# Gas Mix Calculations

## BEST TRIMIX GAS CALCULATIONS FOR OPEN AND CLOSED CIRCUIT DIVING

By David Schranz
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# Outline

- Present best gas mix formulas for open and closed-circuit diving
  - $FO_2$ and $FHe$ are needed to blend Trimix
- Standard OC approach – Fix $PO_2$ and $PN_2$.
- Standard OC methodology extended to closed circuit.
- OC gas mix formulas based on gas density (work of breathing).
- OC gas density-based formulas extended to CC

The formulas in this presentation are based on two papers:

- “CCR Loop Gas Fractions” by David Schranz, May 2025
- “Best Gas Mix” by David Schranz, May 2025

# A Few remarks….

- Capital “$F$” for gas fraction. “$d$” superscript refers to diluent gas. e.g. $FHe^{d}$
- Capital “$P$” for partial pressure
- “$D$” for depth, “$D_{ata}$” for depth expressed in Atmospheres absolute pressure units.
- The small letter “$d$” is used for densities. e.g. $d_{He}$ is the density of Helium
- TGD for Target Gas Density
- SP: CC loop Set Point
- DF: partial pressure of Oxygen resultant from **D**iluent loop **F**lush at $D_{ata}$
- Gas density Temperature dependency ignored. Consult “Best Gas Mix” reference for full temperature results

# OC Standard approach

Gas Fractions:

$$FO_2 = \frac{PO_2}{D_{ata}} \qquad FN_2 = \frac{PN_2}{D_{ata}} \qquad FHe = 1 - FO_2 - FN_2$$

$D_{ata}$: Target operating depth expressed in ATM absolute

$PO_2$ : Target partial pressure of Oxygen at TOD

$PN_2$ : Target partial pressure of Nitrogen at TOD

# CC Standard Case - Example

- Calculate Best Mix for OC Dive to 180fsw using IANTD guidelines for $PO_2$ and an EAD of 80fsw.

$D = 180fsw \rightarrow D_{ata} = \frac{180}{33} + 1 = 6.45\,ata$

$EAD = 80fsw \rightarrow 80fsw = \frac{80}{33} + 1 = 3.42\,ata \therefore PN_2 = 0.791 \times 3.42 = 2.71$

IANTD guideline for max $PO_2$ @ TOD is $PO_2 \leq 1.4$

$\therefore FO_2 = \frac{1.4}{6.45} = 0.217$

$FN_2 = \frac{2.71}{6.45} = 0.418$

$\therefore FHe = 1 - 0.217 - 0.418$

$= 0.365$

BEST GAS MIX IS:

TMX 21.7/36.5

OR

TMX 21/37

# CCR Gas Fractions

- Closed circuit divers typically carry Oxygen and Diluent gas
- The gas in the loop is a mixture of diluent and oxygen as the eCCR maintains set point. The inspired loop gas is what we must consider when constraining Oxygen Toxicity, Narcosis and Work of Breathing.
- We distinguish between the gas loop fractions: $FO_2\,, FN_2, FHe$ and the diluent gas fractions: $FO_2^d, FN_2^d, FHe^d$
- We specify the loop set point as $SP$ and the loop $PO_2$from a complete diluent loop flush $DF$
- Introduce parameter, $\omega$, that gives the amount of dilution of $N_2$ and $He$ when loop brought to setpoint
- Relationship between loop and diluent gas fractions are

$$FO_2 = \frac{SP}{D_{ata}} \qquad FO_2^d = \frac{DF}{D_{ata}}$$

$$FN_2 = \ \omega\, FN_2^d$$

$$FHe = \ \omega\, FHe^d$$

$$\omega = \frac{D_{ata} - SP}{D_{ata} - DF}$$

# CCR Gas Fractions - Example

- CC set point is 1.1 and diluent gas is TMX 14/43. What are the breathing loop gas fractions at 180fsw?

$D = 180\,fsw \rightarrow D_{ata} = 6.45\,atm$  TMX 14/43 $\rightarrow$

$F_{O_2}^d = 0.14$

$F_{He}^d = 0.43$

$F_{N_2}^d = 1 - 0.14 - 0.43 = 0.43$

Need $\omega$ to convert diluent gas fractions to loop gas fractions

$$\omega = \frac{D_{ata} - SP}{D_{ata} - DF}$$

$SP = 1.1$, $DF = PO_2$ of dil flush at $D_{ata}$

$= 0.14 * 6.45 = 0.90$.

$$= \frac{6.45 - 1.1}{6.45 - 0.9} = 0.964$$

$\therefore$ $F_{O_2} = \frac{SP}{D_{ata}} = \frac{1.1}{6.45} = 0.17$

$F_{He} = \omega F_{He}^d = 0.964 * 0.43 = 0.415$

$F_{N_2} = \omega F_{N_2}^d = 0.964 * 0.43 = 0.415$

$\therefore$ Breathing loop gas fractions are:

$F_{O_2} = 17\%$

$F_{He} = 41.5\%$

$F_{N_2} = 41.5\%$.

# CC Standard Case

- Diluent Gas Fractions:

$$FO_2^d = \frac{DF}{D_{ata}} \qquad FN_2^d = \frac{1}{\omega}\frac{PN_2}{D_{ata}} \qquad FHe^d = 1 - FO_2^d - FN_2^d$$

$D_{ata}$: Target operating depth expressed in ATM absolute

$DF$: $PO_2$ in loop after diluent flush at TOD

$SP$: CC Set Point

$PN_2$: Target partial pressure of Nitrogen at TOD

$\omega = \frac{D_{ata}-SP}{D_{ata}-DF}$

# CC Standard Case - Example

- Calculate best diluent mix for a CCR dive to 180fsw with a set point of 1.1, diluent flush $PO_2$ of 0.9 and a max $PN_2$ of 2.70.

$D = 180fsw \rightarrow D_{ata} = 6.45$ $EAD = 80fsw \rightarrow FN_2 = 2.70$

$SP = 1.1$
$DF = 0.9$ $\Rightarrow w = \frac{D_{ata} - SP}{D_{ata} - DF} = \frac{6.45 - 1.1}{6.45 - 0.9} = 0.964$

$\therefore FO_2^d = \frac{DF}{D_{ata}} = \frac{0.9}{6.45} = 0.14$

$FN_2^d = \frac{1}{w} \frac{FN_2}{D_{ata}} = \frac{1}{0.964} \frac{2.70}{6.46} = 0.434$

$FHe^d = 1 - FO_2^d - FN_2^d$
$= 1 - 0.14 - 0.434$
$= 0.426$

$\therefore$ Best Gas Mix is

TMX 14/42.6

or

TMX 14/43

# OC Gas Density / WOB

- The OC gas fraction formulas for the Gas Density / Work of Breathing case are:

$$FO_2 = \frac{PO_2}{D_{ata}} \qquad FHe = \frac{PO_2 \cdot d_{O_2} + (D_{ata} - PO_2) \cdot d_{N_2} - TGD}{D_{ata} \cdot (d_{N_2} - d_{He})} \qquad FN_2 = 1 - FO_2 - FHe$$

$D_{ata}$: Target operating depth expressed in ATM absolute

$PO_2$ : Target partial pressure of Oxygen at TOD

$TGD$: Target breathing gas density at TOD

$d_{O_2} = 1.428\ g/L$

$d_{N_2} = 1.251\ g/L$

$d_{He} = 0.179\ g/L$

$d_{N_2} - d_{He} = 1.072\ g/L$

# Gas Density Formula Intuition

Consider a nitrox gas composed of $O_2$ with fraction given in GD formula ($FO_2 = \frac{PO_2}{D_{ata}}$)

At $D_{ata}$, the Gas Density of the hypothetical gas

gas den = $D_{ata}$*($FO_2$* $d_{O_2}$) + ($D_{ata} - PO_2$)*$d_{N_2}$ $= PO_2 \cdot d_{O_2} + (D_{ata} - PO_2) \cdot d_{N_2}$

The Numerator of the $FHe$ formula is the amount that the gas dens of the nitrox gas is over the TGD.

We then take this excess density and divide it by $D_{ata} \cdot (d_{N_2} - d_{He})$ which the difference between $N_2$ gas and $He$ density at $D_{ata}$.

$$FHe = \frac{PO_2 \cdot d_{O_2} + (D_{ata} - PO_2) \cdot d_{N_2} - TGD}{D_{ata} \cdot (d_{N_2} - d_{He})}$$

# OC Gas Density / WOB Example

- Calculate Best Mix for OC Dive to 180fsw using IANTD guidelines for $PO_2$ and a maximum breathing gas density of 5.2g/L.

180fsw → $D_{ata} = 6.45$ atm

TGD = 5.2 g/L

$PO_2 = 1.4$

$$FO_2 = \frac{PO_2}{D_{ata}} = \frac{1.4}{6.45} = 0.217$$

$$F_{He} = \frac{PO_2 \cdot d_{O_2} + (D_{ata} - PO_2) d_{N_2} - TGD}{D_{ata}(d_{N_2} - d_{He})}$$

$$= \frac{1.4(1.428) + (6.45 - 1.4)(1.251) - 5.2}{6.45(1.072)}$$

$$= \frac{(2.00 + 6.32) - 5.2}{6.91}$$

$$= \frac{3.12}{6.91} = 0.45$$

∴ Best Gas Mix is

TMX 21.7/45

Note: the standard approach from previous example gave a mix TMX 21.7/36.5

# CC Gas Density / WOB

- The CC gas fraction formulas for the Gas Density / Work of Breathing case are:

$$FO_2^d = \frac{DF}{D_{ata}} \qquad FHe^d = \frac{SP \cdot d_{O_2} + (D_{ata} - SP) \cdot d_{N_2} - TGD}{\omega \cdot D_{ata} \cdot (d_{N_2} - d_{He})} \qquad FN_2^d = 1 - FO_2^d - FHe^d$$

| | |
|---|---|
| $D_{ata}$: | Target operating depth expressed in ATM absolute |
| $DF$: | $PO_2$ in loop after diluent flush at TOD |
| $SP$: | CC Set Point |
| $TGD$: | Target breathing gas density at TOD |

$$d_{O_2} = 1.428\ g/L \qquad \omega = \frac{D_{ata} - SP}{D_{ata} - DF}$$

$$d_{N_2} = 1.251\ g/L$$

$$d_{He} = 0.179\ g/L$$

$$d_{N_2} - d_{He} = 1.072\ g/L$$

# CC Gas Density / WOB Example

- Calculate best diluent mix for a CCR dive to 180fsw with a planned set point of 1.1 and a diluent flush $PO_2$ of 0.9 and a maximum loop gas density of 5.2g/L.

$D = 180\,fsw \rightarrow D_{ata} = 6.45$

$SP = 1.1,\ DF = 0.9$

$TGD = 5.2$

$\therefore\ w = \frac{D_{ata} - SP}{D_{ata} - DF} = \frac{6.45 - 1.1}{6.45 - 0.9} = 0.964$

$FO_2^{d} = \frac{DF}{D_{ata}} = \frac{0.9}{6.45} = 0.14$

$FHe^{d} = \frac{SP \cdot d_{O_2} + (D_{ata} - SP)\, d_{N_2} - TGD}{w \cdot D_{ata} \cdot (d_{N_2} - d_{He})}$

$= \frac{1.1(1.428) + (6.45 - 1.1)(1.251) - 5.2}{0.964 * 6.45 * 1.072}$

$= 0.46$

$\therefore$ Best Gas mix is

Tmx 14/46

[compared to a mix of Tmx 14/43 from the standard approach.]

# Summary

| All cases assume a $D_{ata}$ pressure depth | OC/Standard | CC/Standard | OC/Gas Density | CC/Gas Density |
|---|---|---|---|---|
| Input Params | $PO_2$, $PN_2$ | $SP$, $DF$, $PN_2$ | $PO_2$, $TGD$ | $SP$, $DF$, $TGD$ |
| Intermediate Calcs | $FN_2 = \frac{PN_2}{D_{ata}}$ | $\omega = \frac{D_{ata} - SP}{D_{ata} - DF}$ <br> $FN_2^d = \frac{1}{\omega} \frac{PN_2}{D_{ata}}$ | | $\omega = \frac{D_{ata} - SP}{D_{ata} - DF}$ |
| Fraction Oxygen | $FO_2 = \frac{PO_2}{D_{ata}}$ | $FO_2^d = \frac{DF}{D_{ata}}$ | $FO_2 = \frac{PO_2}{D_{ata}}$ | $FO_2^d = \frac{DF}{D_{ata}}$ |
| Fraction Helium | $FHe = 1 - FO_2 - FN_2$ | $FHe^d = 1 - FO_2^d - FN_2^d$ | $FHe = \frac{PO_2 \cdot d_{O_2} + (D_{ata} - PO_2) \cdot d_{N_2} - TGD}{D_{ata} \cdot (d_{N_2} - d_{He})}$ | $FHe^d = \frac{SP \cdot d_{O_2} + (D_{ata} - SP) \cdot d_{N_2} - TGD}{\omega \cdot D_{ata} \cdot (d_{N_2} - d_{He})}$ |
| | | | $d_{O_2} = 1.428\ g/L$ $\quad d_{N_2} = 1.251\ g/L$ <br> $d_{He} = 0.179\ g/L$ $\quad d_{N_2} - d_{He} = 1.072\ g/L$ | |

# Gas Density fractions done Simple!

- Example: $SP = 1.1,\ DF = 0.9,\ D_{ata} = 10.1,\ TGD = 5.2g/L$

1. Calculate $\omega$

   $$\omega = \frac{D_{ata} - SP}{D_{ata} - DF}$$

   $$\omega = \frac{10.1 - 1.1}{10.1 - 0.9} = 0.978$$

2. Calculate Heavy Nitrox Density

   $$SP \cdot d_{O_2} + (D_{ata} - SP) \cdot d_{N_2}$$

   $$1.1 \times 1.428 + 9 \times 1.251 = 12.830$$

3. Subtract TGD

   $$-5.2 = 7.63$$

4. Divide $\omega$

   $$\div 0.978 = 7.80$$

5. Divide by $D_{ata}$

   $$\div 10.1 = 0.772$$

6. Divide by $d_{N_2} - d_{He}$

   $$\div 1.072 = 0.72 = FHe^d$$

7. Calculate $FO_2^d$

   $$FO_2^d = \frac{0.9}{10.1} = 0.089$$

TMx 8.9/72