Understanding Gas Management

by Bob Bailey

People often ask me what I mean when I use the term “Gas Management”. My answer is that it means you’ve developed diving habits that enable you to base your dive plan on the amount of breathing gas you’re bringing with you. Often they’ll then ask why that’s necessary. Isn’t it enough to just watch your SPG and start your ascent when you start to get low? Well, that might work … but it really depends on the type of dive you’re doing, and how comfortable you are “winging it”.

To make the point, let’s consider an analogy. When you’re driving in your car, you monitor your gas supply by occasionally glancing at your fuel gauge. When it reaches a certain point you start looking for a gas station. Now, imagine that you’re driving along and see a sign that says “Next Gas 100 Miles”. Your first instinct is to look at your gas gauge. But does that really tell you enough information to know that you will make it? You’ll also need to know how many gallons your tank holds, and how many miles per gallon your car will get, on average. You might even have to consider that your miles per gallon will vary with terrain and driving conditions.

Diving is like that. Simply checking your gauge doesn’t give you enough information. You also need to know the rate that you consume the air in your cylinder, and possibly factor in conditions that will cause your breathing rate to vary. Only by considering all of these factors will you know that you have enough gas to dive your plan.

This is what we mean by “Gas Management”.

The elements of gas management include knowing:

- How much gas you consume, on average, over a specified time period
- How variations in depth (i.e. your planned dive profile) affect your consumption rate
- How variations in dive conditions and your own physical and mental state affect your consumption rate
- How to know, based on your tank pressure, when it is time to turn around or begin your ascent
- How to use the gas in your scuba cylinder efficiently
- How to reduce the risk of equipment malfunctions that could cause a loss of breathing gas

Thinking Ahead

A typical recreational dive briefing ends with “End the dive with 500 psi”. But what does that mean? How do you do it? And is it *enough* gas in reserve if you or your dive buddy has a problem?

Instead of thinking in terms of how much gas we have in our tanks after the dive is over, let's think in terms of whether or not you have enough gas *during* your dive. During the dive ask yourself "If I need to share my gas with my buddy right now, would I have enough to get both of us to the surface safely?"

Even if you are diving with a DM or other dive professional, it is your responsibility to know how much gas you need to dive your plan. Remember that the guide is there to show you the dive site, not manage your dive for you. It's your responsibility to stick to your plan and manage your gas. In diving, we are each responsible for our own safety.

Why it is important

Gas management is important because we carry with us a limited supply of gas, and … well … none of us can breathe water. We cannot manage more than a few seconds without breathing if we run out of gas. And if we allow ourselves to run too low we might have to ascend at a rate that increases our risk of DCS or lung overexpansion injury. So it's important to do everything we can to keep ourselves out of a situation where we are either too low on gas or out of gas altogether.

It's also important to consider that one reason we dive with a buddy is so that if an emergency does occur, you and your buddy are able to provide each other with a reserve supply of gas in order to be able to ascend to the surface in a controlled manner. For this reason, each of you should manage your gas supply with both divers in mind.

How to develop good gas management skills

We start by finding out how much gas we breathe under different circumstances. Everyone is different, and the rate at which you consume the gas in your scuba cylinder will vary from dive to dive, depending on factors such as your dive profile, your state of mind, your physical condition, and events that occur during the dive.

To help us get an idea of how much gas we breathe, we use a standardized form of measure known as ***Surface Air Consumption*** (SAC) rate.

Your SAC rate is defined as the amount of gas you breathe in one minute at the surface. It can be expressed as pressure (PSI) or volume (cubic feet). For the purpose of this discussion, and to avoid confusion, we will refer to your SAC rate in terms of pressure. When expressing your air consumption rate as volume, we will refer to it as ***Respiratory Minute Volume*** (RMV).

You will often see someone describing their SAC rate as a number … this is not exactly correct, as it is only expressing your air consumption as calculated for a single dive. Your SAC rate is really a range, because it's based on your breathing rate … which does not remain constant over a period of several dives, or even during a single dive.

At the low end of the range is your ***resting SAC***, which is the rate you breathe when you are very relaxed, and at the high end is your ***working SAC***, which is the rate you breathe when you are working hard. Many factors can affect your air consumption rate such as depth (due to narcosis effects), current (because of exertion), stress (because it psychologically causes you to breathe faster), fatigue, excitement, or swimming with a sh-sh-sh-sh-shark.

Because of this, the best way to calculate your SAC rate for dive planning purposes is to track your gas consumption over a number of dives, watch the trends, and consider what factors are affecting your air consumption, and by how much they are affecting it. Then, when planning a dive, you will have a better idea of how to calculate your gas consumption for the anticipated conditions of the dive.

But something else factors into our gas consumption rate … depth. Water pressure affects our air spaces. The deeper we go, the more squeezed our air spaces become. But water pressure also affects the gas we breathe. When we take a breath, our regulator delivers the gas at a pressure that equalizes the pressure of the water around us. Without this equalization our lungs would not be able to function properly, and our breathing would be inhibited. So the deeper we go, the more gas we remove from our cylinder when we take a breath. That is why you can kick around a shallow reef for an hour, while at 100 feet the same cylinder might only last you 25 minutes!

Calculating SAC Rate

So how does this all relate to calculating your SAC rate? The amount of gas you inhale with each breath is directly proportional to the pressure of the water you are swimming in. By knowing your SAC rate … which is calculated at the surface … you can determine how much gas you are consuming at any depth. To do this you convert depth to pressure, expressed in ATA (absolute atmospheres). The relationship between depth and pressure is expressed as:

$$\text{Pressure (ATA)} = \text{depth}/33 + 1$$

In salt water, every 33-foot increase in depth increases our pressure by 1 ATA. By dividing our depth by 33, we can make a conversion from depth to pressure. We add 1 ATA because that is the pressure we are exposed to when we’re at the surface.

So let’s look at an example … if you are swimming at 60 feet, the pressure of the water on your body is:

$$60/33 + 1 = 2.82 \text{ ATA}$$

In order to equalize that pressure and allow you to breathe, your regulator delivers the gas to you at 2.82 times the rate that it would if you were breathing from it at the surface.

Now that we know the relationship between depth, pressure, and gas consumption, let’s look at how this applies to your SAC rate.

Let’s suppose you are doing a dive to an average depth of 40 fsw for 30 minutes and you consume 1,600 psi from your cylinder. To find out how much you breathe per minute at depth …

1,600 psi / 30 minutes = 53.33 psi per minute

To convert this to how much gas you breathe at the surface you must determine the pressure, in atmospheres absolute, at 40 fsw …

40/33 + 1 = 2.21 ATA

And then determine your SAC rate by dividing your depth consumption rate by the pressure, in atmospheres absolute …

53.33 /2.21 = 24.13 psi per minute

To use this number for gas planning, round up to 25 psi per minute.

Pressure and volume … converting SAC to RMV

As I mentioned earlier, your consumption rate can be expressed in equivalent terms of either pressure (SAC = PSI per minute) or volume (RMV = cubic feet per minute). Both of those numbers are important, and are used for different purposes.

- RMV is used for dive planning
- SAC is used for dive execution

Although SAC and RMV are the same value expressed in different terms, there is one important difference. SAC is specific to the cylinder you are using … RMV is not. This is because your cylinder holds a certain volume of gas for every PSI it displays on your pressure gauge. To convert from SAC to RMV, you need to understand how many cubic feet of gas your cylinder holds for every PSI of pressure you can read on your pressure gauge. This is referred to as your cylinder's "baseline", and is expressed as follows:

baseline = volume (in cubic feet) / working pressure (in PSI)

Once you've determined a cylinder's baseline you can use it to convert from SAC to RMV.

RMV = SAC x baseline

Let's look at a couple of examples of calculating baseline for different cylinders.

- A low-pressure steel 95 holds 95 cubic feet of gas at 2,640 PSI … so the baseline for this cylinder is 95/2,640 = 0.036 cubic feet per PSI … which is a very small number.
- By contrast, an AL80 holds 77.4 cubic feet of gas at 3,000 PSI … so the baseline for this cylinder is 77.4/3000 = 0.026 cubic feet per PSI … which is even smaller.

So to look at an example, if you have a SAC rate of 25 PSI per minute using an AL80, you can convert this to volume as follows …

25 (PSI per minute) x 0.026 (cubic feet per psi) = 0.65 cubic feet per minute.

Turnaround pressure

For simple dives, gas management often requires no more than for you to keep a couple of simple numbers in your head. When your gauge reaches that point, you know it's time to take a specific action. Turnaround pressure is one of those numbers.

Turnaround pressure is exactly what the name suggests … the minimum pressure at which you can safely turn the dive and begin to make your way to the surface. It is most often used for shore diving, where you will be making your way up a slope to a specific exit point … usually the same place where you entered the water.

Turnaround pressure is fairly simple on dives where you will be making your way down a slope until it is time to return, then turning around and retracing your route back to the entry point. In that case, you subtract your desired reserve from your starting pressure, divide the remaining gas pressure in half, and subtract that from your starting value.

For example, let's say you are starting with 3,000 psi and you want a reserve of 500 psi. So your usable gas is 2,500 psi. You'll use 1,250 to go out, and 1,250 to return.

3,000 starting pressure – 500 reserve = 2,500 usable gas

Subtracting 1,250 psi from your starting pressure yields a turnaround pressure of 1,750 psi.

In practice, however, dives with that sort of profile are rare. More commonly, you will take a certain amount of time to reach your destination, spend a certain amount of time at your destination, and then return. In this case, take note of your starting pressure and the pressure you are at when you arrive at your destination … let's say, a wreck you want to explore. By noting how much gas you used to get there, and adding it to your desired reserve, you can arrive at a turnaround pressure.

For example, let's say you start with 2,800 psi (short fill) and arrive at your destination with 2,100 psi. You used 700 psi to get there. Adding that to your desired reserve of 500 psi yields a turnaround pressure of 1,200 psi. So by making a simple calculation in your head, you can know that when you reach 1,200 psi in your cylinder, it's time to start heading back upslope to end the dive.

Don't forget that on your return you will need to add some gas to your reserves because you need to do a safety stop. By knowing your consumption rate and the depth of your safety stop you can quickly and easily calculate how much gas you need for your safety stop and factor that amount into your turnaround pressure.

Rock bottom

Rock bottom is defined as the absolute minimum amount of gas you need to get both yourself and your buddy safely to the surface from a specified depth while you are both breathing off of one cylinder. It assumes a worst-case … that one of you had an out-of-air emergency, and that you will be sharing air during the ascent.

There are some “rules and assumptions” that you should take into account when calculating rock bottom pressure. These are …

- Use working SAC rates for both you and your buddy (assume stress).
- Allow one minute at your deepest depth to make the OOA regulator exchange and sort out whatever problem caused the emergency before beginning your ascent.
- Ascend at a rate of 30 feet per minute.
- Make a three-minute safety stop at 15 fsw.
- Allow at least 200 psi reserve at the surface.
- For dives below 80 fsw, add a 1 minute safety stop at one-half the deepest part of your dive.

Calculating Rock Bottom

Calculating Rock Bottom is simple if you envision the actions that must be taken after the emergency occurs in segments. In other words, first you’ll do the regulator exchange and assess the problem, then you’ll ascend to your first stop, perform your first stop (if dive was deeper than 80fsw), ascend to 15’ for the safety stop, perform the safety stop, then ascend to the surface. All you need to do is determine how much air you need for each segment. To calculate RB simply follow these steps...

Step 1- **OOA Regulator Exchange & Problem Assessment at Depth**
time at depth (in minutes) X depth (ata) X RMV of 2 divers (working RMV) =

Step 2- **Ascent from Depth to 1st Stop**
time to ascend (in minutes) X avg depth (max depth to stop depth, in ata) X RMV =

Step 3- ***Stop (1 minute deep stop or 3 minute safety stop)**
stop time X stop depth (ata) X RMV =

Step 4- ***Ascent from 1st Stop to Safety Stop (max depth deeper than 80fsw)**
time to ascend X avg depth (stop depth to safety stop depth) X RMV =

Step 5- **Safety Stop**
time at stop X stop depth (ata) X RMV =

Step 6- **Ascent from Safety Stop**
time to ascend X avg depth (stop depth to surface, ata) X RMV =

Step 7- **Total Gas Used**
Add steps 1-6

Step 8- **Convert to PSI**
CuFt of gas needed / rated volume of tank X rated pressure of tank =

Step 9- **Add 200psi for Reserve**
Add 200 to step 8 for total Rock Bottom

Let's look at an example....

You and your buddy are both diving AL80 cylinders. Your working RMV rate is 1.82 cubic feet per minute and your buddy's is 1.3 for a total RMV of 3.12 CF per minute. You are planning a dive to 66fsw. Let's follow the steps to determine your Rock Bottom...

Step 1- **OOA Regulator Exchange & Problem Assessment at Depth**
1 (minute) X 2.97 ata of 65') X 3.12 (combined RMV) = **9.27 CuFt**

Step 2- **Ascent from Depth to 1st Stop**
Max Depth was not deeper than 80fsw, bypass this step

Step 3- ***Stop (1 minute deep stop or 3 minute safety stop)**
Max Depth was not deeper than 80fsw, bypass this step

Step 4- ***Ascent from 1st Stop to Safety Stop (max depth deeper than 80fsw)**
1.66 (1:40, ascent time, 65' to 15') X 2.21 (avg depth (40'), in ata)X 3.12 = **11.44 CuFt**

Step 5- **Safety Stop**
3 (minutes) X 1.45 (ata of 15') X 3.12 = **13.57 CuFt**

Step 6- **Ascent from Safety Stop**
.5 (30 seconds, 15' to surface) X 1.22 (avg depth (7.5'), in ata) X 3.12 = **1.91 CuFt**

Step 7- **Total Gas Used**
9.27 + 11.44 + 13.57 + 1.91 = **36.19 CuFt Total**

Step 8- **Convert to PSI**
36.19 / 77.4 X 3000 = 1403

Step 9- **Add 200psi Reserve**
1403 + 200 = **1603 psi Total Rock Bottom**

For this dive, you want to start your ascent no later than when there is 1,600 psi in your cylinder or your buddy's cylinder.

Figure 1 illustrates some relationships between depth, amount of gas required, common cylinder sizes, and rock bottom pressures for a new/inexperienced diver. Rock Bottom is based on a working RMV of 2.0 or a working SAC rate of about 70 psi per minute on an AL80 cylinder. Note the diver isn't able to safely dive to 100fsw unless he uses a cylinder with 98CuFt capacity. Additionally, using an AL80, the diver can would probably hit his Rock Bottom for 90fsw (2913) before even reaching 90fsw. A common rule of thumb for some divers use is to never dive deeper than the volume of gas your cylinder holds. In other words, if you're using an 80CuFt cylinder, you'd limit your maximum depth to 80fsw, 100fsw if you're using a 100CuFt cylinder, etc.

Note that while this is the RMV of an actual diver, consumption rates could be higher for divers with less experience, or lower for divers with more experience.

Figure 1. ***Rock Bottom Pressure & Volume for Common Cylinders- Inexperienced Diver (w/ 200psi Reserve)***

Depth	Cylinder Specifications (rated volume/rated pressure)									Gas req'd (CuFt)
	72 3000	80 2640	80 3000	80 3500	98 2640	100 3500	119 3442	120 3500	130 3442	
130'							3009	3034	2772	97.14
120'						3424	2865	2887	2640	92.12
110'					2490	3175	2659	2680	2451	85
100'					2275	2895	2427	2465	2239	77
90'		2510	2913	3263	2086	2650	2225	2242	2054	70
80'	2536	1999	2312	2585	1668	2108	1777	1790	1643	54.5
70'	2305	1821	2103	2349	1523	1919	1621	1632	1500	49.1
60'	2086	1652	1902	2125	1386	1740	1473	1484	1365	43.9
50'	1876	1491	1716	1911	1254	1569	1331	1341	1236	39.1
40'	1690	1347	1547	1721	1137	1417	1206	1214	1121	34.75

Calculating how much gas you will need for your dive plan

For most recreational dives, knowing your turnaround pressure and rock bottom pressure are all the dive planning you will need. The nature of your dive dictates that you will get in the water and conduct your dive until either the pressure in your cylinder or your no-decompression limit dictates that you begin your ascent.

However, for some dives, where a particular destination or goal is the objective of the dive, it may be useful to plan in advance how much gas you will actually need for the dive. In this case, you can estimate your dive profile and calculate your gas requirement in a manner very similar to what we just did for calculating rock bottom pressure … by breaking the dive into segments, calculating how much gas we will need for each segment, and adding them together.

For example, one segment could be your descent to your target depth. By estimating how many minutes it will take, and how deep you are going, you can use your average depth over that interval to determine a reasonable estimate of how much gas you will use for the descent. Multiplying the pressure (ATA) at your average depth by your RMV will tell you approximately how many the cubic feet of gas are required for that part of the dive.

Likewise, you can do the same thing for the time spent at depth, for the ascent to your deep stop, your ascent to safety stop, and the time spent at each of your stops.

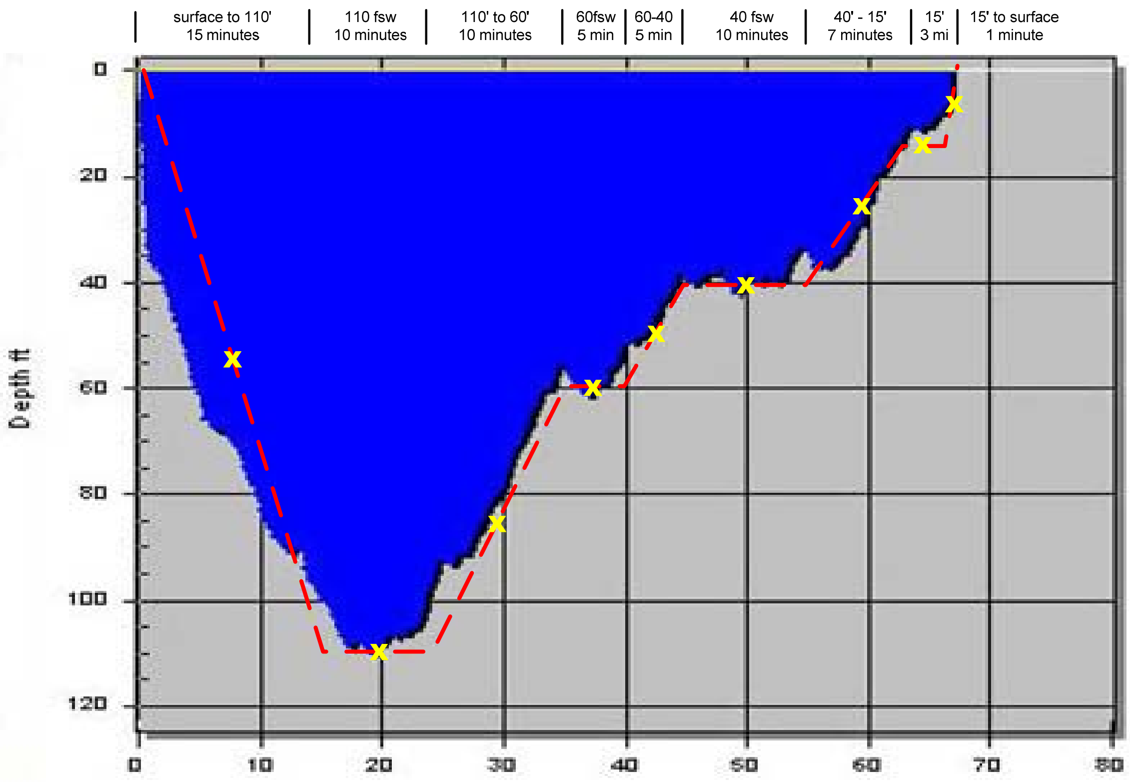
Figure 2 illustrates a planned dive profile superimposed over an actual dive profile. The red dashed line is the planned profile, the callouts along the top are the planned “segments” of the dive, and the yellow X’s represent the average depth for each segment.

By using the relationships we have learned so far, we can estimate our gas consumption within a reasonably close limit.

You can see that while slight variations exist over the course of the dive, the actual dive is fairly close to the planned dive. Actual gas consumption on this particular dive was within just a couple of cubic feet of the planned consumption … well within the limitations of your expected reserve.

This skill can be very valuable for the dive team who has a specific goal in mind, or is planning a deep dive, and wants to be assured that they are carrying enough gas to execute their dive plan.

Figure 2. Planned vs. Actual Dive Profile



For most of us, this is a skill we will rarely, if ever need to use. It depends entirely on the nature of the dive we are planning. However, from a conceptual perspective it is a useful skill to have as an aid to understanding how much air you will actually use on a given dive.

Some good gas management habits

No matter how much effort you put into understanding gas management skills, it's important to develop good basic habits. These habits include things you should do before the dive, during the dive, and after the dive.

Before the dive …

- Confirm each other's tank pressure, and verbalize both divers' turnaround pressure and rock bottom pressure.
- Perform buddy checks to assure that all tank valves are fully opened and that all second-stage regulators are properly stowed and accessible.
- Perform bubble checks on each other to make sure all hose connections are secure and there are no leaks.

During the dive …

- Monitor your own gas on a regular basis … every five minutes, at a minimum. It's a good idea to monitor your gas more frequently as you go deeper, since you will be breathing it down faster at greater depths.
- If you are diving with an unfamiliar buddy, make sure to communicate your pressure to your buddy on a regular basis, and that they communicate theirs to you. This will give you an idea of their actual gas consumption compared to yours, and vice-versa. Familiar dive buddies have generally established this relationship already, through previous experience.
- Keep both your own and your dive buddy's turn pressure and rock bottom pressure in mind. If you have difficulty remembering, write it on a slate or wet notes for reference during the dive.

When not diving …

- Maintain your equipment properly. Keep your regulator serviced in accordance with manufacturer's specifications. Remember that drysuit and BCD valves should be maintained on an annual basis as well.
- Properly rinse your gear in clean, fresh water after every dive to assure that salt deposits, sand, and debris do not cause issues with valves.
- Regularly inspect your regulator hoses and connections for signs of wear or damage.

Some tips for using your air more efficiently

Air consumption is often related to other aspects of your diving, such as buoyancy control, weighting, trim, your breathing pattern, and swimming speed. Once you've determined your air consumption rate, you should track it over a period of time and see if you notice how it changes over time. As overall skills improve, so will your air consumption … often dramatically.

Here are some tips that can help you improve your air consumption, and in general get more enjoyment out of your diving experience.

Breathing

For most of us, scuba diving is the first time in our lives that we have ever actually had to think about breathing. And there is a technique for proper breathing on scuba gear. In general, you want to take long, slow, deep breaths. A complete inhale and exhale should take anywhere from 5 to 8 seconds … sometimes longer for more practiced divers. Rapid breathing affects your buoyancy. Shallow breathing tends to build up carbon-dioxide in our body, which causes us to feel oxygen starved and breathe harder and faster. Practice long, slow, deep breathing on land … and then try it in the water. You will often notice an immediate improvement in your buoyancy control, and over time will notice that as your buoyancy control improves, so does your gas consumption.

Weighting

Improper weighting affects your gas consumption considerably. Too much weight causes you to carry excessive gas in your BCD or wing to maintain neutral buoyancy, and even small changes in depth will cause large buoyancy shifts due tothe expansion or compression of that gas. You should perform weight checks any time you get a new piece of gear, and occasionally as your diving skills improve, because even something as simple as becoming more relaxed underwater will often allow you to lose weights you thought you needed.

Conversely, underweighted divers will struggle to stay down … especially toward the end of the dive as your cylinder loses gas and becomes more buoyant. All that extra work causes you to breathe harder and consume your gas supply at a faster rate.

Trim

Humans are psychologically oriented in a vertical position … after all, it’s what we’ve done since we learned how to walk. When learning scuba we must teach ourselves to move about in a horizontal position. Proper trim is very important to good gas consumption. Water is 800 times heavier than air, and we cannot efficiently move through water in the same way we move through air. Maintaining a horizontal position means that as we move through the water, we have to push less water out of our way than we would in a vertical position. It also radically increases the efficiency of our fins to move us in the direction we want to go. Both of those are huge factors in terms of our air consumption, because it reduces the amount of work we need to do to move around.

Swimming speed

Many divers … new divers in particular … tend to swim rather quickly. While that will get you from point to point faster, it will also increase your air consumption dramatically. In fact, the faster you go the more air you will consume getting from one place to another. Slow down … it’s not a race! There are lots of tiny creatures (and even some large ones that are good at camouflage) that you will likely not see if you are swimming quickly. Going slow, and keeping your fin kicks relatively small, will not only improve your air consumption dramatically, it will help you get more enjoyment out of your dive.