**Primary Sources**

[US Navy Diving Manual - revision 7 2016](https://www.navsea.navy.mil/Portals/103/Documents/SUPSALV/Diving/US%20DIVING%20MANUAL_REV7.pdf?ver=2017-01-11-102354-393) - USNDM

[MK 25 Mod 2 Underwater Breathing Apparatus Technical Manual](https://navytribe.files.wordpress.com/2015/11/navsea-ss600-a3-mma-010.pdf) - MK25 TM

Looking for a manual for the MK 16 UBA, the civilian version was the CCR 1000.

**General Knowledge**

**Abbreviations**

atm - Atmosphere of pressure

pp - Partial pressure

msw - meter of sea water

fsw - feet of sea water

UBA - Underwater breathing apparatus

**Water Pressure[[1]](#footnote-0)**

1 atmosphere of pressure is exerted at sea level. Each 10 msw (equivalent to approximately 33 fsw) is equal to an additional 1 atmosphere of pressure. Example - 30 msw exerts a pressure of 4 atmospheres.

**Partial Pressure of gas [[2]](#footnote-1)**

The fraction of a given gas in a given volume multiplied by the pressure of the gas. On the surface this is basically the percentage of each gas. At 2 atmospheres of pressure it is double the base percentage, etc.

Example - Air is 21% oxygen. At 1 atmosphere of pressure (the surface) the partial pressure of O2 (ppO2) is .21. At 2 atmospheres of pressure the ppO2 is .42. At 5 atmospheres of pressure the ppO2 of air is 1.05.

**Breathing[[3]](#footnote-2)**

Respiratory Rate - Number of complete breathing cycles in 1 minute. Breathing occurs at a relaxed state of approximately 12-16 breaths, and exercising can exceed 30 breaths per minute.

Tidal Volume - The amount of air inhaled AND exhaled in 1 breath. Tidal volume at rest is approximately 1 half liter, and can exceed 3 liters at severe exertion. So the amount of **inhaled** breathing gas is ½ the tidal volume.

Respiratory Minute Volume - Tidal volume summed over the course of a minute. So the amount of **inhaled** breathing as is ½ respiratory minute volume.

Oxygen Consumption - Oxygen consumption is depth independent(is not related to diving depth), rather it is related to the metabolic workload of the individual. It can range from .3 l/min at rest to over 4 l/min at severe exertion.[[4]](#footnote-3)

Breathing Gas Inhalation- The amount of inhaled breathing gas is depth dependent. On the surface at 1 atm swimming requires approximately 30 l/min. At 10msw the pressure is now 2 atm, so the gas only occupies half the normal volume. Hence it will take twice as much gas to fill the same space. It will require 60 l/min of gas to swim at the same exertion level. Functionally this means the volume of gas respirated dramatically increases as depth increases.[[5]](#footnote-4)

**Medical Issues with Diving[[6]](#footnote-5)**

Humans function without issue between about .16 and 1.3 ppO2. There are outliers of course, and it’s not actually fatal until you get a good deal beyond these values. There are significant psychomotor issues and medical concerns with being outside of these ranges however. Hypoxia is too little O2, symptoms begin below a ppO2 .16, and a ppO2 of .10 is unconsciousness[[7]](#footnote-6). Too much O2 can cause Central Nervous System Oxygen Toxicity, these begin around a ppO2 of 1.3.[[8]](#footnote-7) The longer the exposure to high ppO2 levels and the higher the ppO2 the greater the risk.

Nitrogen causes a narcotic effect, starting at a ppN2 of 4.[[9]](#footnote-8) Nitrogen narcosis clears quickly once the ppN2 is lowered with no lasting effects. Most individuals are heavily affected by 200 fsw (approximately 60msw), which on compressed air would be a ppN2 of 5.5, some can function deeper than this.[[10]](#footnote-9)

Decompression - **To be researched**

**General Underwater Breathing Apparatus Information**

**Open Circuit**

This is what most people think when they think of “SCUBA diving.” There is a tank with breathing gas(this can be mounted/carried pretty much anywhere on the diver), and a hose that runs to a mouthpiece. The diver inhales breathing gas from the mouthpiece and when they exhale, the gas is exhausted into the ocean.

**Closed Circuit**

Any UBA where the exhaled gas is not exhausted into the water. Shore supplied diving with an umbilical is an example of a closed circuit system.

**Semi Closed Circuit**

A UBA where some of the gas in the breathing loop is exhausted at some point. Pretty much all rebreather systems that are used below 50m are semi closed when ascending.

**Rebreathers**

As the name implies the breathing gas is either wholly or partially reused. At the most basic breathing into and out of a plastic bag is a rebreather (not a safe one however). Functional rebreathers have some mechanism to remove CO2 from the breathing loop, and to replace the oxygen that is metabolized.

Closed circuit UBAs don’t create a noise or visual signature with the gas exhaust. Semi-closed circuit systems are just as low signature as closed circuit systems, except when rapidly ascending. Rebreathers provide massively extended dive times compared to open circuit UBA’s.

Rebreather systems do not tolerate water in the system well. A flooded rebreather is basically useless, and is not field serviceable. There are many failure points (human, mechanical, and electronic) on rebreathers that can kill you. Open circuit systems can’t really be flooded, and in general are extremely sturdy (you’ll break before the gear does), and relatively simple to maintain and use.

Military diving is done across all UBA types. Closed circuit rebreathers using pure O2 as the breathing gas are what most people think of for “combat diving.” They are depth limited to about 17 msw (50fsw per the manuals), and are in general to be operated at depths of 6 msw/20 fsw or shallower.[[11]](#footnote-10) A semi-closed rebreather is used when the depth required exceeds the capabilities of a pure O2 closed circuit system. Open circuit systems can be used in non-tactical situations, or situations where the visual or audible signature risk is not a concern (foul weather or heavy surface activity).

**MK 25 Mod 2 UBA[[12]](#footnote-11)**

Pure O2 closed circuit rebreather

Capacity - 410 liters of O2 at 207 bars in a 1.9 liter tank [[13]](#footnote-12)

Operates at a partial pressure of approximately .75 O2. [[14]](#footnote-13)

Operating depth - Expected 20 fsw, max of 50 fsw for short periods[[15]](#footnote-14)

In short the MK 25 operates by purging the breathing loop and breathing bag initially to lower the amount of air in the system and replace it with pure O2. This gives it an approximate ppO2 of .75. Once the diver is breathing off the mouthpiece, when they inhale the breathing bag deflates. If it fully deflates the demand valve trips and more O2 is added until the inhalation is completed. On exhalation, the exhaled gas is passed through the CO2 scrubber and back into the breathing bag. The exhaled gas has a decreased volume, having lost the consumed O2. This gas volume is replaced by the demand valve at the next inhalation. As there is no exhausted gas, this means only the portion of each breath that is metabolized oxygen is consumed. Over a minute's time 30 l of O2 might be inhaled, but only 1.4 l of O2 is actually metabolized, so the remaining 28.6 l stay in the system. This gives the system a MASSIVE endurance advantage compared to an open circuit system. A similar sized open circuit system with a 30 l/min consumption would have about 13-14 minutes of endurance compared to almost 3 hours on the MK 25.

**Pseudo Code:**

Initialize/load all variables

Loop

Pure o2 rebreather still on?

No - Exit script

Yes - start

Are we in the water?

No - jump back to beginning

Yes - start (repeat every 4 seconds)

Check depth

Calculate pressure (depth/10)+1

if CL volume is < pressure add O2 till it matches (decrease tank gas in response) //CL is counterlung

/\*this basically functions to add O2 back into the system that has been metabolized, and to add gas to the breathing bag/counterlung as depth is increased. There is no need to vent gas, as the ppO2 will be incapacitating before the depth you’d have to ascend from to over inflate the BB/CL could be reached.\*/

Calculate o2 consumption

Are we sprinting?

Yes - We use .167 l O2 per breath

//2.5 l/min O2 consumption / 15 breaths a minute

No - We use .093 l O2 per breath

//1.4 l/min O2 consumption / 15 breaths a minute

Subtract O2 consumed from CL

Wait - 4 seconds

Do general housekeeping calculations

Calculate ppO2 - for medical script

//there is no ppO2 monitoring in the MK25

Back to the start of the loop

Changes made to base ADE to function as a closed circuit O2 rebreather

Added an O2 cylinder titled: use\_ade\_item\_cylinder\_single\_6ltr\_300bar\_o2.sqf

adeVarGasamountInLiter = 400;

adeVarCylinderVolume = 2;

adeVarCylinderPressure = 200;

adeVarPercentO2 = .75;

adeVarPercentN2 = .25;

adeVarPercentHe = .0;

adeVarDiverWithoutGas = 0;

player removeItem "ade\_item\_cylinder\_single\_6ltr\_300bar\_o2";

playSound "ade\_sound\_zischen";

hint "Filled rebreather using single 2l cylinder, filled with 200bar of pure oxygen.";

player addItem "ade\_item\_cylinder\_single\_6ltr\_empty";

Added the O2 cylinder to the equipment initialization script (skipped here, those are some long lines of code). Mod’ed the modstart script, basically left everything the same but what’s below.

//Start endless loop

while {true} do

{

//*Just completely removed the equipment check so it would work with whatever.*

//Pause loop until player wears the mod rebreather

// waitUntil {vest player == “"ade\_item\_rebreather"};

//If player is under water, start

if (eyePos player select 2 < 0) then

{

//If the player is sprinting, uppen the air usage

/\**As his calculations are based on using the 1 minute data, and dividing it into seconds, I just plugged in the correct values for O2 use per minute\*/*

if (((speed player) > 8) && (isNull objectParent Player)) then

{

\_adeVarBreathingVolumePerMinute = 2.5; //25;

//systemchat "2.5";

}

else

{

\_adeVarBreathingVolumePerMinute = 1.6; //15;

//systemchat "1.6";

};

**MK 16 Closed Circuit Closed Mixed Gas Electrically Controlled UBA**

Mixed gas rebreather with either a fixed ppO2 (mod 0) or a dual set point (mod 1)

Capacity

432 liters of O2 at ~207 bars in a ~2 liter tank [[16]](#footnote-15)

*Not confirmed, the tanks look the same size though -* 432 liters of diluent in 2 liter tank

Diluent is either N2O2 (ie compressed air) or 12/88 HeO2[[17]](#footnote-16)

*Not confirmed, but based on other rebreathers* Counterlung volume should be about 3 l

Mod 0 operates at a ppO2 of .75 O2. [[18]](#footnote-17)

Mod 1 operates at a ppO2 of .75 O2 through 10msw, and ppO2 of 1.3 after that, and will return to ppO2 of .75 on the ascent at ~4msw.[[19]](#footnote-18)

Operating depth - Mod and gas dependent, but 90msw approximately.[[20]](#footnote-19)

The MK 16 operates in a similar fashion to the MK 25, in terms of having a breath bag/counterlung and a CO2 scrubber. Then it’s a bunch of electronics. Once the counterlung (usually the term when discussing mixed gas rebreathers for some reason) is initially inflated (not sure if you use O2 or O2 and diluent initially, still looking for a manual) it functions as follows. The inhalation deflates the counterlung, and if it deflates it completely the demand valve opens adding diluent until the inhalation stops. The diver exhales, and the exhaled gas goes through the breathing loop, through the CO2 scrubber and into the counterlung. Again just like in the MK 25 the only gas missing that needs to be replaced is the metabolized O2. As the gas sits in the counterlung the O2 sensors determine the ppO2 and add oxygen to elevate it if need be. If the ppO2 is high, it doesn’t do anything, and it just lets the diver “breath down” the extra oxygen.

As the diver descends the pressure increases which causes a decrease in the volume of the gas in the counterlung. The diluent is added to the counterlung to make up the volume. As the diluent contains O2, this will cause a spike in the ppO2 which again is just “breathed down.” On ascent as the pressure decreases the volume of the gas in the counterlung expands, and the excess pressure is vented. As the max allowed ascent rate for the MK 16 is ~10 m a minute the amount of vented gas is relatively low. Too fast of a descent can cause a dangerous spike in ppO2. Too fast of ascent can exceed the system's ability to add oxygen leading to a dangerously low ppO2. Too much exertion can use more O2 than the system can add, leading to low O2 levels.

The Mod 0 has a fixed .75 ppO2, and the mod 1 uses a ppO2 from surface to 10msw, transitions to a ppO2 of 1.3 on descent, and transitions to a ppO2 of .75 on ascent at 4msw.

*High ppO2’s are better regarding decompression times and issues.*

**Pseudo Code:**

//Player selects mod 0 or mod 1 as an equipment option from armory

MGUBA rebreather still on?

No - Exit script

Loop

Yes - start

Are we in the water?

No - jump back to beginning

Yes - start (repeat every 4 seconds)

Check depth

Calculate pressure (depth/10)+1

/\*Max of 1.2/l min O2 consumption for MK16 system, so I’m using a tidal volume of approximately 2 liters (probably high to be honest), so 1 l on inhale means CL volume is always equal to pressure\*/

if CL volume is < pressure add diluent to it till it equal

Add O2% of diluent to O2 total, rest to diluent total

if CL volume is > pressure vent CL to equal

Calculate o2 consumption

Are we sprinting?

Yes - We use .167 l O2 per breath

//2.5 l/min sprint use, will overdraw system with attendant hypoxic issues

No - We use .08 l O2 per breath

//1.2 l/min O2 max for MK 16 system

Subtract O2 consumed from CL O2 total and CL volume

If O2 difference between current and desired O2 to hit set point is >1l add 1l O2 back //max O2 addition possible

else

Add difference back to get to set point

//O2 vol for given ppO2 is fixed based on CL volume

Back to the start of the loop

\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

**Actual code with hard coded cylinders:**

//Basic

adeVarCLvol = 1; //base volume of gasses in the counterlung at start

adeVarCLO2 = 1; //Volume of O2 in the CL at the start

adeVarCLHe = 0; //Volume of He/diluent in the CL at the start

adeVartempgas = 0; //temp variable handle gas calculations

adeVarO2vol = 410; //starting volume of O2 in cylinder

adeVarDiltvol = 410; //start volume of diluent in cylinder

adeVarO2setpoint = .75; //starting ppO2 setpoint for system

adeVarO2percent = .21; //starting calculated oxygen fraction of system

//Start endless loop

while {true} do

{

//If player is under water, start

if (eyePos player select 2 < 0) then

{

adeVarDepth = (((getPosASL player) select 2) \* -1);

adeVarAmbientPressure = ((adeVarDepth / 10) + 1);

if (adeVarAmbientPressure > 2) then

//sets the O2 setpoint as we descend/ascend

{

adeVarO2setpoint = 1.3;

//systemchat "ppO2 1.3";

}

else

{

adeVarO2setpoint = .75;

//systemchat "ppO2 .75";

};

if (adeVarCLvol < adeVarAmbientPressure) then

//adjusts the total CL volume with diluent based on depth pressure

{

systemchat "adding HE";

adeVartempgas = adeVarAmbientPressure - adeVarCLvol;

adeVarCLvol = adeVarAmbientPressure;

adeVarDiltvol = adeVarDiltvol - adeVartempgas;

adeVarCLO2 = adeVarCLO2 + (adeVartempgas \* .12);

adeVarCLHe = adeVarCLHe + (adeVartempgas \* .88);

};

//If the player is sprinting, uppen the air usage

//Need to add a static option as well

if (((speed player) > 8) && (isNull objectParent Player)) then

{

\_adeVarBreathingVolumePerMinute = .167; //25;

//systemchat ".167";

}

else

{

\_adeVarBreathingVolumePerMinute = .08; //15;

//systemchat ".08";

};

adeVarCLO2 = adeVarCLO2 - \_adeVarBreathingVolumePerMinute;

//decrease oxygen in the CL based on movement type

adeVarO2percent = adeVarO2setpoint / adeVarAmbientPressure;

//calculate the O2 percent of the system to be at O2 setpoint

if (adeVarCLO2 < adeVarO2percent) then

//add O2 to get to setpoint, and subtract it from the O2 cylinder

{

systemchat "adding O2";

adeVartempgas = adeVarO2percent - adeVarCLO2;

adeVarCLO2 = adeVarCLO2 + adeVartempgas;

adeVarO2vol = adeVarO2vol - adeVartempgas;

};

**Other rebreathers**

Outside the US military there are other types of rebreathers of course. There are ones that allow a transition from pure O2 closed circuit to semi open mixed gas, with all kinds of fancy electronics, ability to hot swap cylinders etc. Are we looking at simulating only what we have data for, or do we want options?

**Open Circuit**

Pretty simple, take respiratory minute volume, divide by two, multiply by depth, and that’s your gas consumption every minute. Gas mix etc comes into play with decompression and depth. Base ADE does the first part well, except using straight respiratory minute volume gives you the amount of gas inhaled and *exhaled*, thus using double the gas it should.

**Diving Gasses**

Compressed Air

Pure O2

Nitrox/EAN

Trimix

HeliOx

HydrOx

**Bottom time and decompression**

To be added

1. USNDM 2-9.3 pg 2-12 [↑](#footnote-ref-0)
2. USNDM 2-12.1 pg. 2-24 [↑](#footnote-ref-1)
3. USNDM 3-4.5 pg 3-8 [↑](#footnote-ref-2)
4. USNDM 3-4.8 pg 3-11 [↑](#footnote-ref-3)
5. USNDM 3-4.8 pg 3-11 [↑](#footnote-ref-4)
6. USNDM 3-5 pg 3-11 [↑](#footnote-ref-5)
7. USNDM 3-5.1 pg 3-12 [↑](#footnote-ref-6)
8. USNDM 3-9.2.2 pg 3-42 [↑](#footnote-ref-7)
9. USNDM 3-9.1 pg 3-40 [↑](#footnote-ref-8)
10. USNDM 3-9.1.1 pg 3-41 [↑](#footnote-ref-9)
11. USNDM 16-3 pg. 16-7 [↑](#footnote-ref-10)
12. MK25 TM [↑](#footnote-ref-11)
13. MK25 TM 3.2.1.1 pg 3-4 [↑](#footnote-ref-12)
14. MK 25 TM 2.3.4 pg 2-6 [↑](#footnote-ref-13)
15. USNDM 16-3 pg. 16-7 [↑](#footnote-ref-14)
16. Data taken from [CCR-1000 article](http://www.therebreathersite.nl/05_Reviews/CCR1000/CCR1000.html)  [↑](#footnote-ref-15)
17. USNDM 15-5 pg. 15-17 [↑](#footnote-ref-16)
18. USNDM Fig. 15-7 pg. 15-34 [↑](#footnote-ref-17)
19. USNDM Fig. 15-8.2.8 and 15-8.2.13 pg. 15-20 and 15-21 [↑](#footnote-ref-18)
20. USNDM 16-3 pg. 16-7 [↑](#footnote-ref-19)