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Breathing Rates and Breathing Air Constituents

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Abstract
The abstract summarizes use of various factors to be considered for using calculation of breathing air usage. It also discusses human body metabolism and the variations in breathing rates. This article provides various codes and standards TLV values.

Keywords: Breathing air, EN12021, Oxygen, and TLV**.**

1. Introduction

Normal dry air, at standard temperature and pressure (STP of 101.325 kPa and 0°C), consists of 20.95 per cent oxygen, 78.08 per cent nitrogen, 0.0314 per cent carbon dioxide, 0.93 per cent argon and trace amounts of 14 other gases. It may be noted that these are expressed by volume; the proportions are different if expressed by mass. For humans, there are two principal metabolic fuels. Glycogen (carbohydrate) is the primary fuel used by muscle as workload increases. It has an RQ (respiratory quotient) of 1.0. RQ is the steady state ratio of the volume of carbon dioxide produced to the volume of oxygen consumed. Fatty acids, the other metabolic fuel, are used more at rest and have an RQ of 0.7. The average RQ that results from constant low levels of activity, as expected in entrapped conditions, is about 0.80. This RQ can then be used to then calculate the amount of carbon dioxide produced as oxygen is consumed. The metabolism of one liter of oxygen produces 20 kJ of metabolic heat.

2. Work rate

At complete rest and in a non-stressed state, a 70 kg person will breath in air at a rate of about 7.5 litres per minute and expire air at 17 per cent oxygen and 3.2 per cent carbon dioxide. This results in a ‘resting’ oxygen uptake of 0.3 litres of oxygen per minute and a resting carbon dioxide discharge of 0.24 litres per minute. However, the rate of breathing is primarily triggered by the carbon dioxide content of inspired air with higher carbon dioxide levels triggering faster respiration rates. Moreover, it does not take a significant increase in activity levels, or body weight, to make a substantial increase in metabolic rates and thus oxygen consumption and carbon dioxide production. Venter et al (1998a) found an average oxygen consumption for 12 entrapped individuals of 0.44 litres per minute, at STP, over 24 hours (including sleeping). A figure of 0.5 litres per minute over a non-sleeping entrapment period of 12 hours is a prudent, conservative design value. This corresponds to a metabolic rate of about 160 W or 80 W/m2 for a typical miner with a body skin area of about 2 m2, which is equivalent to a breathing rate of about 12.5 litres per minute of fresh air.

3. Carbon dioxide

Carbon dioxide is twenty times more soluble in blood than is oxygen (McPherson, 1993). As the carbon dioxide content of the inspired air rises, the breathing rate becomes faster. Normal air is 0.03 per cent carbon dioxide or 300 ppm. The TLV-TWA (time-weighted threshold limit value) for carbon dioxide is 5000 ppm (0.5 per cent) , headache and an increased rate of breathing occur at 10 000 ppm (1%), the TLV-STEL (short-term exposure limit) is 30 000 ppm (3%) (resulting in a doubling of normal breathing rate), panting and intoxication occur above 50 000 ppm (5%) with unconsciousness occurring at about 100 000 ppm (10%). These figures apply where the oxygen content of the air is normal. Note that the maximum carbon dioxide content in self-contained self-rescuer operation, under the European Standard EN401-1993 (Chemical Oxygen Escape Apparatus), is limited to a maximum of three per cent or 30 000 ppm (and to an average of 1.5 per cent).

4. Oxygen

Perhaps surprisingly, a declining oxygen content triggers only a minor increase in breathing rate, this being governed by the carbon dioxide content of inspired air as discussed above. The normal lower working limit for oxygen is 19 per cent. At 18 per cent there is a slight increase in breathing effort. At 16 per cent, a flame lamp will go out, but this still continues to trigger only a slight increase in heart and breathing rates. At 14 per cent, emotional upset, impaired judgement and faulty co-ordination occur. At 12 per cent, cardiac damage can occur along with vomiting. At 10 per cent, a person would lapse into unconsciousness and death (Hartman et al, 1997). Again, these figures apply where the carbon dioxide content of the air is normal. Note that the minimum oxygen content in self-contained self-rescuer operation, under the European standard EN401, is limited to 21 per cent with an excursion to 17 per cent for up to two minutes at the start of SCSR operation. The minimum oxygen content under the Guidelines for Safe Mining (Anon, 1996) is 17 per cent whilst the minimum allowed under Worksafe Australia Standard is 18 per cent (Anon, 1990).

5. Oxygen and carbon dioxide limits

There are no known hard and fast rules for establishing simultaneous limits to low oxygen and high carbon dioxide concentrations for emergency situations (Schroder, 1989). However, based on EN401 guidelines for self-rescuers, the analysis given above, and the fact that the combined physiological cost to the body of simultaneous low oxygen and high carbon dioxide levels will be greater than that if only one or the other were to occur, suitable 'emergency' working limits for the design of ERSs would be:

- For 'open' systems such as compressed air: 19 per cent oxygen and 0.5 per cent (5000 ppm) carbon dioxide; and
- For 'closed' systems, 18 per cent oxygen and 1.25 per cent (12 500 ppm) carbon dioxide, which is also in accordance with other guidelines (Anon, undated).

It can be shown that for a person breathing at a rate of 12.5 litres per minute within a 'dead air' space of one cubic metre, an oxygen level of 18 per cent will be reached at 58 minutes. Whereas carbon dioxide levels will reach the TLV of 0.5 per cent at only 12 minutes, and the 'upper' working limit of 1.25 per cent at 30 minutes. This indicates that the air supply to an ERS is governed by the rate of build-up of carbon dioxide, and not the drop in oxygen. This has been confirmed in 24 hour tests done by Venter High oxygen limits Some of the chemical devices for providing oxygen result in very high levels of oxygen in the chamber. This can result in oxygen levels of over 50 per cent in the enclosure

At rest	7.5 l/m	17%	3.2%	0.3 l/m
Entrapped	12.5 l/m			0.5 l/m
Walking	26 l/m			1.2 l/m
Max.exert	65 l/m			0.65 l/m

Agency standards for CO_2 in the work place

Agency	Low end CO2	High end CO2
OSHA PEL	5000 TWA	30,000 STEL
ACGIH TLV	5000 TWA	30,000 STEL
NIOSH REL	5000 TWA	30,000 STEL

[1]Applies to CO2 concentration in the workplace considered safe for a 40-hour week.
[2]Based on a 10-minute period for NIOSH and a 15-minute period for OSHA and ACGIH.
PEL = Permissible Exposure Limit
TLV = Threshold Limit Value
REL= Recommended Exposure Limit
TWA= Time Weighted Average
STEL= Short Term Exposure Limit

6. Air Temperature to End-User

The temperature of the breathing air supplied to the end user shall be within the normal comfort zone of 22°C ± 3°C. Transients in air temperature shall be tolerable, however, only for short periods as follows:
(i) 26°C to 29°C for maximum period of 15 minutes.
(ii) 30°C to 34°C for maximum period of 5 minutes.
The end user air supply temperature shall not exceed 35°C at any time to ensure operating personnel comfort.

7. Conclusions

It is essential to consider all the parameters listed above while designing the Breathing air system and during operations of these system, the quality of the air needs to be tested once in a month to ensure the quality of the air meets the Breathing air standard EN 12021.

Oxygen	21±1% by volume of dry air
Contaminants	No contaminants
Lubricants	Not exceeding 0.5 mg/m^3
Odour and taste	The air shall be without significant odour or taste.
Carbon di oxide(CO_2)	not exceed 500 ml/m^3 (500 ppm).
Carbon monoxide	not exceed 15 ml/m^3 (15 ppm).
Water content	No free liquid water
Dew point	Air for compressed air line breathing apparatus shall have a dewpoint sufficiently low to prevent condensation and freezing.

References

[1] D.J Brake and G.P Bates, Criteria for the design of emergency refuge stations for an underground metal mine By D J Brake1, Fellow and G P Bates2
[2] Drager Australia Fresh air bases
[3]EN 12021 Respiratory Protection devices and Breathing air.