Chambers and bells

SECTION FOUR

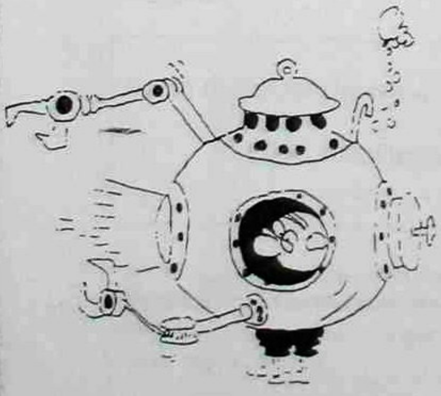
Pressurising the chamber

Air chambers are used for short decompressions, or for the treatment of decompression sickness. Generally, divers will spend a only few hours under pressure.

A saturation chamber, or system of chambers, is designed to accommodate a number of divers for several weeks at a time. The atmosphere must be carefully controlled to maintain decent living conditions. You have to control temperature, humidity, carbon dioxide and oxygen. Maintaining the correct PPO2 is essential to avoid long term damage to the lungs.

Pressurising an air chamber is quite straightforward. You just blow in the air. Whatever depth you go to, there's 21% oxygen, 79% nitrogen. The atmosphere is safe and breathable (except for a touch of nitrogen narcosis) all the way down to 50 msw (165 fsw).

Coming back up is just as easy. No problem with percentages or partial pressures.



A saturation chamber is much trickier. You're blowing heliox in on top of the air that's there before you start, and you have to end up with the right PPO2 at the bottom depth.

The final PPO2 will depend on the oxygen that was in the air before you started, and the oxygen that's in the heliox.

The usual procedure is to start the pressurisation with a fairly rich mix, 15 - 20% oxygen, that's breathable at shallow depths.

Then you carry on to the bottom with a weak mix, usually 2%. For very deep dives, you might use pure helium.

In theory, there's no reason why you shouldn't start with a weak mix. The air that's in there already gives a perfectly safe PPO2.

Knocking out divers

In practice there's a risk that a leak - a door not sealing or a valve left open - might let the air out while you let the weak mix in. This would flush the chamber with the weak mix, dropping the PPO2 to dangerously low levels. This has happened, and left a chamber full of unconscious divers.

If you have to start with a weak mix, it's a good idea to keep the divers breathing something safe on the BIBS until you know you have a seal. BIBS stands for Built In Breathing System - face masks available in the chamber for emergencies and decompression sickness treatment.

In all pressurisations, it's good idea to stop at 1 msw and watch the gauges. If you have a leak, it'll show up straight away.

Getting it right

To get the right PPO2, you have to put in the right depth of rich mix. If you get it wrong, your final PPO2 will be wrong and you'll have to mess around adding oxygen or flushing.

When dealing with chambers, you tend to work in depths rather than pressures.

Depth of rich mix (msw) =

$$\frac{\textbf{PPO2 added(mb) - (Bottom depth x \% weak mix)}}{\textbf{(\% rich mix - \% weak mix)}}$$

"PPO2 added" is the amount of oxygen you have to add to make up the PPO2 you need at the end. Remember that there's usually 210 mb of air in there before you start. To get a PPO2 of 600 mb, O2 added would be (600 - 210) mb = 390 mb.

Example 17

You want to pressurise a chamber to 90 msw, using 12% and 2%. The final PPO2 must be 600 mb. What depth of 12% should you add to start the pressurisation?

Depth of rich mix (msw) =

$$\frac{\text{PPO2 added(mb)} - (\text{Bottom depth} \times \%\ \text{weak mix})}{(\%\ \text{rich mix} - \%\ \text{weak mix})}$$

PPO2 added = (600 - 210)mb = 390 mb
Bottom depth = 90 msw
% weak mix = 2
% rich mix = 12

$$\text{Depth of rich mix} = \frac{390 - (90 \times 2)}{(12 - 2)}\ \text{msw}$$

$$= \frac{(390 - 180)}{10}\ \text{msw}$$

$$= \frac{210}{10}\ \text{msw}$$

$$= 21\ \text{msw}$$

You would start the pressurisation by adding 21 msw of 12%, then carrying on to bottom depth with 2%

If you work in fsw, this is the formula:

Depth of rich mix (fsw) =

$$\frac{3300 \times \text{PPO2 added(AT)} - (\text{Bottom depth} \times \%\ \text{weak mix})}{(\%\ \text{rich mix} - \%\ \text{weak mix})}$$

Example 18

You want to pressurise a chamber to 250 fsw, using 16% and 2%. The final PPO2 must be 0.5 AT. What depth of 16% should you add to start the pressurisation?

Depth of rich mix (fsw) =

$$\frac{3300 \times \text{PPO2 added(AT)} - (\text{Bottom depth} \times \%\ \text{weak mix})}{(\%\ \text{rich mix} - \%\ \text{weak mix})}$$

$$PPO2\ added = (0.5 - 0.21)AT = 0.29\ AT$$
$$Bottom\ depth = 250\ fsw$$
$$\%\ weak\ mix = 2$$
$$\%\ rich\ mix = 16$$

$$Depth\ of\ rich\ mix = \frac{(3300 \times 0.29) - (250 \times 2)}{(16 - 2)}\ fsw$$

$$= \frac{(957 - 500)}{14}\ fsw$$

$$= \frac{457}{14}\ fsw$$

$$= 32.6\ fsw$$

You would start the pressurisation by adding 33 fsw of 16%, then carrying on to bottom depth with 2%

What's a negative depth?

Those questions were easy enough, but try this one. You'll get a silly answer.

Example 19

You want to pressurise a chamber to 200 msw, using 12% and 2%. The final PPO2 must be 500 mb. What depth of 12% should you add to start the pressurisation?

Depth of rich mix (msw) =

$$\frac{PPO2\ added(mb) - (Bottom\ depth \times \%\ weak\ mix)}{(\%\ rich\ mix - \%\ weak\ mix)}$$

$$PPO2\ added = (500 - 210)mb = 290\ mb$$
$$Bottom\ depth = 200\ msw$$
$$\%\ weak\ mix = 2$$
$$\%\ rich\ mix = 12$$

$$Depth\ of\ rich\ mix = \frac{290 - (200 \times 2)}{(12 - 2)}\ msw$$

$$= \frac{(290 - 400)}{10} \text{ msw}$$

$$= \frac{-110}{10} \text{ msw}$$

$$= -11 \text{ msw}$$

What is a depth of -11 msw? The 11 msw doesn't mean much, but the minus sign tells you that you can't get the right PPO2 with these gases. What do you do?

All the way with 2%

Even if you missed out the 12% and pressurised the chamber all the way from the surface on 2%, you'd have too much oxygen. There's a handy formula to check this, and it only works on the metric system:

PPO2 increase (mb) = depth increase (msw) x percentage

Percentage is the oxygen percentage of the gas used to increase the depth.

If you added 200 msw of 2%, straight from the surface, the PPO2 would increase by (200 x 2)mb = 400 mb. Since you've already got 210 mb in there, this would take you over the 600 mb you want.

In this particular case, it's only slightly too high. The divers' would use up the surplus very quickly and bring the PPO2 down to its correct level.

For deeper dives, you'd have to use 1.5% or 1%. For very deep dives you might need to use a rich mix then pure helium.

This is avoided as much as possible. There have been several cases, most of them fatal, where a diver on the seabed has been supplied with pure helium by mistake. It's safer not to have the stuff available at all.

How much gas do you need?

$$\text{Free gas volume} = \text{Chamber volume} \times \frac{\text{depth added(msw)}}{10}$$

$$\text{Free gas volume} = \text{Chamber volume} \times \frac{\text{depth added(fsw)}}{33}$$

Those of you with razor sharp minds will notice that these are basically the floodable volume x pressure formula used to work out how much gas there is in a quad.

It's important to remember (everybody forgets) that you're dealing with gauge depth, not absolute depth. If you used absolute depth, you'd be including the air that was in the chamber before you started. You're not interested in that.

Example 20

A chamber system has a volume of 40 m^3. What volume of gas would it take to pressurise it to 150 msw?

$$\text{Free gas volume} = \text{Chamber volume} \times \frac{\text{depth added(msw)}}{10}$$

$$\text{Free gas volume} = 40 \times \frac{150}{10}\ m^3$$

$$= 600\ m^3$$

You would need 600 m^3 of gas

Example 21

A chamber system has a volume of 1200 ft^3. What volume of gas would it take to pressurise it to 500 fsw?

$$\text{Free gas volume} = \text{Chamber volume} \times \frac{\text{depth added(fsw)}}{33}$$

$$\text{Free gas volume} = 1200 \times \frac{500}{33}\ m^3$$

$$= 18182\ ft^3$$

You would need 18182 ft^3 of gas

Example 22

A chamber system has a volume of 30 m^3. It is to be pressurised to 90 msw, with 21 msw of 12% and 69 msw of 2%. What volume of each gas would be needed

$$\text{Free gas volume} = \text{Chamber volume} \times \frac{\text{depth added(msw)}}{10}$$

Pressurisation on 12%

$$\text{Free gas volume} = 30 \times \frac{21}{10}\ m^3$$

$$= 63\ m^3$$

Pressurisation on 2%

$$\text{Free gas volume} = 30 \times \frac{69}{10}\ m^3$$

$$= 207\ m^3$$

You would need 63 m^3 of 12% and 207 m^3 of 2%

Aborting a pressurisation

You're 20 minutes into a pressurisation when the job's cancelled. You can't just bleed the chamber and let them out, they'll bend, and a full saturation decompression might take a couple of days. What you gonna do?

Since the decompression time depends on the amount of inert gas they've been breathing, all you have to do is work out the PPHE and then find a bounce decompression table with the same, or greater PPHe. *

The US Navy PPHe tables are useful here. You can work out the PPHe in the chamber (in fsw) and use the appropriate table.

If you don't use the US Navy tables, it's case of trial and error with the tables you do use.

Make an intelligent guess at a suitable bounce table, work out the PPHe and compare it with the chamber. If it's OK, use it. if not, try another. Work fast. The longer the divers are in there, the longer they'll take to come out. And get somebody to check your calculations. You don't want to bend everybody.

Example 23

A saturation pressurisation is aborted at 70 msw, when the PPO2 is 400 mb. You have bounce dive tables for 78 msw using a 18% mix, 80 msw using 16% and 82 msw using 16%.

Choose a suitable bounce table to decompress the divers.

At 70 msw, the pressure is 8 bar. The PPO2 is 400mb, or 0.4 bar, so the PPHe must be (8 - 0.4) bar = 7.6 bar.

Try the 78 msw table using 18%

Partial pressure = absolute pressure x decimal ~~percentage~~

absolute pressure = 8.8 bar
decimal percentage = 0.82 PP He 100% - 18% O2
(it's the helium percentage you're interested in!)

Partial pressure = 8.8 x 0.82 bar
= 7.22 bar

This is less than the PPHe in the chamber. This table is no good.

Try the 80 msw table using 16%

Partial pressure = absolute pressure x decimal percentage

absolute pressure = 9 bar

decimal percentage = 0.84

Partial pressure = 9 x 0.84 bar
= 7.56 bar

Still not enough!

Last try! 82 msw table using 16%

Partial pressure = absolute pressure x decimal percentage

absolute pressure = 9.2 bar
decimal percentage = 0.84

Partial pressure = 9.2 x 0.84 bar
= 7.73 bar

Success! The PPHe is greater than that in the chamber. You could use this table to decompress the divers.

Example 24

A saturation pressurisation is aborted at 300 fsw. The PPO2 is 0.4 AT. Which USN PPHe table could you use to decompress the divers?

$$\text{Absolute pressure} = \frac{300}{33} + 1 \text{ ATA}$$

$$= 10.09 \text{ ATA}$$

PPO2 = 0.4 AT
PPHe = (10.09 - 0.4) AT
= 9.69 AT

For the USN tables, you have to express this partial pressure in fsw. 1 AT is the same as 33 fsw, so

Partial pressure(fsw) = Partial pressure (AT) x 33
= 9.69 x 33 fsw
= 319.77 fsw

You could use the USN 330 PPHe table (next deepest)

Daily gas use

About every twenty minutes, the divers in the chamber will want cups of tea, ice cream, yesterdays newspapers, Playboy, or a screwdriver and 4mm bolt for the thing they're making.

This means regular use of the medical lock, and a gas use. Nobody ever actually calculates gas use on the lock, but this is how you do it. It's a familiar formula:

$$\textbf{Free gas volume} = \textbf{lock volume} \times \frac{\textbf{depth added(msw)}}{\textbf{10}}$$

$$\textbf{Free gas volume} = \textbf{lock volume} \times \frac{\textbf{depth added(fsw)}}{\textbf{33}}$$

To find the volume of the lock, take out your tape and measure the length and diameter. Halve the diameter to get the radius. If you're working in m3, measure in metres, if you're working in ft3, measure in feet.

$$\textbf{Volume of lock} = \pi \times \textbf{length} \times \textbf{radius}^2$$

You'll probably find π on your calculator. If not, use a value of 3.14.

Example 25

A medical lock is 0.8 metres long and 0.3 metres in diameter. The chamber is at 160 msw. How much gas is used when the lock is operated.

$$\textit{Volume of lock} = \pi \times \textit{length} \times \textit{radius}^2$$

$$\begin{aligned} \textit{length} &= 0.8 \textit{ metres} \\ \textit{radius} &= 0.15 \textit{ metres} \\ \textit{radius}^2 &= 0.0255 \end{aligned}$$

$$\begin{aligned} \textit{Volume of lock} &= \pi \times 0.8 \times 0.0255\ m^3 \\ &= 0.057 m^3 \end{aligned}$$

Free gas volume $= \text{lock volume} \times \dfrac{\text{depth added(msw)}}{10}$

Depth added $= 160 \text{ msw}$

Free gas volume $= \dfrac{0.057 \times 160 \text{ m}^3}{10}$

$= 0.912 \text{ m}^3$

When the lock is operated, 0.912 m^3 gas is used

Adding gas to the chamber

From time to time you add gas to the chamber, either to replace routine losses or to increase the chamber depth. If there's oxygen in the gas, as there almost always is, adding gas will increase the PPO2. You've already seen a metric version of the formula:

PPO2 increase (mb) = depth increase (msw) x percentage

If you're working in fsw, it's a bit more cumbersome:

$$\textbf{PPO2 increase (AT)} = \frac{\textbf{depth increase(fsw) x decimal percentage}}{\textbf{33}}$$

Note that one formula uses the actual percentage, the other uses decimal percentage.

Adding oxygen to the chamber

The divers in saturation are, of course, using oxygen all the time. On modern systems, pure oxygen is added to the atmosphere automatically to maintain the correct PPO2.

When the automatic system breaks down (it couldn't really, could it?), or if you're working on an old system, you'll have to add it by hand.

Instinct vs precision

It's really a matter of instinct. You open the valve, count your heart beats or whistle a tune until you think it's OK, then close the valve. Put your feet up and wait until it circulates, then check your analysis equipment.

It usually works, but if you want real precision, look at the depth gauges when you make the add.

10 cm of oxygen increases the PPO2 by 10 mb 1 fsw of oxygen increases the PPO2 by 0.03 AT

How much oxygen do you need?

On average, divers in a chamber use 0.7 m^3 (25.4 ft^3) of oxygen each per day. This is the amount of oxygen that they use metabolically, and it's not affected by depth.

The divers are not all in the chamber all the time (sometimes they actually have to go diving) but it's easier to assume they are. This also gives you a safety margin to cover bad weather or other down time.

Example 26

9 divers are in saturation for 5.5 days. How much oxygen will they use in the chamber?

$$\text{Oxygen use} = 9 \times 5.5 \times 0.7\ m^3$$

$$= 34.65\ m^3$$

The divers will use 34.65 m^3 of oxygen

Oxygen and decompression

During decompression, things get a bit trickier. On some tables, you have to raise the PPO2 to a higher level before you start. Then you have to maintain the required PPO2.

Every time you bleed gas out of the chamber, you're bleeding out oxygen as well. The PPO2 drops and you have to add some more oxygen.

As the chamber gets shallower, the oxygen represents a higher percentage of the total volume, and the volume of oxygen coming out increases. So the volume added increases.

In short, calculating the oxygen use is complicated.

Oxygen used = ln(initial pressure) x PPO2(bar) x chamber volume

When the percentage of oxygen reaches 23% (or thereabouts), you stop adding it. Higher percentages would cause an unacceptable fire risk.

The formula **doesn't** take this into account, so your answer will be slightly on the high side. Don't worry about it.

Initial pressure is the **absolute** pressure in the chamber at the start of the decompression.

ln is "logarithm to the base e", a mathematical function found on most scientific calculators. The key might be labelled "ln" or "log e".

Enter the initial pressure, press "ln" and then multiply by the PPO2 and chamber volume. If you don't have ln on your calculator, look in Appendix 11.

You'll also need to add on the metabolic oxygen use during the decompression, and any oxygen you have to add to raise the PPO2 to the level need for decompression.

Example 27

A decompression from 95 msw takes 2 days, with a PPO2 of 600 mb. There are two divers in the chamber, and the chamber volume is 10 m^3. How much oxygen is used?

Take this problem one step at a time:

Metabolic use

$$\textit{Oxygen use} = 2 \times 2 \times 0.7\ m^3$$

$= 2.8\ m^3$

Use during decompression

$$\text{Oxygen used} = \ln(\text{initial pressure}) \times PPO2 \times \text{chamber volume}$$

$$\text{Initial pressure} = 10.5 \text{ bar}$$
$$\ln(\text{initial pressure}) = 2.35 \text{ (from calculator)}$$

$$PPO2 = 0.6 \text{ bar}$$
$$\text{Chamber volume} = 10\ m^3$$

$$\text{Oxygen used} = 2.3 \times 0.6 \times 10\ m^3$$
$$= 13.8\ m^3$$

$$\text{Total oxygen use} = (2.8 + 13.8) m^3$$
$$= 16.6\ m^3$$

Example 28

4 divers are in saturation for 8 days at 110 msw, with a PPO2 of 400 mb. Before starting the decompression, the PPO2 is raised to 600 mb. The decompression takes 3 days. The chamber volume is 15 m^3. How much oxygen is used?

As before, go one step at a time:

Metabolic use for the whole dive

$$\text{Oxygen use} = 6 \times 11 \times 0.7\ m^3$$
$$= 46.2\ m^3$$

Oxygen required to make up the level to 600 mb

$$\text{Free gas volume} = \text{floodable volume} \times \text{pressure added}$$

This is a slight variation on the formula. It's the oxygen added that we're interested in, not the whole lot. The floodable volume is the chamber volume.

$$\text{Floodable volume} = 15\ m^3$$
$$\text{Pressure added} = (600 - 400) \text{ mb}$$
$$= 200 \text{ mb}$$

$$= 0.2 \text{ bar (pressures must be in bar)}$$

$$\text{Free gas volume} = 15 \times 0.2\ m^3$$

$$= 3\ m^3$$

Use during decompression

$$\text{Oxygen used} = \ln(\text{initial pressure}) \times PPO2 \times \text{chamber volume}$$

$$\text{Initial pressure} = 12 \text{ bar}$$

$$\ln(\text{initial pressure}) = 2.48 \text{ (from calculator)}$$

$$PPO2 = 0.6 \text{ bar}$$

$$\text{Chamber volume} = 15\ m^3$$

$$\text{Oxygen used} = 2.48 \times 0.6 \times 15\ m^3$$

$$= 22.32\ m^3$$

$$\text{Total oxygen use} = (46.2 + 3 + 22.32) m^3$$

$$= 71.52\ m^3$$

Fire

Whenever you have a lot of oxygen in the atmosphere, you have a fire risk. But there's an awful lot of hysteria about the subject.

Saturation chambers, where the risk is generally low, have smoke alarms, fire extinguishers and sprinkler systems. Air chambers, where the risk is generally high, have a bucket of sand.

So what are the facts? Fact number one is that fire risk doesn't just depend on oxygen levels. You have to have something to start the fire and something to burn. If you keep inflammable items out of the chamber, and keep matches and lighters away, you should be OK.

Fact number two is that a fire will not start if there's less than 8% oxygen in the atmosphere. It doesn't matter what the PPO2 is. At 8% you can't get enough oxygen molecules together to cause trouble.

This means that most of the time, in most saturations there is no risk. You may get an overheating electric cable giving off nasty fumes (don't underestimate the risk of poisoning!) but it won't ignite.

As the oxygen levels increases, the risk of ignition increases. The safe maximum is usually set at about 23%, with a PPO2 of 600 mb. You get to this level at about 16 msw (about 50 fsw) during a saturation decompression. Thereafter, just keep the oxygen at 23% and the PPO2 will drop as the decompression continues.

At greater concentrations, the risks increase rapidly. At 24 msw (about 80 fsw), in air, a single spark could set your overalls ablaze. The percentage here is 21%, the PPO2 714 mb.

The speed with which the fire spreads, once it's started, depends on the PPO2. If it's high enough you'll get a flash fire, more like an explosion and invariably fatal.

The riskiest place to be is an air filled welding habit. Oxygen concentrations are high, there are sparks and flames and usually something, somewhere that will burn.

Next is an air chamber, with divers breathing oxygen on BIBS. The masks leak, and if the chamber isn't flushed regularly oxygen can reach frightening levels. All serious chamber fires to date have been in air chambers.

Saturation chambers are generally quite safe, but don't get careless. There are always risks.

Temperature changes

Chamber temperatures are always known accurately, and a temperature change will show as a change in chamber depth. It's possible to mistake a decrease in depth due to temperature for a slow leak.

You can waste a lot of time looking for this non-existent leak, so it's a good idea to check temperature changes first.

You can use the same formula that you used for pressure changes in a scuba bottle.

$$\textbf{Final pressure} = \textbf{Initial Pressure} \times \frac{\textbf{Final temperature (}^{\circ}\textbf{K)}}{\textbf{initial temperature(}^{\circ}\textbf{K)}}$$

(Temperatures are in °K, that's °C + 273. Look in the Appendix 4 if you'd like to know why)

Another version that's useful for chambers is:

$$\textbf{Depth change} = \textbf{Absolute depth} \times \frac{\textbf{temperature change}}{\textbf{temperature}(^{o}K)}$$

The temperature is the temperature at the absolute depth in question. If the temperature decreases, the depth decreases and vice-versa.

Example 29

A chamber is at 145 msw and 28°C. At the start of the shift, the temperature was 32°C. If the life support crew had not added gas to maintain depth, by how much would the depth have decreased?

$$\text{Depth change} = \text{Absolute depth} \times \frac{\text{temperature change}}{\text{temperature}(^{o}K)}$$

$$\begin{aligned}\text{Absolute depth} &= (145 + 10)\text{msw} \\ &= 155 \text{ msw}\end{aligned}$$

$$\begin{aligned}\text{Temperature change} &= (32 - 28) \\ &= 4^{o}K\end{aligned}$$

(^{o}K and ^{o}C are the same size, you just start counting at different places)

$$\begin{aligned}\text{Temperature} &= (273 + 28)^{o}K \\ &= 301^{o}K\end{aligned}$$

$$\text{Depth change} = \frac{155 \times 4}{301} \text{ msw}$$

$$= 2.05 \text{ msw}$$

The depth change would have been 2.05 msw

This is quite enough to start you looking for a leak!

Bleeding the chamber

Suppose you want to take a chamber back to the surface to put somebody else into saturation. You get the divers to move out, close it off from the rest of the system, and open the valve.

A while later, the gauges say zero, the door drops open and you step inside to do a few checks. When you come round (if somebody gets you out alive) you spend some time wishing you'd paid more attention to your physics.

When you bleed a chamber or bell, **the percentages stay the same.** If there was 4% oxygen in the chamber when you started, there'll be 4% oxygen in the chamber when you reach surface.

At 90 msw, 4% is 400 mb. That's fine. On the surface, 4% is 40 mb. That's not enough. You would collapse instantly, and die if nobody got you out.

If you see somebody unconscious in a chamber (or any enclosed space), don't just rush to the rescue. If he can't breath, neither can you. The chances are that you'll collapse as well, and that would be two dead bodies. **Get some breathing equipment, get a rope, get assistance.**

Start singing

If you bleed a chamber to the surface, flush it with air or allow it to ventilate until it's safe. If in doubt, stick your head through the door and sing. Your voice will tell you if there's helium in there.

While it's flushing, make sure nobody else can get in. Stand guard or bolt up the door and put up a notice.

Joining chambers together

In a split level saturation, one lot of chambers are at one depth, another lot are at another depth. From time to time, you may need to blow down or bleed a chamber from one depth to the other.

If you're blowing a chamber down, you can check the final PPO2 with:

$$\boxed{\text{PPO2 increase (mb)} = \text{depth increase (msw)} \times \text{percentage}}$$

or, for fsw:

$$\boxed{\text{PPO2 increase (AT)} = \frac{\text{depth increase (fsw)}}{33} \times \text{decimal percentage}}$$

Example 30

Chamber 1 is at 97 msw, with a PPO2 of 400 mb. It is blown down to 130 msw, using 2%. What is the PPO2 at 130 msw?

PPO2 increase (mb) = depth increase (msw) x percentage

depth increase = 33 msw
percentage = 2

PPO2 increase (mb) = 33 x 2 mb
= 66 mb

The PPO2 at 130 msw is 466mb

If you're bleeding a chamber, remember that in a bleed percentages stay the same, and work out the final PPO2 accordingly.

Example 31

Chamber 1 is at 320 fsw, with a PPO2 of 0.4 AT, percentage 3.74% It is bled to 265 fsw. What is the PPO2 at 265 fsw?

Percentages stay the same during a bleed

Percentage at 265 fsw = 3.74%

Partial pressure = absolute pressure x decimal percentage

$$\text{Absolute pressure} = \frac{\text{Depth(fsw)}}{33} + 1 \text{ ATA}$$

$$= \frac{265}{33} + 1 \text{ ATA}$$

$$= 9.03 \text{ ATA}$$

Percentage = 3.74%
Decimal percentage = 0.0374

Partial pressure = 9.03 x 0.0374 AT
= 0.338 AT

The PPO2 at 265 fsw is 0.338 AT

This is clearly too low. You'd have to bleed gently and correct the PPO2 as you went.

Of course, if you're joining chambers, the chamber atmospheres will mix when the doors open. The final PPO2 will depend on the total volume of oxygen in the system.

You can find this volume by using the familiar formula:

Free gas volume = floodable volume x pressure

In this case, though, since you're only interested in oxygen, you use the partial pressure of oxygen, not the absolute pressure.

Example 32

After equalisation, Chamber 1 has a volume of 12m³ and a PPO2 of 480mb. Chamber 2 has a volume of 8m³ and a PPO2 of 400mb.

What is the final PPO2 when the atmospheres are completely mixed?

Oxygen volume in Chamber 1

Free gas volume = floodable volume x pressure

floodable volume = 12m³

Pressure of oxygen (PPO2) = 480mb
= 0.48 bar

Oxygen volume = 12 x 0.48 m³
= 5.76 m³

Oxygen volume in Chamber 2

Free gas volume = floodable volume x pressure

floodable volume = 8m³
Pressure of oxygen(PPO2) = 400mb
= 0.4 bar

$$\text{Oxygen volume} = 8 \times 0.4\ m^3$$
$$= 3.2\ m^3$$

$$\text{Total oxygen volume} = (5.76 + 3.2)\ m^3 = 8.96 m^3$$

$$\text{Total chamber volume} = (12 + 8)\ m^3 = 20 m^3$$

Turn the formula around:

$$\text{Pressure} = \frac{\text{free gas volume}}{\text{floodable volume}}$$

$$= \frac{8.96}{20}\ \text{bar}$$

$$= 0.448\ \text{bar}$$
$$= 448\ \text{mb}$$

The final PPO2 is 448mb

In practice, it might take a while for the atmospheres to mix.

Pressurising the bell

The bell is normally locked on and blown down with the rest of the saturation system. Working depth is usually deeper than the living depth in the chambers, and the bell will have to be pressurised by several metres at the start of each dive.

Example 33

A chamber and bell are at 185 msw, with a PPO2 of 400 mb. For the dive, the bell is separated from the chamber and blown down on 4% to a working depth of 200 msw. What is the PPO2 in the bell at working depth?

$$\text{PPO2 increase (mb)} = \text{depth increase (msw)} \times \text{percentage}$$

$$\text{depth increase} = 15\ \text{msw}$$
$$\text{percentage} = 4$$

$$\text{PPO2 increase (mb)} = 15 \times 4\ \text{mb}$$

$= 60\ mb$

The PPO2 in the bell is 460mb

Chemical sampling tubes

These are often called Drager tubes, after one of the major manufacturers. A measured volume of gas is drawn through the tube and the chemicals inside change colour according to the concentration of the gas.

The most widely used tubes are those for CO_2 detection. They're carried as standard in most diving bells.

The tubes give a percentage reading and are calibrated for use on the surface. If they're used in a bell you have to adjust the reading accordingly.

True percentage

Suppose a sample is taken in a bell at a pressure of 12 bar. The scale reading shows 1%. Since the pressure is 12 bar, 12 times the normal volume of gas has gone through the tube, and it's reading 12 times too high.

$$\textbf{True percentage} = \frac{\textbf{Scale reading}}{\textbf{Absolute pressure}}$$

In this case:

$$\text{True percentage} = \frac{1\ \%}{12} = 0.08\%$$

Partial pressure

It's usually the partial pressure that matters, not the percentage, and you can find that directly. Just **divide** the scale reading by 100 to give you the partial pressure in bar or AT.

On the metric system, multiply the scale reading by 10 to give the partial pressure in mb. (If you're mathematically inclined, you can easily see why this works. If you're not, just believe it.)

PSE and SEP

Some companies use Percentage Surface Equivalent (PSE), also known as Surface Equivalent Percentage (SEP). This is simply the scale reading. It's just another way of expressing partial pressure. The maximum SEP for CO_2 in a bell is usually 2%, a partial pressure of 20mb.

Example 34

The bellman uses a chemical sampling tube to take a CO_2 reading in the bell. The scale reading is 1.4%. If the bell is at 400 fsw, give the true percentage of CO_2, the $PPCO_2$ and the SEP.

True percentage

$$\text{True percentage} = \frac{\text{Scale reading}}{\text{Absolute pressure}}$$

$$\text{Scale reading} = 1.4\%$$

$$\text{Absolute pressure (ATA)} = \frac{\text{Depth (fsw)}}{33} + 1$$

$$= \frac{400}{33} + 1 \text{ ATA}$$

$$= 13.12 \text{ ATA}$$

$$\text{True percentage} = \frac{1.4}{13.12}\ \%$$

$$= 0.08\%$$? 0

= 0106

Partial Pressure

$$\text{Partial pressure} = \frac{\text{Scale reading}}{100}$$

$$= \frac{1.4\ AT}{100}$$

$$= 0.014\ AT$$

SEP

The SEP is simply the scale reading, which is 1.4%

All the gas you'll ever need

A diving operation can run for months, with 3 teams of divers in saturation, pressurisations and decompressions every few weeks, three bell runs every day, sometimes two bells running back to back.

It takes a lot of gas, even with a recovery system. You have to work out the requirements accurately, to make sure that you get the supplies you need and to figure out what it's all going to cost.

If you've got this far in the book, you're quite capable of doing the calculation. It's just a matter of organisation.

What you need to know

These are some of the things you need to know before you start:

- Volumes of the chamber system and bells
- Living depths
- Working depths
- Number of days diving
- Number of divers in saturation
- How many pressurisations and decompressions are planned?
- Is a gas recovery system being used for the dives?
- Is a gas recovery system being used for the chambers?
- The treatment mixes needed for each depth range

Stage by stage

Carry out the calculations stage by stage, working through the planned operation, and keep a running total of the volumes of each gas mix. You might work through it like this:

Gas to pressurise the system
Metabolic oxygen consumption in the chamber
Gas for the operation of the medical locks
Gas for pressurisations to put new divers into saturation
Oxygen use during decompression
Gas for the bell bottles
Gas to pressurise the bell from living depth to working depth
Gas to pressurise the bell trunking
Divers' gas consumption
Gas reserves

Gas reserves should be worked out according to company policy, but will probably be based on a document called "Guidance note on the minimum quantities of gas required offshore". It's the Association of Offshore Diving Contractors guidance note AODC 014.