Scuba air quality

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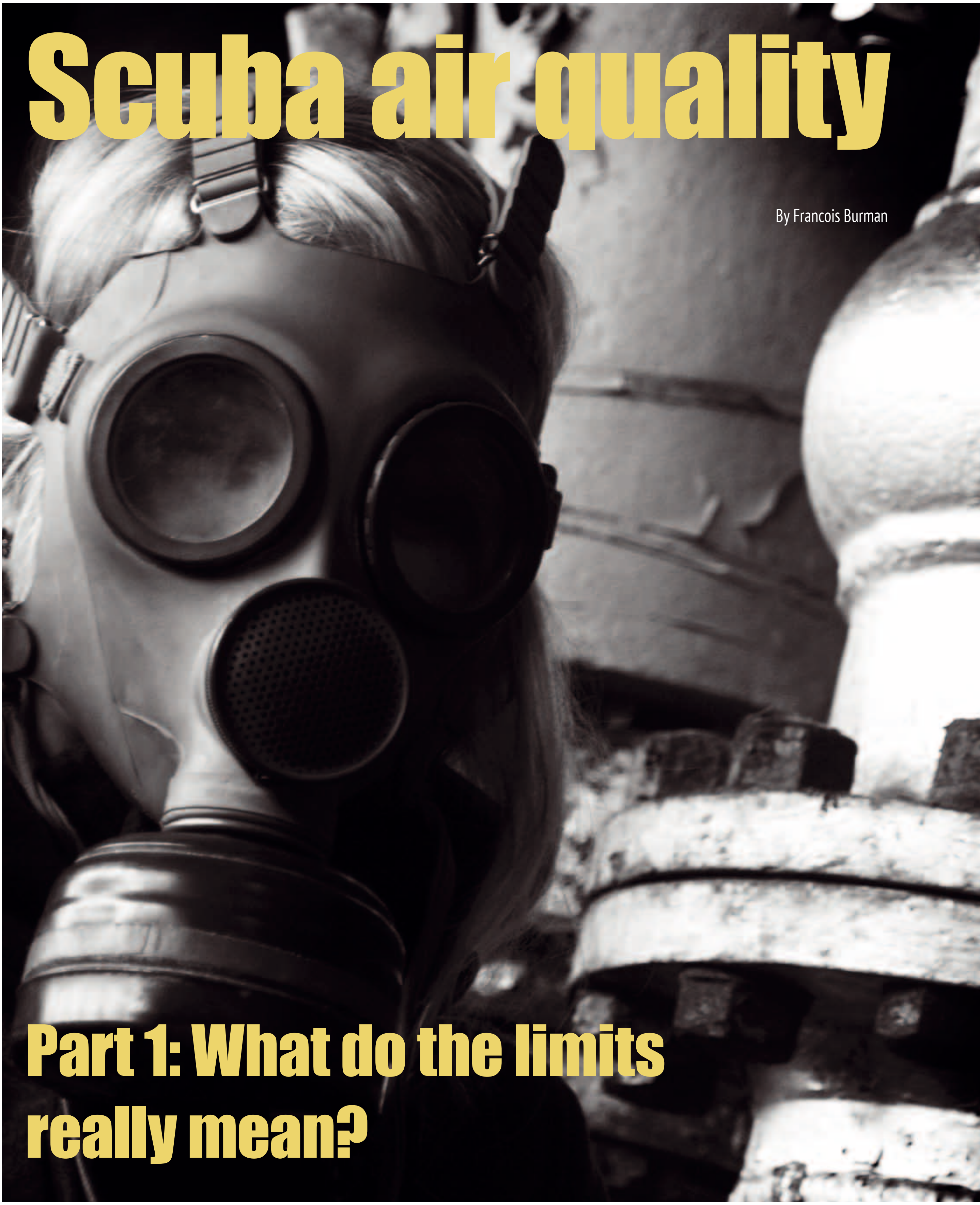

Part 1: What do the limits really mean?

Studies have determined the human impact of contaminants on breathing air.

IN THIS FIRST OF TWO PARTS, THE RATIONALE BEHIND SET CONTAMINANT LIMITS FOR ACCEPTABLE SCUBA AIR QUALITY IS EXPLAINED.

OUR knowledge-base on air quality for scuba diving has traditionally been driven by commercial and military diving practices. These empirically derived requirements were typically based on experience; either on what can realistically be achieved, or on accidents or the lack thereof.

Over the past 50 years or so, medical investigative work has been performed to determine the human impact of common contaminants in breathing air. In addition to this, occupational health and safety approaches, commonly referred to as Hazard Identification and Risk Assessment (HIRA), have been applied where other notable toxic or debilitating elements have found their way into breathing systems.

The first part of this two-part series offers some rationale behind the contaminant limits. In Part 2, a discussion will follow on how breathing air is analysed.

WHAT ARE THESE CONTAMINANTS?

Contaminants can be divided into three levels that represent the likelihood of them occurring in a compressed-air cylinder intended for the diver, namely:

- Those most commonly found in compressed air (carbon dioxide [CO_2], carbon monoxide [CO], moisture [H_2O], condensed oil, particles and odour)
- Those found in certain geographic locations (volatile hydrocarbons and organic compounds such as methane [CH_4])
- Relatively rare but reported toxic substances (for example vapours from cleaning products and halogenated solvents, emissions from motor vehicles, sulphur, and nitrogen-based products and fumes)

The air compression process can only introduce oil (vaporised or condensed), particulates and some amounts of CO_2 and CO. All the other contaminants, including larger amounts of CO_2, CO and especially moisture, must be available in the environment in order to be present in the filled cylinder.

As a general rule, occupational health practices require that we analyse environmental conditions in the vicinity of where we are aware of potential hazards. Compressors used to produce breathing air require a thorough risk analysis prior to site selection of the compressors' intake, with consideration of weather conditions, potential local toxic fumes and exhaust from buildings or internal combustion engines.

Lubricating oils for breathing air compressors are selected on the basis of their high temperature stability, inertness and acceptability for human exposure.

Finally, it remains an accepted fact that we do not monitor or analyse the air that we breathe unless we have reason to be concerned.

We therefore need to be pragmatic in our assessment of limits and, as a general rule, we know that exposure to contaminants in compressed air has mainly occurred due to a loss of controls, external influences and incidents, and where equipment has been neglected.

SAFETY ASSESSMENT

The following table indicates the primary safety concerns (namely human, fire and equipment safety) that apply to the contaminants we are concerned with.

Group 1: Contaminants always potentially present in compressed air

Compound: **Carbon dioxide (CO_2)**
Sources: Ambient environment, internal combustion and cooking processes, human and animal respiration, microbial breakdown of organic matter, conversion of CO to CO_2 in compressor filters, and motor vehicle exhaust systems.
Human safety: Elevated levels stimulate the respiratory centre, increasing rate of breathing. Increase in depth increases respiratory risk. Patients with high PaO_2 are at greater risk of oxygen-induced seizures with elevated $PaCO_2$. Elevated levels lead to minor perceptive changes, discomfort, dizziness or stupor and finally to unconsciousness and even death.
Fire safety: No concerns.
Equipment: No concerns.

Compound: **Carbon monoxide (CO)**
Sources: Ambient environment, internal combustion processes, furnaces, gas burners, cigarette smoke and overheated compressor oils.
Human safety: It decreases the carrying capacity of haemoglobin, resulting in a decreased amount of oxygen available to the tissues which leads to hypoxia. A highly toxic contaminant with environmental levels magnified by increased chamber pressure.
Fire safety: No concerns.
Equipment: No concerns.


There are three levels of contaminants: Commonly found in compressed air, found in certain areas and relatively rare.

Compound: **Moisture (H_20)**
Sources: Ambient environment (humidity), drying processes (laundry), some combustion and other processes.
Human safety: Elevated levels of moisture are desirable (for comfort and reduced dehydration), whereas dry air inhibits growth of bacteria.
Fire safety: Very dry conditions enhance production of static electricity.
Equipment: Excessive moisture may cause regulators to freeze as adiabatic cooling takes place during pressure reduction. Regulators may fail to open causing downstream over-pressurisation of piping and equipment.

Excessive moisture enhances corrosion and oxidation (rust) of air storage vessels.

Excessive moisture causes filtration elements and chemicals to saturate, resulting in reduced filtration efficiency and effectiveness as well as elevated pressure drops. Excessive moisture can interact with some ultra-fine carbon filtration units generating strong chemical odours and resulting in nausea and respiratory irritation.

Compound: **Oil (condensed)**
Sources: Mostly compressor lubricating oil (introduced internally). Also from ambient evaporated oil from compressor oil leaks and surrounding equipment, motor vehicle exhaust fumes, pollens (introduced through the compressor intake), and even contaminated air pipes between the air processing plant and the chamber.
Human safety: Larger condensed particles are removed by the body's clearance mechanisms; smaller particles are retained and may be hazardous depending on the type and the amount (symptoms include inflammation or even rupturing of alveoli).
Fire safety: There are significant fire concerns, irrespective of the type of condensed oil.
Equipment: There is no concern at the levels usually controlled for. The maximum level of 5 mg/m³ equates to a dew point temperature of -64°C, or 6 ppm_v, which is significantly lower than the lowest required levels for H_20.

Compound: **Particles**
Sources: Ambient environment (micro-particles of dust and pollens); breakdown products in compressors, piping systems and filtration media; as well as post-construction debris in pipes and controls.
Human safety: Particles smaller than 10 µm have the potential to cause shortness of breath, especially in patients with respiratory conditions (e.g. asthma and bronchitis), as well as a reduction in the ability to resist infection.
Fire safety: Large concentrations of particulates can serve as a source of ignitable fuel.
Equipment: Larger particles are known causes of failure in pressure regulators, which may cause valves not to seal when closed and may erode valve seats, discs and seals.

Compound: **Odour**
Sources: Ambient environment and cleaning compounds used on air supply systems.
Human safety: It is generally only related to comfort levels. Odours from volatile, toxic or otherwise harmful substances indicate potential safety issues related to these contaminants.
Fire safety: There is no concern from odour. Contaminants with fire risks (oils, volatile organic compounds [VOC], etc.) are discussed under the relevant contaminant sections.
Equipment: No concerns.

> “PATIENTS WITH HIGH PaO_2 ARE AT GREATER RISK OF OXYGEN-INDUCED SEIZURES WITH ELEVATED $PaCO_2$.

Group 2: Contaminants present in specific areas

This group may be significantly larger than discussed here, but the following analysis serves to indicate where potential hazards may exist for clinical hyperbaric facilities.

Volatile hydrocarbons include organic compounds. However, methane is the most commonly occurring compound of these compounds and is separated from the analysis.

Some standards require that all hydrocarbons be grouped as a total hydrocarbon (THC) limit. This does not allow for easy identification of potential sources.

Contaminant: **Volatile hydrocarbons and VOC**
They include, but are not limited to, toluene, xylene, benzene, ethane, styrene and acetone.
Sources: Ambient environment as a result of exposure to building materials, plastic materials, industrial chemicals, and cleaning compounds, adhesives, furniture, flooring, heating and combustion processes. Overheating compressors are reported as a potential source.
Human safety: Generally hazardous in terms of carcinogens, neurological and narcotic effects, organ damage as well as general distress. Initial symptoms include fatigue, headaches, confusion, numbness, cardiac irritation and depression.
Fire safety: There are significant fire concerns in terms of low ignition temperature and low flashpoint fuels.
Equipment: There is no significant concern at the expected levels.

Compound: **Methane (CH_4)**
Sources: Ambient environment, especially in certain geological areas and near decaying or fermenting organic matter, landfills or domestic animals (cattle). CH_4 may permeate buildings and enter the compressor intake.
Human safety: It is not toxic (may be an asphyxiant where oxygen is reduced to below 16%).
Fire safety: There are significant fire concerns with CH_4 because it is a highly flammable fuel.
Equipment: No concerns.

Some common contaminants are always potentially present in compressed air.

> PARTICLES SMALLER THAN 10 MM HAVE THE POTENTIAL TO CAUSE SHORTNESS OF BREATH.

Group 3: Rare but reported contaminants

This group is too diverse and extensive to discuss in a similar fashion to the previous two groups.

Typical contaminants include vapours from cleaning products or solvents that are not covered under Group 2 as well as environmental compounds including hydrogen sulphide (H_2S), SO_2, NO, N_2O, NO_2, NO_x fumes, ozone, lead compounds, asbestos and many others.

Each of these has specific deleterious effects on humans, but there are neither significant fire issues nor equipment issues – at least not in the concentrations expected in the air.

Nitrogen oxide products, loosely referred to as NO_x, are associated with decreased lung function, increased severity of respiratory problems, chronic inflammation and irreversible structural changes, amongst other related respiratory conditions and complications.

Most occupational health and safety regulations for any public enterprise provide regulations, limits and guidelines for identification and exclusion. In terms of this article, we will exclude several of these from the requirements for acceptable air quality for scuba diving and accept that they will be controlled by occupation HIRA practices.

WHAT ARE SAFE LIMITS?

The limits depicted in the table below are based on the effect on the human physiology, the fire risks and the risks to equipment.

All human exposure limits are expressed as the surface equivalent value (SEV) and for the purposes of air diving a maximum depth of 50 metres of seawater (MSW) is assumed. Limits tabulated are generally stated as the "no-effect level" which is the dose with no known toxic or debilitating effects.

FINALLY, A NOTE ON SOUTH AFRICAN REGULATIONS

Traditionally, our local regulations were contained in a standard known as SABS 019, the code of practice for transportable compressed gas containers. This regulation contained a table listing limits for impurities in compressed air for breathing. However, the latest revision of this standard no longer contains this table and instead we are referred to SABS 532 (issued in 2009 as SANS 532) which is the standard for industrial, medical, propellant, food and beverage gases, refrigerants and breathing gases.

We have lost some of the required guidance in this process and DAN-SA, together with the Compressed Gas Association of South Africa, has requested the SABS to provide an update to SABS 532 to include limits for the common contaminants of concern to scuba divers. We have hopefully provided practical, achievable and realistic limits for their consideration. AD

Contaminant Safe Limits

	Human exposure	Fire risk	Equipment risk	Achievable	SABS limits
CO_2	5 000 ppm_v for $pO_2 \geq 3$ ATA 15 000 ppm_v for $pO_2 \leq 1.6$ ATA	None	None	≤ 350 ppm_v Normal air contains 300 ppm_v	SABS 532: < 500 ppm_v SABS 019: < 500 ppm_v
CO	60 ppm_v	None	None	≤ 5 ppm_v	SABS 0532: NS SABS 019: < 10 ppm_v
H_20	RH: ≤ 50% – 60% Based on control of bacterial growth	RH: > 30% Dew point > 3°C	HP: Lowest ambient less than 44°C	Dew point -64°C based on 5 mg/m³	SABS 532: < 100 ppm_v SABS 019: < 25 mg/m³ < 200 bar: < 50 mg/m³ > 200 bar: < 35 mg/m³
Oil	≤ 5 mg/m³	≤ 0.1 mg/m³	None at ≤ 5 mg/m³	≤ 0.5 mg/m³	SABS 532: NS SABS 019: < 0.5 mg/m³
Particles	≤ 50 mg/m³ No particles ≤ 10 µm	≤ 5 mg/m³	No limits determined	0.01 mg Size 0.5 µm	SABS 532: NS SABS 019: < 0.5 mg/m³ for particles > 5 µm
Odour	None	None	None	None	None
VOC	≤ 5 ppm_v	LEL ≤ 1% Limit 1 000 ppm_v	None	≤ 5 ppm_v	OHS requirement
CH_4	≤ 5% (5 x 104 ppm_v)	LEL ≤ 5% Limit 5 000 ppm_v	None	10 ppm_v	OHS requirement
H_2S	≤ 50 ppm_v	None	>> Human limit	≤ 1 ppm_v	OHS requirement
SO_2	≤ 5 ppm_v	None	None	≤ 1 ppm_v	OHS requirement
NO_x7	≤ 10 ppm_v	None	None	≤ 0.5 ppm_v	OHS requirement