process. Medical grade helium, which has a remaining one percent impurity level (10,000 ppm), may contain substances that are not safe to breathe at pressure. Therefore, it is imperative to procure diving-grade helium (grade 5) or better with a total impurity level of not more than 30 ppm to guarantee a safe breathing gas mix. This commitment to quality and safety is essential in all applications where helium is used, particularly in environments where human health and safety are at stake (Burman, 2023).

The justification of the question portrayed in Figure 9 about the oxygen purchased is identical to that of Figure 8 regarding helium. Notably, there is more awareness of the oxygen quality as compared to helium.

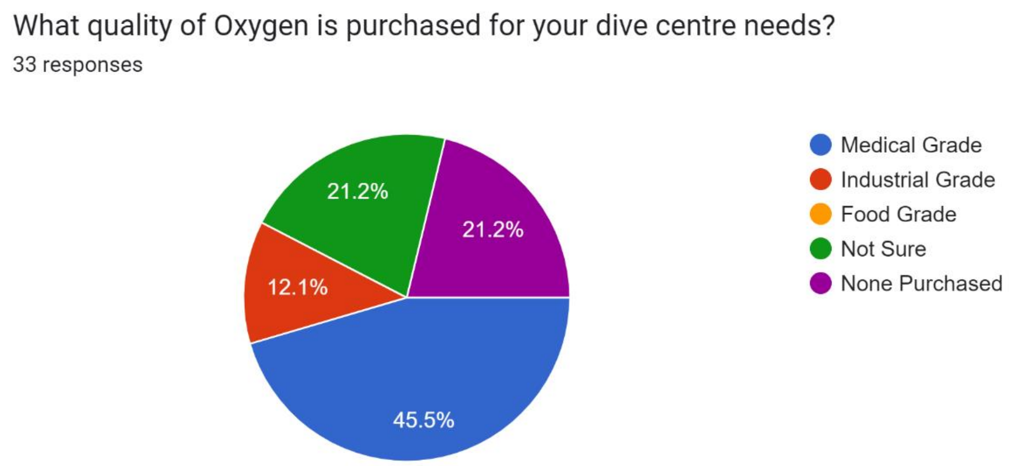

Figure 9. Oxygen quality

In the European Union (EU), the quality of oxygen for SCUBA breathing gases is regulated by the established standard EN 12021:2014. This standard sets out the requirements for compressed gases used in breathing apparatus, ensuring that breathing air is free from contaminants and at a safe level for divers.

To ensure that life support gases, which include oxygen acquired from industrial gas suppliers, meet the necessary quality standards for safe diving, it is recommended to use medical grade oxygen 99.5% (WHO, 2022). The regulation of this oxygen by the World Health Organisation and European Pharmacopoeia Agency ensures its safety for breathing. The stringent standards for the gas, guarantee that the resulting blends meet the requirements (Europe, 2024). Purchasing Medical oxygen 99.5% might require a doctor's prescription since it is considered a medicine, according to '*Article 1 Paragraph 2 Directive 2001/83/EC Community code relating to medicinal products for human use*' , Therefore it needs to be treated as such (EEC, 2001).

The data of Figures 8 and 9 show the quality of gas acquired for the blending of breathing gases by dive centres. Dive centres must ensure that the quality of gases purchased from suppliers meets the necessary standards. Dive centres need to establish strong relationships with gas suppliers to ensure that their blending gas needs are consistently met to the required quality standards. Additionally, it is the responsibility of dive centres to verify the type of gas purchased to ensure it aligns with their specific requirements as stated in EN standards (RECREATIONAL DIVING SERVICES REGULATIONS, 2012). This verification process is essential to guarantee the safety and well-being of divers, as the composition of breathing gases directly impacts their experience underwater. By meticulously confirming the type of gas acquired, dive centres play a crucial role in upholding industry standards and prioritizing the welfare of their clients.

The survey questions in Figure 10 and Figure 11 related to the oxygen as a breathing gas. However, oxygen in the emergency oxygen kits is considered as a medicinal product (WHO, 2022).

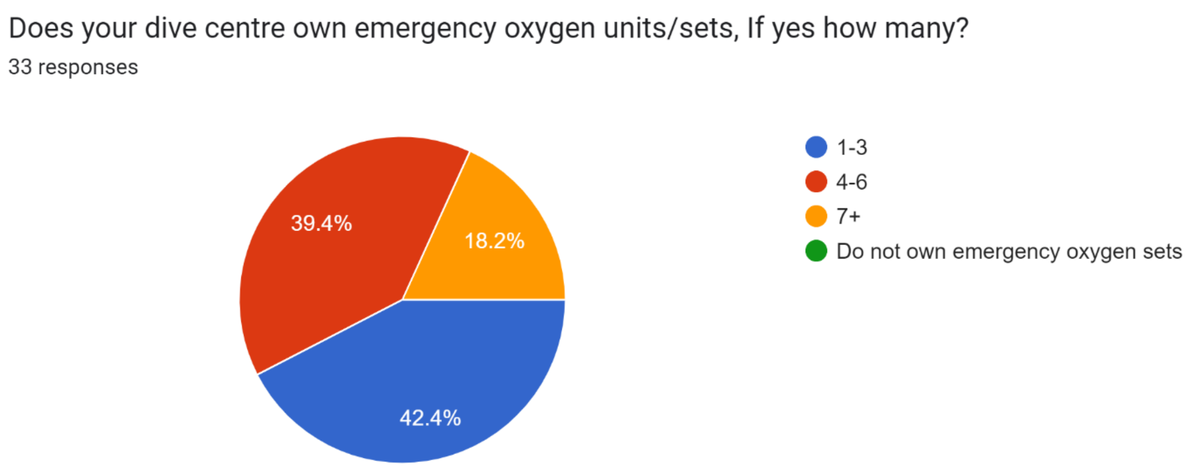

Figure 10 Emergency Oxygen kits

Based on the findings in Figure 10, it is apparent that every dive centre surveyed confirmed that they possess emergency oxygen kits. Under the diving regulations of the Maltese Islands, dive centres must have emergency oxygen accessible during their planned dives (RECREATIONAL DIVING SERVICES REGULATIONS, 2012). Without any exceptions, it is evident that all the dive centres included in the survey are prepared to comply with this regulation.

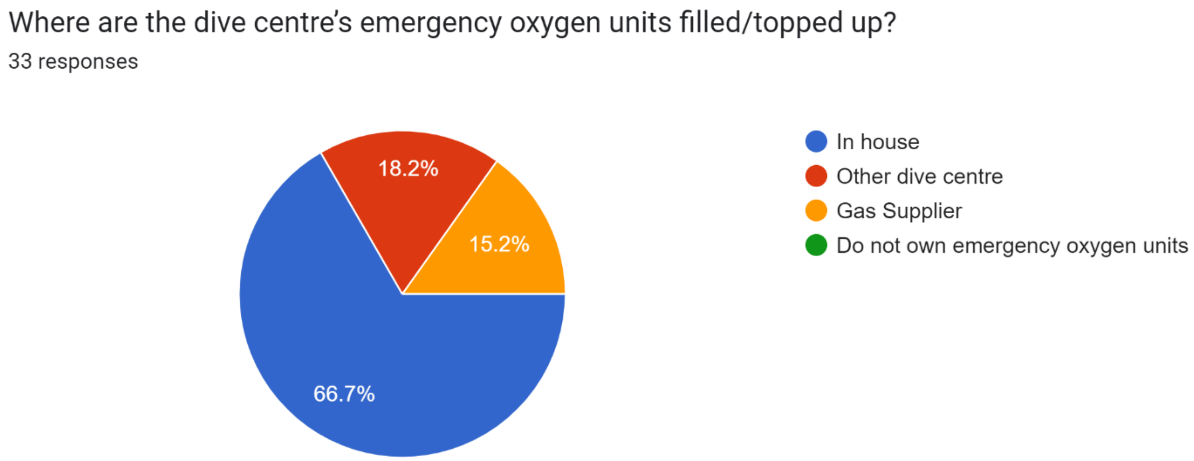

Figure 11 Emergency oxygen filling

The procurement of medical oxygen to fill emergency oxygen cylinders is subject to similar challenges as outlined formerly in relation to oxygen quality (Figure 9). Moreover, there is a possibility that gas suppliers may interpret Article 11 Paragraph 1 of Directive 2003/94/EC, which pertains to the principles and guidelines of good manufacturing practice for medicinal products, as a restriction on refilling third-party cylinders. This could lead to potential refusal by gas suppliers to refill cylinders not supplied by them, as medicinal oxygen may be perceived as only permissible in the suppliers' packaging, akin to other medicines (EEC, 2003).

The data presented in Figure 11 indicates that a small number of survey participants are obtaining their emergency oxygen cylinder fills from gas suppliers, which is a positive finding as it demonstrates that local gas suppliers are serving third-party oxygen cylinder needs. However, it is concerning to note that the majority of participants reported filling their emergency oxygen cylinder kits in-house or at other dive centres. This raises potential safety and quality control issues. Upon reviewing Figure 9 it is concerning to note that a small portion of dive centres indicated that they use industrial-grade oxygen. This raises the alarming possibility that emergency oxygen kits could be filled with such oxygen. This issue warrants further investigation and action to ensure the safety and quality of oxygen used in dive centres. Industrial-grade oxygen is not appropriate for breathing and even less suitable for medicinal use. It is imperative to address the utilisation of medicinal-grade oxygen to mitigate potential complications in the future.

Air purity tests are crucial for ensuring that breathing air compressors are functioning properly and producing air that meets EN standards. These tests help to identify and measure any impurities that may be present in the compressed air, which could potentially pose a risk to divers using the breathing gases during their dives. By establishing acceptable levels of impurities, these tests play a vital role in safeguarding the quality of the breathing gases used for diving, ultimately contributing to the safety and well-being of divers. It is essential to adhere to these standards to minimise the potential health risks associated with inhaling contaminated air while diving. Regular air purity testing is therefore an important aspect of maintaining the integrity and reliability of diving equipment, ensuring that divers can breathe clean and safe air throughout their underwater adventures.

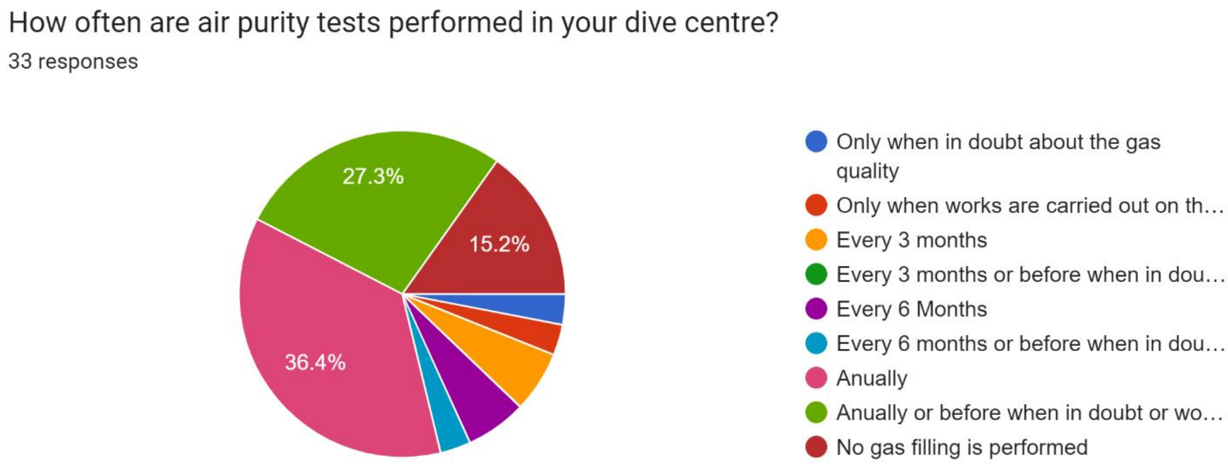

Figure 12. Air purity test frequency

Figure 12 shows the frequency of air purity tests, indicating that most participants reported conducting these tests annually. It is noted that this frequency often coincides with the annual service of the compressor by the supplier. However, it is important to highlight that Maltese law and EN 12021 do not specify a frequency for these tests, potentially leading to misinterpretation of the standards. In light of this, it would be advisable to consult established regulations, such as the Health and Safety Executive of the United Kingdom (HSE). for further guidance. The HSE requires air purity tests to be carried out every three months or when repair or maintenance work is conducted on the compressor (HSE, 2018).

The study involved analysing randomly collected air samples, obtained from dive centres that independently fill their breathing gas cylinders. The air samples were taken from pre-filled cylinders prepared for their customers and the results presented in Figure 13.

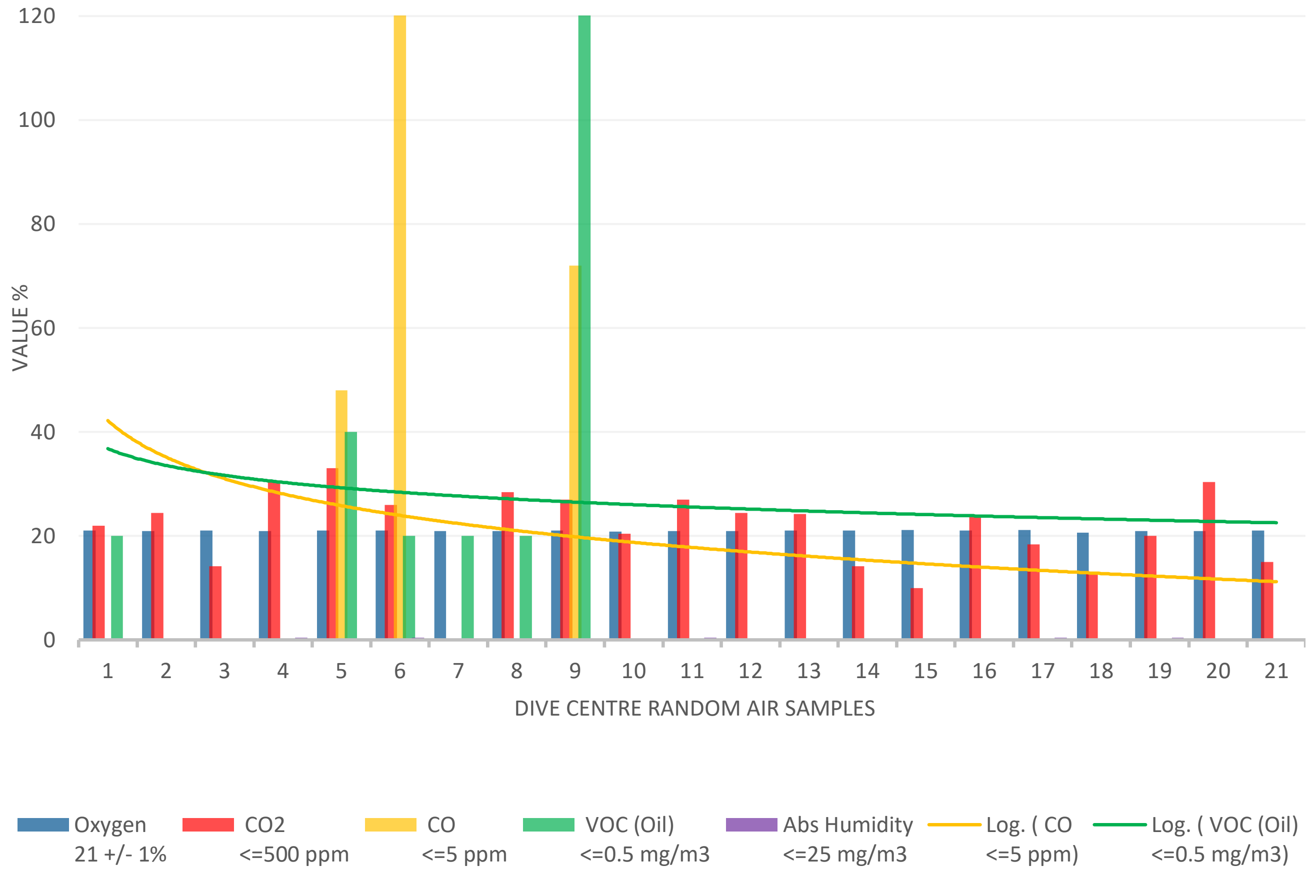

Figure 13. Random sample air purity test

The chart in Figure 13, shows the oxygen levels expressed as a percentage read directly from the testing unit, whilst the impurities are expressed as a percentage of the maximum allowable limits stipulated in EN 2021:2014.

The majority of the dive centres produced breathing air with levels of contaminants within acceptable limits. Nevertheless, two sets of results had one parameter going notably over the acceptable limit. On the chart of Figure 13, one can also see the logarithmic trendlines of the two parameters found to be unacceptable. The trendlines indicate that across the whole data set, the levels were not alarming. However, individually the situations merited a serious inquiry into the compressors delivering the air to the samples.

Dive centre number ‘6’ has a set of readings with a high carbon monoxide (CO) level which originated from a compressor unit driven by an internal combustion engine. Compressors driven with an engine are vulnerable to high CO contents due to exhaust from the engine, being aspirated by the intake of the compressor. Risk mitigation measures would include appropriate positioning of the air intake of the compressor relative to the exhaust outlet of the driving engine, regular maintenance, adequate cooling, and the use of carbon monoxide alarms are encouraged (Lippmann & Millar, 2022).

Dive centre number ‘9’ has readings with a high volatile organic compound (VOC) reading, originated from an electric motor-driven compressor. It was explained by the dive centre that the compressor had persistent issues with a compression stage in the unit. Furthermore, the breathing air filter, which soon needed to be replaced , was compromised due to the same fault.

Dive centre number ‘5’, although having results with in the thresholds of the air purity standard has VOC’s and CO levels elevated compared to other dive centres. The area where this compressor is located is in a busy area and it was explained that it is common to have these levels, whilst the high VOC was explained due the Filter being within an hour of its lifetime. The dive centre concerned stated that previous air purity tests on all its compressors were always well within the thresholds.

The dive centres involved have demonstrated genuine concern for the situation at hand and have voluntarily pledged to address and monitor the issues. It is commendable to see the level of commitment and prompt action taken by all parties to rectify the situations once they were made aware of them.

Upon reflection on the data in Figure 12 ‘Air purity test frequency’ and Figure 13 ‘Air purity tests’, it is apparent that an increase in the frequency of testing may be warranted. This suggests an evaluation of testing schedules, as it is evident that the current testing frequency may not be sufficient to adequately address the need to satisfy the EN standards. Thus, it is imperative to carefully consider and possibly implement a frequency of air purity testing schedule to ensure that it aligns with the requirements and demands of modern dive centres. This examination may reveal that more frequent testing is required to effectively address the needs of the industry. It is crucial to recognise the importance of this consideration to ensure that the testing frequency is adequate for the circumstances of present-day dive centres.

The HSE model discussed in the literature review, is an appropriate model to adopt and would have certainly brought the issue to light much earlier, in these circumstances (HSE, 2018). Furthermore, the Hazard Identification and Risk Assessment program, as pointed out by Mr Francois Burman in the literature review, is a valuable resource for dive centre owners, operators, staff, and dive professionals. It focuses on realistic and pragmatic assessments of risks, providing tools and strategies to proactively mitigate incidents that could lead to serious outcomes. This proactive approach promotes safety within our communities and ensures the continued success of the diving industry (DAN Europe Foundation, 2024).

Introducing equipment that allows the data log to incorporate the parameters typically used for air purity analysis, would represent a significant advancement in preventing breathing gas contamination. This additional data logging could provide valuable insights into potential developing trends, enabling timely interventions to prevent or resolve issues even before they become problematic. However, it is important to acknowledge that the systems capable of this level of monitoring come at a substantial cost, which can be too much of a burden, especially to small business dive centres. Conducting a thorough cost-benefit analysis would be essential in determining the potential justification for investing in such equipment. While the initial expense may be considerable, the long-term benefits, in terms of ensuring air quality and diver safety, could ultimately outweigh the costs.

4.3 Awareness of local regulatory and standard quality requirements in air filling and gas blending

In order to guarantee adherence to regional regulatory and standard quality requirements for gas blending and air filling. Industry professionals must remain informed and aware of the specific regulations and standards that apply to their area. This includes understanding the legal framework governing gas handling, storage, and transportation, as well as the technical specifications for gas composition and purity.

Additionally, knowledge of any industry-specific guidelines or best practices is crucial for maintaining the highest level of quality and safety in air-filling and gas-blending operations. By staying informed and adhering to local requirements, professionals can uphold the integrity of their products and services while also contributing to the overall safety and reliability of the gas supply.

The following questions were asked to gauge the perceived versus the actual knowledge of the EN standards. It is important to make this assessment in order to understand any potential gaps or misconceptions. By asking these questions, we can gain insight into how well individuals believe they understand the standards versus their actual level of knowledge. This can help identify areas for further education or clarification, ultimately leading to a better understanding and implementation of the EN standards.

Figure 14 requires an answer ranging from 1 to 5 with 1 being the least knowledgeable and 5 being very knowledgeable.

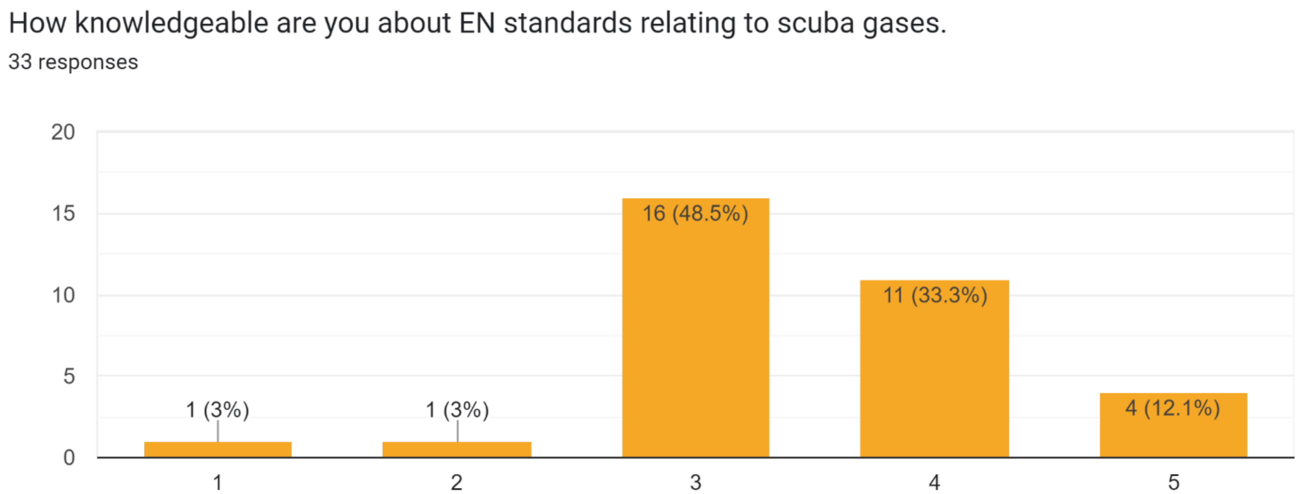

Figure 14. EN standard awareness

Figure 14 shows that a sizeable portion of the participants demonstrated a perceived elevated level of knowledge regarding EN standards. The responses indicated that the majority of participants considered themselves to be at least moderately knowledgeable, if not very knowledgeable, about these standards. It is important to note that the question itself may have been somewhat ambiguous, yet the responses still pointed towards a noteworthy awareness of EN standards among the dive centres. However, awareness of the standards does not mean knowledge of its content and does not imply that these standards are upheld . Moving forward, it may be beneficial to further clarify the questions related to EN standards to obtain a more precise understanding of the participant's knowledge and awareness in this area.

According to the standard EN 144-3:2003, cylinders that contain gas with 22% oxygen (O2) or more must be equipped with an outlet connection thread of M26 x 2. By adhering to this standard, dive centres can ensure that they conform to the essential requirements of the directive concerned and associated EFTA regulations. This compliance serves as one method for meeting the specific criteria outlined in the directive and its related EFTA regulations (CEN, 2003). Having separate outlet connections for gases with high oxygen levels is useful to help prevent mishandling by unqualified divers during its use. The survey question in Figure 15 enquires about this subject with the dive centres participating in the study.

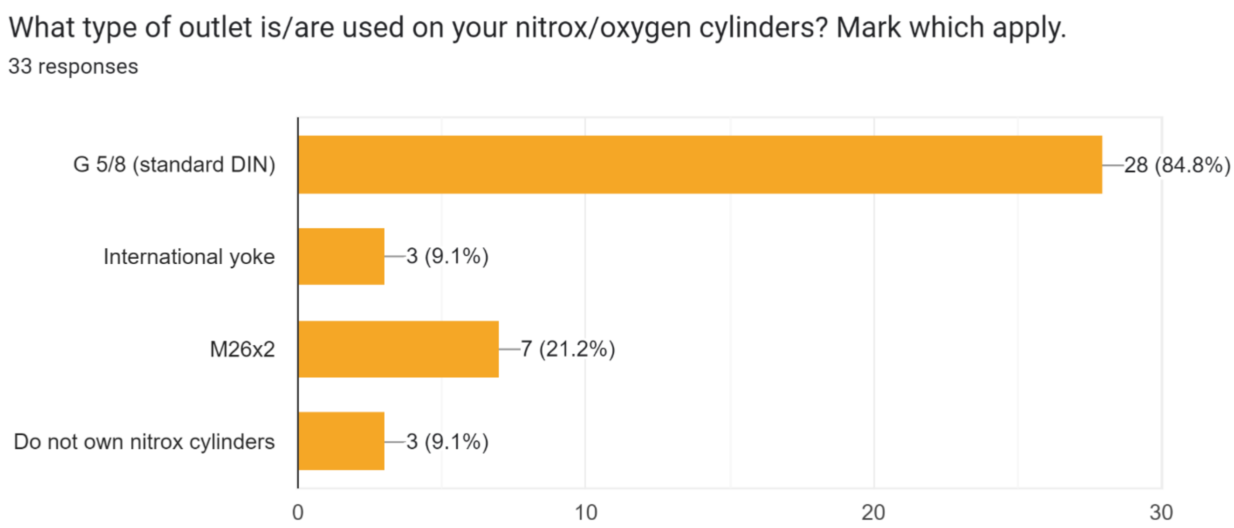

Figure 15. Gas cylinder outlet valves

Most dive centres across the Maltese Islands are well aware of the requirements for SCUBA equipment to conform to EU standards, as stated in Figure 14 'EN standard awareness', but the data in figure15 shows that only 21.2% have some conformity with this regulation.

The reasons for this no compliance is often due to the demands of their clients. Some clients that bring their own equipment may come from non-EU countries where this rule does not apply, while others, from within the EU, may agree to continue using equipment without the necessary conformity. Additionally, some clients simply do not want to deal with adapters and prefer the flexibility of using standard DIN-fitting SCUBA regulators. As a result, dive centres find themselves in an uncomfortable position, balancing the need to comply with regulations while also meeting the demands and preferences of their diverse clientele.

Figure 16 and Figure 17 require an answer ranging from 1 to 5 were 1 means unsatisfied and 5 very satisfied. These survey questions are asked to give an indication of the dive centres perception of the breathing gas quality offered.

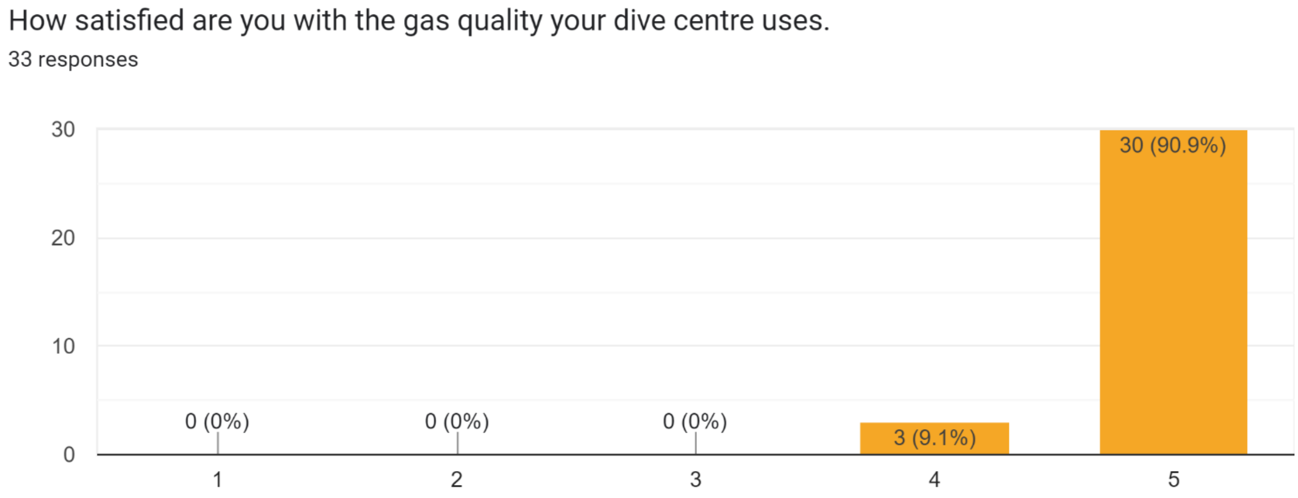

Figure 16. Quality satisfaction

Figure 16 shows a very high level of satisfaction among dive centres regarding the quality of their air supply. The majority of dive centres expressed a very high level of satisfaction, indicating the significance placed on maintaining superior gas quality. This level of contentment reflects a keen sense of pride and dedication to upholding industry standards and that dive centres prioritise the quality of their air supply. Conversely, the discrepancies between perceived and actual knowledge of the EN standards, as collaborated by the data in Figure 13, create a misleading sense of security when evaluating the quality of gas being offered.

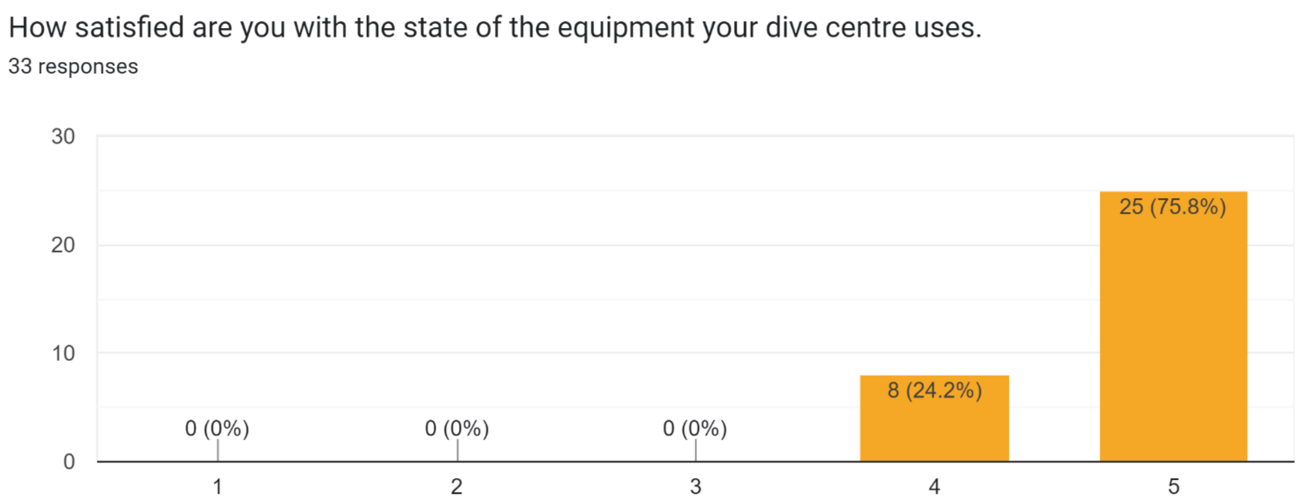

Figure 17. Equipment

The data presented in Figure 17 indicates that a considerable number of dive centres are satisfied with their gas-filling equipment, with a majority expressing an elevated level of satisfaction. This level of contentment suggests that dive centres place a considerable emphasis on the quality and reliability of their gas-filling equipment. It also reflects a sense of pride and dedication to providing excellent service to their customers. This feedback can also serve as insight for suppliers in understanding the needs and preferences of dive centres, ultimately leading to further improvements in the quality of gas-filling equipment in the local dive centres.

The final question in the survey, was to leave any comments they deem fit, a field was provided for the respondents to fill in with a comment or suggestion of their choosing.

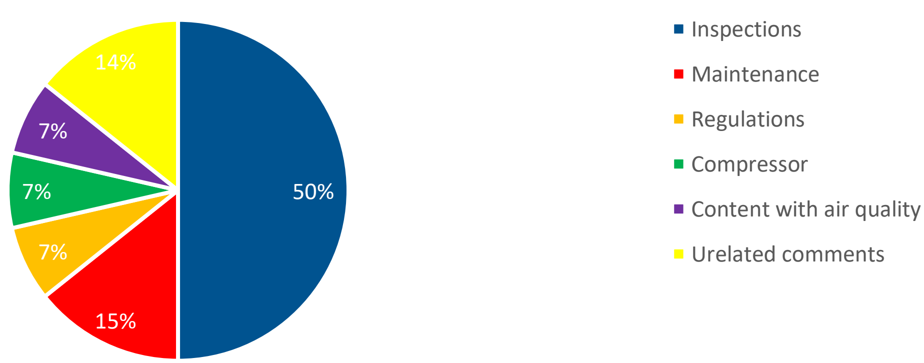

Figure 18. Open Comments

Out of all the responses received, 14 individuals chose to comment. Seven comments predominantly expressed the need for better inspections with diving-oriented inspectors, to ensure air quality and dive centre-related standards are met. Additionally, two comments highlighted the importance of regular maintenance to uphold air quality. One comment raised concerns about local regulations impacting air quality, while another mentioned the cost associated with analysis. Two comments were totally unrelated. Furthermore, one respondent suggested a compressor upgrade to potentially improve air quality. Lastly, one respondent stated that they believe the current air quality is good.

The majority of comments in Figure 18 focused on inspections, with the consensus being that the inspections are inadequate. The next largest portion of comments were concerns about maintenance. This group believes that equipment maintenance is inadequate and advocates for additional training, with an equal proportion were a group of irrelevant remarks. The remaining comments expressed a desire for more rules, assistance with compressor upgrades, and satisfaction with the quality of breathing gases.

This study of local diving centres yielded useful information on breathing gas management, filling, and blending. A sizable number of diving centres participated, demonstrating considerable industry involvement. The investigation looked into the ownership of compressors and cylinders, gas blending processes, and gas quality monitoring. The findings revealed that some centres rely on others for gas filling, while many are involved in speciality gas blending. Safety compliance is critical, which includes gas quality monitoring, cylinder maintenance, and adherence to standards like EN 12021:2014. Dive facilities demonstrated an understanding of legal and quality requirements, particularly EN standards, and overall practices strive to prioritise air quality while increasing professionalism and reliability. Air sample analysis revealed adequate air quality, with instances of parameter exceedance necessitating more testing and adherence to industry best practices.

5. Final Arguments

This study sought to address critical questions regarding the breathing gas quality and monitoring in the dive centres of the Maltese Islands, by evaluating the research objectives to establish:

- The state of compliance with the local breathing gas standards and regulations when filling breathing gases
- The type and frequency of monitoring, in gas quality and filling procedures of the diving centres across the Maltese Islands.
- Identify areas for improvements in the filling procedures and quality monitoring of breathing gases.

To determine the objectives of the study a survey questionnaire was conducted with the central research questions being:

- Do all dive centres perform compressed air fills and what portion of these blend gases, Nitrox, Trimix and Heliox
- Awareness of local regulatory and standard quality requirements in air filling and gas blending.
- Method of monitoring gas quality and records kept of gas filling and blending

Out of the 42 dive centres approached, 33 responded, indicating a strong level of engagement within the industry. While a few dive centres were unable to participate, the overall response rate demonstrates a significant willingness within the dive centre community to contribute to enhancing the local diving industry. The findings of this study are expected to pinpoint ways to improve the quality of breathing gases, ultimately contributing to a safer diving experience.

The survey revealed that not all dive centres fill breathing gases, with a small percentage indicating that they do not own a breathing air compressor. This reliance on other centres for cylinder gas filling may pose logistical challenges and potential delays. Additionally, it was found that a considerable proportion of dive centres with compressors are involved in blending other breathing gases, highlighting an evolution towards more technical diving activities within dive centres.

Gas blending for diving warrants extra care to ensure the safety of gas blenders and divers breathing the gases. Greater awareness of local regulatory and standard quality requirements is essential for maintaining the highest level of quality and safety in air-filling and gas-blending operations. Particular attention needs to be given to air quality, the breathing air compressors produce, and equally important is the quality of the gases purchased.

The responses in the survey questionnaire indicate a commitment to gas quality among dive centres, ensuring some level of scrutiny on the breathing gases they fill and blend. This commitment is crucial and reflects a collective effort to prioritise diver safety. Routine air purity tests were reported to be carried out annually by most participating dive centres, usually aligning with the annual service of the breathing air compressor.

Expanding on the first stated objective of the study, from the random air purity tests performed, a couple of readings were found to be out of acceptable limits. These findings give reason and strengthen the argument for re-evaluation of air purity testing frequency schedules. More testing may be warranted, to ensure adequacy in monitoring and addressing the needs of modern dive centres.

The participants asserted their elevated level of familiarity with the relevant standards. However, an examination of their responses revealed a discrepancy between their perceived expertise and their actual knowledge. This discrepancy challenges the participants claim of comprehensive understanding and highlights the need for further assessment and clarification of their knowledge.

5.1 Conclusions

The survey findings shed light on various aspects of equipment ownership, gas blending, quality monitoring, and compliance with standards in dive centres. The commitment to gas monitoring and quality maintenance is evident, but there are opportunities for improvement in gas logging practices and testing frequencies. Furthermore, enhanced awareness of local regulatory requirements and proactive measures to address gas quality issues will contribute to safer and more reliable breathing gas quality.

In light of the findings presented in this study, it is evident that the majority of dive centres across the Maltese Islands are currently engaged in the activities of gas filling and blending. However, it is also apparent that there exist areas in need of improvement in equipment maintenance, gas blending practices, and the frequency of air purity testing. These areas are crucial for enhancing safety standards within the diving industry.

Due prominence is required to understand the significance of adhering to local regulatory and quality standards to ensure the safety of divers. By doing so, dive centres can contribute to the overall advancement of safety measures within the industry, thereby safeguarding the well-being of divers who partake in these activities.

This study underscores the importance of continuous improvement in safety standards within dive centres and highlights the need for ongoing vigilance and adherence to established regulations and quality standards to uphold the safety of divers.

5.2 Recommendations

In the field of diving industry safety, several areas warrant further exploration to enhance safety standards and practices. Building upon existing research and knowledge, future studies should consider delving into topics such as equipment maintenance practices in dive centres, and gas blending techniques. By addressing these areas, the diving industry can continue to improve the quality of its products with these safety measures and minimise risks for divers and professionals alike.

Future research should continue to monitor the effectiveness of EN ISO 18119:2018+AM1:2021 in reducing cylinder-related incidents and explore advancements in materials and technology that could further improve SCUBA cylinder safety. Additionally, studies could assess the global adoption of this standard and its impact on diving operations. Furthermore, studying equipment maintenance practices in dive centres, by exploring the reliability and safety of diving equipment, is valuable due to the impact it may have on breathing gas quality. Additionally, the study can examine the training and qualifications of personnel responsible for maintenance. By understanding current practices and identifying potential areas for improvement, future studies can provide valuable insights for establishing standardised maintenance protocols that prioritise safety.

Another recommendation is research into evaluating gas blending techniques, to optimise the quality and consistency of the breathing gases blended. Such a study may also involve analysing the impact of gas impurities and identifying best practices for gas storage and handling. By gaining a deeper understanding of gas blending techniques, researchers can contribute to the development of guidelines that promote the safe production and use of breathing gases in diving operations.

In conclusion, more studies are needed in the diving industry dealing with equipment maintenance, and gas blending techniques, as these greatly impact the quality of the breathing gases. By addressing these topics, researchers can contribute to the continual improvement of safety standards and practices within the diving industry. Ultimately, the insights gained from these studies have the potential to enhance the overall safety and well-being of divers, dive centre staff, and other professionals involved in the underwater environment.

5.3 Evaluation, Reliability and Validity

The research employed a mixed methods approach to thoroughly examine the data, blending quantitative and qualitative methods as required. The survey data depended on the honesty of the participating dive centres, and it can be presumed that the respondents had the best of intentions. Conversely, it is still possible that the responses were skewed with the perception that it would present a positive image of their business.

Before the main survey, a preliminary survey was conducted to ensure the questions were comprehensive and the time needed for completion was reasonable. The respondents, who were mostly part of the PDSA, were asked about the quality of breathing gas, equipment, maintenance, filling procedures, and standards. In addition, questions about perceptions were included to evaluate dive centres' dedication to quality.

The air purity tests were performed using a DE-OX test unit with serial number 90102121. The certificate of conformity for this unit is in Appendix 2: 'Air testing unit certificate of compliance.' Procedures for the air testing were developed with the manufacturer, and the air purity test steps are detailed in Appendix 3: 'Air purity test procedure.' A total of 21 dive centres consented to a sample being taken and analysed. The five dive centres that do not fill gases in their centres were omitted from the sampling exercise. The other dive centres that did not participate in the sampling exercise, was simply due to unavailability. All participants in the study co-operated willingly and none refused to have their gas sampled and tested.

The study focused mainly on PDSA members but did not exclude non-member dive centres, with participation from over 78% of the dive centres approached. The respondents represent more than 50% of the total dive centres across the Maltese Islands. Out of 42 invited participants, 33 responded, with two businesses no longer operational during the survey period. Initially, limited responses were received via email, leading to direct communication with dive centres via phone or in person. The findings were compiled using Google Forms for creating bar and pie charts, while Microsoft Excel was used for the air purity test chart.

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Appendices

Appendix 1 : Dissertation Survey Questionnaire

Breathing gas quality and monitoring in the dive centres of the Maltese Islands.

Gas quality and monitoring survey

1. Email

Dissertation Consent Form

Title of Research: Breathing Gas Quality and Monitoring in Dive Centres of the Maltese Islands

Researcher: Arthur Gauci I.D. 143987M

Degree: BSc. Diving Safety Management

Dear Sir / Madam,

I, Arthur Gauci , a student at the Institute of Tourism Studies am currently in the final year of my BSc. Diving Safety Management. I am carrying out research on Breathing Gas Quality and Monitoring in Dive Centres of the Maltese Islands.

I would like to explore your views on this matter by asking you some questions. The purpose of this form is to provide you with information so you can decide whether to participate in this study. Any questions you may have will be answered by the researcher.

There are no known risks related with this research project other than possible discomfort with the following:

- You will be asked to be honest when answering questions.

The information in the study records will be kept strictly confidential. All data will be stored securely and will be made available only to those individuals conducting the study. No reference will be made in oral or written reports that could link you to the study. Your identity will not be revealed in any publications that result from this study.

You can terminate your participation at any time without prejudice. You also do not have to answer individual questions you don't want to answer. Your name will not be attached to the questionnaire and I will ensure that your participation remains confidential.

Participant's declaration

I have read this consent form and am giving the opportunity to the researcher to ask questions. I hereby grant permission to use the information I provide as data in the above-mentioned research project, knowing that it will be kept confidential and without use of my name.

Tick all that apply.

☐ I confirm my consent

3. Dive Centre's Name *

4. Contact Person *

Equipment

5. Does your dive centre own diving cylinders? Mark which apply. *

Tick all that apply.

- [ ] Air cylinders
- [ ] Nitrox cylinders
- [ ] Twinsets
- [ ] Stage Or Deco cylinders (used with mixes of Oxygen 40%>)
- [ ] Rebreather Diluent cylinders
- [ ] Rebreather Oxygen cylinders
- [ ] Dry suit inflation cylinders
- [ ] Pony cylinders
- [ ] Do not own cylinder

6. What type of outlet is/are used on your nitrox/oxygen cylinders? Mark which apply. *

Tick all that apply.

- [ ] G 5/8 (standard DIN)
- [ ] International yoke
- [ ] M26x2
- [ ] Do not own nitrox cylinders

7. Does your dive centre own emergency oxygen units/sets, If yes how many? *

Mark only one oval.

- ( ) 1-3
- ( ) 4-6
- ( ) 7+
- ( ) Do not own emergency oxygen sets

8. Does your dive centre own compressors, if yes how many do you own? *

Mark only one oval.

- 1
- 2
- 3
- 4+
- Do not own a compressor

9. Do the Compressors in your dive centre have an air chiller/cooler? *

Mark only one oval.

- Yes
- No
- Not all
- Do not own a compressor

10. Do the Compressors in your dive centre have built in gas monitoring (Relative humidity etc.)? *

Mark only one oval.

- Yes
- No
- Not All
- Do not own a compressor

11. Does the gas monitor on the compressor always function correctly? *

Mark only one oval.

- Yes
- No
- Not on all compressors
- No gas monitoring
- Do not own a compressor

12. What type of breathing air filters are used in the compressors? Mark which * apply.

Tick all that apply.

- [ ] Manually refilled with media Compatible pre
- [ ] filled filters.
- [ ] Manufacturer supplied original filters.
- [ ] Do not own a compressor

Blending

13. Does your dive centre perform gas blending in-house if yes what is blended? * Mark which apply.

Tick all that apply.

- [ ] Nitrox
- [ ] Trimix
- [ ] Heliox
- [ ] No gas blending performed in house.

14. Which method of Gas Blending is/are used? Mark which apply. *

Tick all that apply.

- [ ] Partial Pressure Blending
- [ ] Continuous flow blender attached to compressor
- [ ] Oxygen generator connected to compressor (membrane or pressure swing)
- [ ] No gas blending is performed
- [ ] No gas filling at all is performed.

15. Which gases are purchased from gas suppliers? Mark which apply. *

Tick all that apply.

- [ ] Oxygen
- [ ] Helium
- [ ] Other Gases (Argon etc.)
- [ ] None Purchased

16. What quality of Oxygen is purchased for your dive centre needs? *

Mark only one oval.

- ( ) Medical Grade
- ( ) Industrial Grade
- ( ) Food Grade
- ( ) Not Sure
- ( ) None Purchased

17. What purity grade of Helium is purchased for your dive centre needs? *

Mark only one oval.

- ( ) Grade 4 (99.99%-99.998%)
- ( ) Grade 5 (99.999%-99.9995%)
- ( ) Grade 6 (99.9999%)
- ( ) Not Sure
- ( ) Not Purchased

18. Does your dive centre own a gas booster pump *

Mark only one oval.

- ( ) Air driven
- ( ) Electrically driven
- ( ) Do not own a gas booster pump.

19. Where are the dive centre’s emergency oxygen units filled/topped up? *

Mark only one oval.

- In house
- Other dive centre
- Gas Supplier
- Do not own emergency oxygen units

Quality monitoring

20. During gas filling/blending in your dive centre which parameters are monitored? * Mark which apply.

Tick all that apply.

- [ ] O2 He
- [ ] CO2
- [ ] CO
- [ ] Relative Humidity
- [ ] Oil/VOC's
- [ ] Methane
- [ ] Odours/Smells
- [ ] None monitored
- [ ] No gas filling is performed
- [ ]

21. During gas filling/blending in your centre which of the previous parameters monitored are logged? Mark which apply. *

Tick all that apply.

- [ ] O2 He
- [ ] CO2
- [ ] CO
- [ ] Relative Humidity
- [ ] Oil/VOC's
- [ ] Methane
- [ ] Odours/Smells
- [ ] None monitored
- [ ] No gas filling is performed
- [ ]

22. What measure indicates replacement of the breathing air filter on your compressors *

Mark only one oval.

- Logged operating hours (manual)
- Logged operating hours (auto alert)
- Air Moisture level (manual monitor)
- Air moisture level (auto alert)
- Air filter moisture level alert (auto)
- Air filter moisture level alert (manual)
- Logged hours with temperature (auto alert)
- Mixed methods (more than one compressor)
- Not sure
- No compressor owned

23. How often are air purity tests performed in your dive centre? *

Mark only one oval.

- Only when in doubt about the gas quality
- Only when works are carried out on the compressor
- Every 3 months
- Every 3 months or before when in doubt or works are carried out on the compressor
- Every 6 Months
- Every 6 months or before when in doubt or works are carried out on the compressor
- Annually
- Annually or before when in doubt or works are carried out on the compressor
- No gas filling is performed

24. Which, if any, of the following Gas fills are logged? Mark which apply. *

Tick all that apply.

- Nitrox
- Trimix
- Air
- None
- No gas filling is performed

25. Does your dive centre train staff for gas filling or blending procedures? *

Mark only one oval.

- Yes, training on bespoke in house procedures is given
- Not required, the training organisations procedures are followed
- No training given.
- No gas filling performed

26. Are gas filling or blending checklists and procedures available in your dive centre? *

Mark only one oval.

- ⬭ Available, we have bespoke in house checklists and or procedures
- ⬭ Available, we use the training organisation procedures and or checklists
- ⬭ Not available but we observe the training organisation procedures.
- ⬭ Not available but we follow a procedure agreed upon in house
- ⬭ None available, and none followed.
- ⬭ No gas filling performed

27. Which of the following equipment do you offer in your dive centre? Mark which * apply.

Tick all that apply.

- ☐ Cylinders
- ☐ Regulators
- ☐ Instruments and gauges
- ☐ No equipment offered

28. Which of the offered equipment is serviced / inspected in house ? Mark which * apply.

Tick all that apply.

- ☐ Compressor, booster pump and filling panels
- ☐ Cylinders
- ☐ Regulators
- ☐ Instruments and gauges
- ☐ No equipment owned
- ☐ No equipment serviced in house

29. Which equipment servicing / inspections do you log in your dive centre? Mark * which apply.

Tick all that apply.

- [ ] Compressor, booster pump and filling panels
- [ ] Cylinders
- [ ] Regulators
- [ ] Instruments and gauges
- [ ] No equipment owned
- [ ] No logs are kept

30. How satisfied are you with the gas quality your dive centre uses. *

Mark only one oval.

	1	2	3	4	5	
Unsatisfied	◯	◯	◯	◯	◯	Satisfied

31. How satisfied are you with the state of the equipment your dive centre uses. *

Mark only one oval.

	1	2	3	4	5	
Unsatisfied	◯	◯	◯	◯	◯	Satisfied

32. How knowledgeable are you about EN standards relating to scuba gases. *

Mark only one oval.

	1	2	3	4	5	
Not Knowledgeable	◯	◯	◯	◯	◯	Very Knowledgeable

33. Please comment on what could be improved, regarding gas quality and monitoring, equipment maintenance, training, and standards?

Appendix 2 : Air testing unit certificate of compliance

TEMC DE-OX
Via Donna Prassede, 5/A
20142 MILANO
Tel/Fax +39 02 8463648 +39 080 4490264
E-Mail: temc@iol.it Website: http://www.temc.it

Milano 20/07/2021

Subject: DE-OX SUB MULTIGAS COLOR COMPLIANCE WITH EN12021

In reference to your kind requirement we state that our digital measurement instruments DE-OX SUB MULTIGAS COLOR in the configuration with CO, CO2, O2, Dew Point, VOC OIL vapour sensors follow the accuracy required by "UNI EN12021 Compressed gases for breathing apparatus" international norm:

GAS	UNITS	LIMITS	DE-OX ACCURACY
Oxygen	%	21±1	±2% FS
Carbon Dioxide	ppm	500	±2% FS
Carbon Monoxide	ppm	5	±5% FS
VOC OIL VAPOUR based on Isobutylene calibration	mg/m3	0,5	±3% FS
Dew Point	°C	<11	±3 °C
Absolute Humidity	mg/m3	25	±4 mg/m3

Thus we declare that following the requirements stated in the UNI EN12021 norm, with reference to point 7 *(Sampling and Testing)*, our DE-OX SUB MULTIGAS COLOR is suitable to detect gas concentrations in compliance with UNI EN12021 norm requirements.

The above statement is valid, provided that tests are conducted following guidelines issued by the manufacturer. In particular, the instrument must be checked and calibrated on a regular basis with certified sample gases at least every 6 months by a trained and certified operator in gas analysis.

Best regards

TEMC
Dr. Ing. Eugenio Mongelli

P.Iva IT 12974650157 - C.F.MNGGNE65D08H501M - Codice Univoco SDI USAL8PV
Iscrizione REA MILANO 1524315 - Codice Meccanografico MI 301081 - RAEE IT08030000004631 - NATO CAGE: AM649

Appendix 3 : Air purity test procedure

A sample cylinder form pre filled cylinders that are ready for use by prospective customers. The testing procedure to be conducted as follows:

- Pre-assemble the flow restrictor, flow meter and humidity sensor.
- Connect the flow restrictor assembly to the air sample air cylinder. Do not attach the outlet to analyser unit at this point.
- Power up the analyser unit, whilst waiting for the initialisation and warm up procedure to.
- Gently open the cylinder valve and dial in the flow rate to exceed 5 litres per minute.
- Continue the elevated flow until the system has settled and the humidity readings have stabilised.
- Decrease the flow output to read between 2 and 3 litres per minute.
- Affix the flexible tubing to the analyser unit whilst ensuring a consistent flow for several minutes.
- Proceed with the calibration of the oxygen sensor on the analyser unit.
- As soon as the measurements are steady, record the results. A picture of the screen of the analyser would suffice.
- Finally, the analyser can be powered off and the attachments can be safely removed. And packed in their protective case.

Appendix 4 : Raw Data

Air Purity Test

Sample number	Oxygen 21 +/- 1%	CO2 <=500 ppm	CO <=5 ppm	VOC (Oil) <=0.5 mg/m3	Abs Humidity <=25 mg/m3
1	21	110	0	0.1	0
2	20.9	122	0	0	0
3	21	71	0	0	0
4	20.9	153	0	0	0.1
5	21	165	2.4	0.2	0
6	21	130	15.2	0.1	0.1
7	20.9	0	0	0.1	0
8	20.9	142	0	0.1	0
9	21	135	3.6	2.2	0
10	20.8	102	0	0	0
11	20.9	135	0	0	0.1
12	20.9	122	0	0	0
13	21	121	0	0	0
14	21	71	0	0	0
15	21.1	50	0	0	0
16	21	120	0	0	0
17	21.1	92	0	0	0.1
18	20.6	65	0	0	0
19	20.9	100	0	0	0.1
20	21	75	0	0	0
21	20.9	152	0	0	0

Comments

1	ITS course for tank and regulator maintenance, in late Autumn
2	
3	
4	Trained & Authorised persons performing inspections not only to registered & legal dive centres but to all those places filling tanks for scuba purposes.
5	
6	a local set of regulations or law preferably
7	Regular inspection from the authorities
8	As part of the MTA dive centre audits: Perform checks on the calibration certificates for service tools such as cylinder/regulator thread gauges along with checking validity of service technician certificates specific to manufacturer requirements i.e. technicians holding a generic equipment service certificate from 10 years ago are performing jobs on a branded regulation which needs a manufacturer specific training course and certificate. This would be for in-house servicing & the service centres. It feel like the only time (if ever) these items are checked are when something goes wrong as apposed to routine checks.
9	in my opinion a dive centre should not be allowed to perform test cylinders in house
10	xxx
11	
12	
13	
14	
15	
16	The price of air analysis could be better.. There is little available in malat for independent UKAS accredited laboratory analysis just drager tubes..
17	n O T h i n G
18	Requirements for air quality test every 6 months is a joke. During summer, I replace compressor filters twice weekly!
19	a more strictor monitoring for all dive centres
20	

21	
22	Upgrade compressor
23	
24	
25	more informed MTA checks
26	
27	
28	Thing Gas quality on Malta is good
29	
30	
31	Our Diving Cetre follows the actually Standards for Gas blending. We also Cheking our gas quality with our manufacturer of the compressor.
32	
33	Malta should learn to have proper dive centre inspectors, not hotel inspectors.