Understanding Gas Management

What is gas management?

The essence of gas management is the ability to know, both before and during your dive that you have enough gas in your scuba cylinder to safely execute the dive you are planning to do. It is also about knowing that if anything goes wrong with either you or your buddy, you each have enough gas in reserve to get both divers to the surface in a safe and controlled manner.

Think of gas management as the knowledge to determine:

- 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

Why is it 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 manages his or her gas supply with both divers in mind.

How do we 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 a variety of factors that include your dive profile, your state of mind, your physical condition on dive day, 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. It's important to note that your SAC rate is really just a starting point.

What is SAC, and how do we determine it?

SAC 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 class, 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 … and your breathing rate 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're working hard, are looking at a sh-sh-sh-sh-shark, or are under stress.

Many other things can affect your air consumption rate … including depth (due to narcosis effects), current (because of exertion), stress (because it psychologically causes you to breathe faster), fatigue, excitement, and a host of other factors.

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.

To calculate your SAC rate, you must first have a basic understanding of how depth affects your gas consumption. At the surface, we are at atmospheric pressure, or 1 ***atmosphere absolute*** (ATA). The reason we choose to use gas consumption at the surface as a baseline, rather than gas consumption at a specific depth, is because it makes calculating our consumption at any given depth … or multiple depths … easier.

As we learned in Open Water class, water pressure affects our air spaces … the deeper we go, the more squeezed our air spaces become. But water pressure doesn't affect the gas that's in our scuba cylinder … until we breathe it. When we breathe, 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. The deeper we go, the greater the water pressure becomes … and the higher the pressure of gas that comes through our regulator with each breath we take. The result is that as we go deeper, we consume more gas with each 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 15 minutes!

So how does this all relate to calculating your SAC rate? Consider that the amount of gas you inhale with each breath is directly proportional to the pressure of the water you are swimming in, and that 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. The relationship between depth and pressure is:

Pressure (ATA) = depth/33 + 1

As we all learned in OW class, 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 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.

So how do I calculate my SAC rate?

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.

When you are planning a dive, you want to know how much gas you will need … so you calculate volume. When you are executing a dive, you monitor the gas remaining in your cylinder in PSI, so pressure is what you care about.

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. The value of cubic feet per PSI is called your cylinder's "baseline", and is expressed as follows:

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

For example, 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, as a basis of comparison, at 500 PSI, an LP95 contains about 18 cubic feet of gas, while an AL80 contains only about 13 cubic feet of gas. As you can see, for planning purposes, knowing how much gas your cylinder contains at a given pressure matters. Once you have determined a SAC rate that's suitable for the dive plan, you can convert it to RMV by multiplying the SAC rate by the cylinder's baseline.

RMV = SAC x baseline

For 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.

Converting your gas consumption rate from pressure to volume is useful for a number of gas management applications, which we'll examine a bit later on.

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 lowest pressure at which you can be when you 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, you can 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.

There are other "rules of thumb" that can be applied to recreational diving … some are more conservative than others. A common one is the "Rule of Thirds" … one third of your gas for going out, one third for coming back, and one third for reserve. Depending on your comfort level, you may wish to apply this more conservative standard. What is important is that you understand the importance of knowing how much gas you need to make a comfortable, controlled return and turning the dive when you reach that predetermined pressure.

Rock bottom

Rock bottom is defined as the absolute minimum amount of gas you need to get you 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 …

- Since you will both be rather stressed during an emergency, you should use your working SAC rates to calculate rock bottom pressures.

- You will need about a minute at your deepest depth to make the OOA regulator exchange and sort out whatever problem may have caused the emergency before beginning your ascent.
- You will ascend at a rate of 30 feet per minute.
- You will make a three-minute safety stop at 15 fsw.
- You should allow 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.

One final rule … you should never calculate a rock bottom of less than 500 psi. This is to take into account the possibility that your SPG doesn’t read the low end of the scale accurately (the most likely place for SPG errors to occur).

So let’s look at an example …

Let’s say you and your buddy are both diving AL80 cylinders. Your working SAC rate is 50 psi per minute, and your dive buddy’s is 60 psi per minute. So your total surface air consumption is 110 psi per minute. You are planning a dive to 65 fsw. To calculate your rock bottom you need to consider the following:

- Your combined air consumption for one minute at 65 fsw is 330 psi (110 combined SAC rate times 3 ATA).
- Your air consumption from 65 fsw to 15 fsw will take 1 minute and 40 seconds. Your average depth for that time will be 40 fsw, so your average pressure will be 2.21 ATA … so your combined air consumption for the ascent to safety stop will be 245 psi.
- Your pressure at 15 fsw is 1.45 ATA, so your air consumption for a 3 minute safety stop will be 480 psi.
- Your ascent from safety stop will take ½ minute, at a pressure of 1.23 ATA. So you will use 68 psi.
- Reach the surface with a reserve of 200 psi

Adding up the numbers, your rock bottom at 65 fsw will be …

$$330 + 245 + 480 + 68 + 200 = 1{,}323 \text{ psi}$$

On this dive, you should begin ascending to a shallower depth before you reach this pressure in either your cylinder or your buddy’s cylinder.

For those who hate math …

Table 1 shows some relationships between depth, common cylinder sizes, and rock bottom pressures. It assumes a working RMV for each diver of 1.0 cubic feet per minute … about 40 psi per minute for an AL80 cylinder.

Note that while this is a reasonable gas consumption rate for an experienced diver, consumption rates could be much higher for divers who are either relatively inexperienced or out of shape.

Table 1. Rock Bottom Pressures and Volumes for Specified Cylinders and Depths

Depth	Cylinder Specifications (size/working pressure)									
	72 3000	80 2640	80 3000	80 3500	95 2640	100 3500	119 3442	120 3500	130 3442	Total volume (cubic feet)
40	910	762	839	946	674	797	693	697	651	17.04
50	995	830	916	1035	730	868	752	757	705	19.08
60	1247	1029	1142	1299	898	1079	927	933	865	25.12
70	1360	1118	1244	1418	973	1174	1005	1012	937	27.83
80	1480	1214	1352	1544	1054	1275	1089	1096	1014	30.73
90	1608	1315	1468	1679	1139	1383	1178	1186	1095	33.80
100	1744	1423	1590	1821	1230	1497	1272	1281	1181	37.06
110	1888	1537	1719	1972	1326	1618	1372	1381	1272	40.51
120	2039	1656	1855	2131	1426	1745	1476	1487	1368	44.13
130	2198	1782	1998	2298	1532	1878	1587	1598	1469	47.94

You can use this table as a reference … the rock bottom numbers you should use for your own dive planning will be proportionally higher or lower depending on the actual working consumption rates for you and your dive buddy.

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 out how much gas you will actually need to do 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.

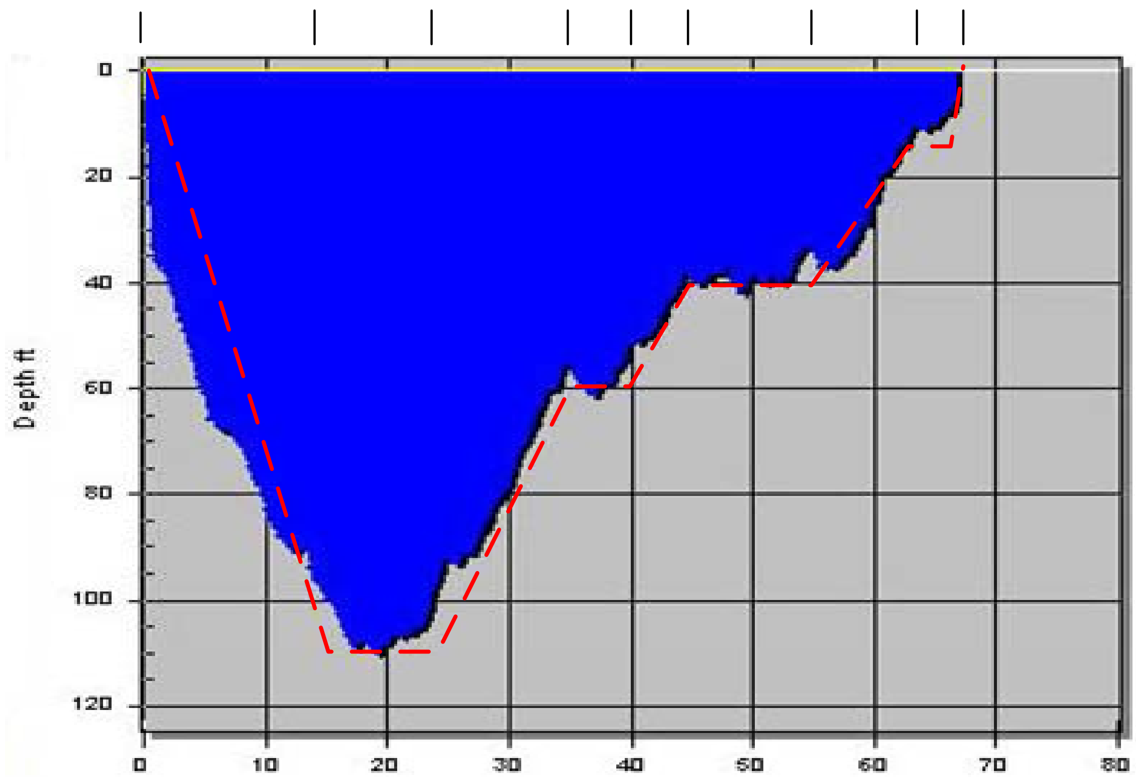
Likewise, you can do the same thing for the time spent at depth, for the ascent to your deep stop, your ascent to safety stop, and the time spent at each of your stops.

Figure 1 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 adequate gas to do the dive they are planning.

Figure 1. 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 equally important to develop good basic habits that enable you to monitor your gas consumption during the dive, and to minimize the risk of running low or out of gas during the dive. 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

Scuba diving presents most of us with the first time in our lives that we have ever actually had to think about breathing. For the most part, it's something we just do and never give a whole lot of thought to. But underwater it affects us dramatically. And there is a technique to 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 our 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 will affect your gas consumption considerably. Divers who are overweighted will go through their gas faster because they have to carry excessive gas in their BCD or wing to maintain neutral buoyancy, and even small changes in depth will cause excessive changes in their buoyancy because of the expansion or compression of that extra gas. You should perform weight checks any time you get a new piece of gear, and occasionally as your diving skills improve, because simply learning how to relax more underwater will often allow you to lose weights you thought you needed. Conversely, underweighted divers will struggle to stay down … working harder than they need to, which will also cause you to breathe harder than you should and consume your gas supply at a faster than needed rate.

Trim

Humans are psychologically oriented in a vertical position … it's what we've done since we learned how to walk, and 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 move 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 about.

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 miss if you speed by. Going slow, and keeping your fin kicks relatively small, will improve your air consumption dramatically.

Summary

Understanding the relationships between depth, pressure, and gas consumption will help you develop safer diving habits, and increase your awareness of the importance of proper dive planning. It will help you relax in the assurance that you have plenty of gas for the dive you plan to do. And it will make you a better, more confident diver and dive buddy.

As a recreational diver, it will often be the case that you will need nothing more than a basic understanding of the concepts presented in this course … knowing how much gas you breathe over a certain time interval, when to turn around, and when to ascend to a shallower depth.

As you develop your skills, and decide that perhaps you want to try more aggressive dives, the knowledge presented here will serve as a starting point to more advanced topics such as decompression theory, or the use of mixed gases for recreational diving.

It is my hope that the knowledge provided in this seminar, and the material presented in this article, will help to make you a better, safer diver.