The Mathematics Behind Partial Pressure Gas Blending
or
"Why You Shouldn't Calculate Your Mix in Your Head"

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Foreword

My undergraduate degree is in mathematics. As graduation approached, several of my math friends and I discussed why we chose this major and one common theme was that we found it to be... easy. We were wired to see the world in terms of numbers and symbols, and so problem solving revolved around the "story" rather than the "formulas."

When I took my divemaster and instructor courses -- and my Nitrox gas blending class -- I tried to convey to my fellow students to concentrate on the problems we were being asked to solve rather than merely on which formula to apply, and many had trouble with that; they couldn't "see" the problem in symbolic terms so the formulas were their only lifeline.

The physics of gas is an essential science for SCUBA divers and, yet, most divers don't understand the science behind our sport. This is just as true for mixed-gas divers, even many who dive with Nitrox.

This paper was not written to explain gas physics, per se, but to step through the math -- actually, the algebra! -- of how gases with varying amounts of oxygen are mixed together to prepare the specific blend that we request (or are offered). I won't explain how to *use* Nitrox but I will attempt to step through the essential formulas used by gas blenders to prepare the Nitrox. While the various textbooks do a varying job providing the formulas to the reader, most divers don't read the blender manual and the manual often skips essential steps. I'll try not to.

Suggestions, corrections, and/or any other comments about this manual are welcome.

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Part 1: The Basics

Although not a treatise on physics and gas laws, this section will introduce the scientific basis for *partial pressure blending*, one of the most common ways in which Enhanced Air Nitrox gas is blended. It will introduce Dalton's Law, which shows how a gas comprises its component elements, and show how it can be applied to the combination of gases to create nitrox mixes.

1.1. Gas Composition and Dalton's Law

All SCUBA divers -- particularly those certified to use Nitrox -- know that air is composed primarily of two gases, namely, oxygen (O_2) and nitrogen (N_2).[1]

Dalton's Law[2] is a law of physics that states, in essence, that the pressure of a gas is the sum of the pressure of all of its component gases. So, for example, if a gas is composed of elements A, B, and C, then the total pressure of the gas (P) is the sum of the pressure of the three component gases:[3]

$$P_{TOTAL} = P_A + P_B + P_C$$

This formula shows that the total pressure is the sum of the individual gas pressures but does not tell us what those individual pressures are. We can calculate the *fractional pressure* of each gas if we know the fraction of the whole that each component gas occupies. Note that the sum of the fractional percentage (F) of all of the component gases will come to 100%:

$$F_{TOTAL} = 100\% = F_A + F_B + F_C$$

For discussion purposes, let's say that we have some gas mixture that is composed of 42% gas A, 27% gas B, and 31% gas C. This would be denoted:

$$F_A = 42\% = 0.42$$
$$F_B = 27\% = 0.27$$
$$F_C = 31\% = 0.31$$

Armed with this information, we can calculate the fractional pressure of each gas, which is merely the product of the total pressure of the gas and the fractional percentage of each individual gas:

$$P_A = P_{TOTAL} \bullet F_A$$
$$P_B = P_{TOTAL} \bullet F_B$$
$$P_C = P_{TOTAL} \bullet F_C$$

---

[1] For this discussion, we will ignore the trace elements in air such as argon, carbon dioxide, etc.
[2] Named for John Dalton, who discovered this principle in 1801.
[3] Dalton's Law assumes a constant temperature of all of the component gases.

As an example, suppose that our theoretical gas is in a tank at a pressure of 900 pounds per square inch (psi), or 60 bar.[4] The fractional pressure of gases A, B, and C would be:

IMPERIAL	**METRIC**
P_A = 900 psi • 0.42 = 378 psi	P_A = 60 bar • 0.42 = 25 bar
P_B = 900 psi • 0.27 = 243 psi	P_A = 60 bar • 0.27 = 16 bar
P_C = 900 psi • 0.31 = 279 psi	P_A = 60 bar • 0.31 = 19 bar

This is relevant to SCUBA divers because of the composition of air. According to Dalton's Law, the pressure of air is the sum of the pressure of the nitrogen plus the pressure of the oxygen:

$P_{AIR} = P_{N2} + P_{O2}$

SCUBA divers know that the pressure of air at sea level is 14.7 psi (imperial) or 1 bar (metric), also denoted as 1 atmosphere (ATM). We know that oxygen comprises 20.9% of air; since we are ignoring trace elements in air, this leaves the remaining 79.1% of air to be composed of nitrogen (Figure 1.1). The fraction (F) of oxygen and nitrogen in air could then be denoted:

F_{O2} = 20.9% = 0.209
F_{N2} = 79.1% = 0.791

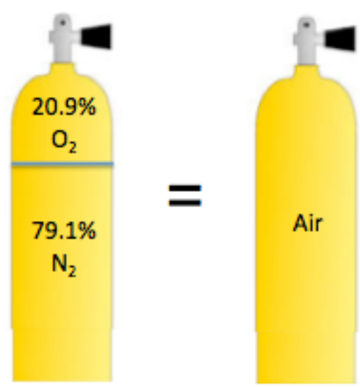


Figure 1.1. *Fraction of the component gases of air.*

We can now calculate the *fractional pressure* of oxygen and nitrogen in the air at one atmosphere:

$P_{O2} = P_{AIR} \bullet F_{O2}$
$P_{N2} = P_{AIR} \bullet F_{N2}$

[4] 1 bar = 14.7 psi.

IMPERIAL	METRIC
P_{O2} = 14.7 psi • 0.209 = 3.1 psi	P_{O2} = 1 bar • 0.209 = 0.209 bar
P_{N2} = 14.7 psi • 0.791 = 11.6 psi	P_{N2} = 1 bar • 0.791 = 0.791 bar

Figure 1.2 shows the fractional pressure concept graphically. Air is a mixture of its component gases, oxygen and nitrogen. What is true for air is also true for the gases used for SCUBA, including Nitrox and Heliox;[5] all are blends of different gases with different compositions of each component gas.

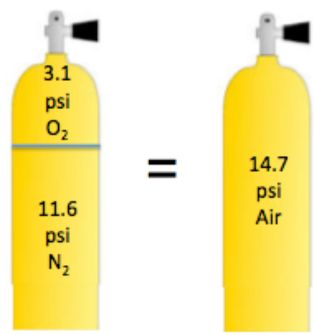


Figure 1.2. *Fractional pressure of the component gases of air.*

This concept will be extended in later sections since SCUBA divers see gases at pressures up to 3000 psi (204 bar) and above. But the composition of a given gas remains the same, regardless of the pressure.

1.2. Air Plus Oxygen Equals EAN

Enhanced Air Nitrox is simply air with a higher percentage of oxygen than air's 20.9%. A common nomenclature is to denote EANx, where x is the desired O_2 percentage (e.g., EAN32 would be Nitrox with a 32% O_2 mix). In EAN, oxygen is used to displace (or dilute) the amount of nitrogen.

We know that the total pressure of the mix is the sum of the pressures of the component gases; in this case, the component gases are air and oxygen (Figure 1.3). For some desired pressure (denoted P_D) of a particular EANx mix (denoted M_D), we know that:

$$P_D \bullet M_D = P_{O2} \bullet 100\% + P_{AIR} \bullet 20.9\%$$

where P_{O2} and P_{AIR} are the pressure of oxygen and air, respectively.

[5] Heliox is a SCUBA gas composed to oxygen, nitrogen, and helium. It will not be discussed further in this paper.

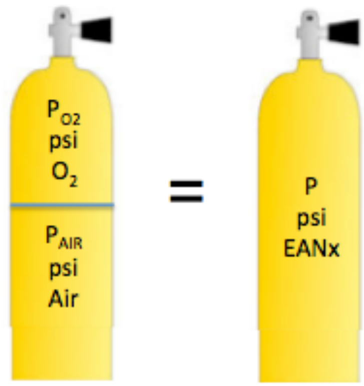


Figure 1.3. *A given EANx mix at a given pressure is a combination of some pressure of air and some pressure of oxygen.*

So, how much air and oxygen do we need to mix to obtain the right blend for our desired EANx? Let's go back to the formula:

$$P_D \bullet M_D = P_{O2} \bullet 100\% + P_{AIR} \bullet 20.9\%$$

If we know the desired gas pressure and EANx mix, then the only things we don't know are the pressure of oxygen and air. But we do know one more thing; namely, that the total pressure of the EANx gas will be the sum of the pressures of the component gases, or:

$$P_{O2} + P_{AIR} = P_D$$
$$P_{AIR} = P_D - P_{O2}$$

Armed with this information, we can solve for P_{O2} as follows:

$$P_D \bullet M_D = P_{O2} \bullet 100\% + P_{AIR} \bullet 20.9\%$$

$$P_D \bullet M_D = P_{O2} \bullet 1.0 + (P_D - P_{O2}) \bullet 0.209$$

$$P_D \bullet M_D = P_{O2} \bullet 1.0 + P_D \bullet 0.209 - P_{O2} \bullet 0.209$$

$$P_D \bullet M_D = P_{O2} \bullet (1.0 - 0.209) + P_D \bullet 0.209$$

$$P_D \bullet M_D - P_D \bullet 0.209 = P_{O2} \bullet 0.791$$

$$P_D \bullet (M_D - 0.209) = P_{O2} \bullet 0.791$$

$$\frac{P_D \bullet (M_D - 0.209)}{0.791} = P_{O2}$$

Using some real numbers might help make this appear more practical.

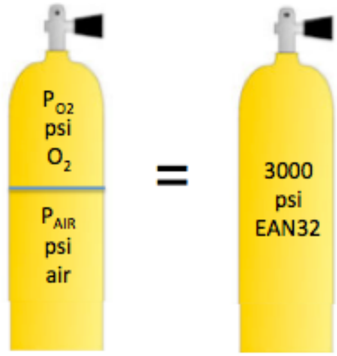


Figure 1.4. *Mixing air and oxygen to prepare a 3000 psi mix of EAN 32.*

Suppose we want to combine oxygen and air prepare a 3000 psi (204 bar) tank of EAN32 gas. We know:

P_D = 3000 psi = 204 bar　　　　M_D = 32% = 0.32

Using our formula and these values, we can calculate:

$$P_{O2} = \frac{P_D \bullet (M_D - 0.209)}{0.791}$$

IMPERIAL

$$P_{O2} = \frac{3000 \bullet (0.32 - 0.209)}{0.791}$$

= 3000 • 0.111 / 0.791
= 421 psi

METRIC

$$P_{O2} = \frac{204 \bullet (0.32 - 0.209)}{0.791}$$

= 204 • 0.111 / 0.791
= 29 bar

Now that we know the pressure of the oxygen, we can calculate the necessary pressure of regular air using the formula $P_{AIR} = P_D - P_{O2}$ = 2579 psi (175 bar) (Figure 1.5).

We can test these computed values by putting everything back into the original formulas:

IMPERIAL

$P_D \bullet M_D$ = 3000 • 0.32 = 960 psi

$P_{O2} + P_{AIR} \bullet M_{AIR}$ = 421 + 2579 • 0.209
= 421 + 539
= 960 psi

METRIC

$P_D \bullet M_D$ = 204 • 0.32 = 65 bar

$P_{O2} + P_{AIR} \bullet M_{AIR}$ = 29 + 175 • 0.209
= 29 + 36
= 65 bar

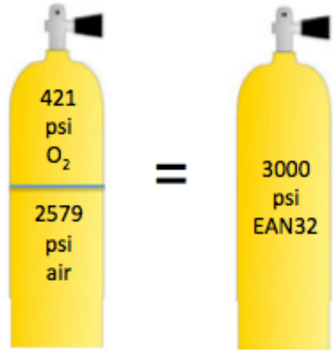


Figure 1.5. *The oxygen and air mix required to form EAN32.*

1.3. SIDENOTE: What's In An Empty Tank?

Divers are always told to not end a dive with less than some amount of gas in their tank, generally 500 psi (34 bar). One reason, of course, is that divers are ill-advised to use all of their air without a reserve. More pragmatically, however, is the fact that if the pressure gets too low, there is opportunity for moisture to accumulate in the tank.

There are many reasons, however, that a blender may start with an empty tank. Some blenders empty the tank because it is easier to calculate the required mixture of component gases and, in some cases, it makes financial sense to start with an empty tank (this is due to the type of component gases being employed). A tank may also be empty after an annual visual exam.

But is a tank ever really "empty"? Empty implies that there is nothing is the tank; i.e., 0 psi (0 bar). But unless there's a vacuum, that's not really the case; we exist at 1 ATM of pressure. Therefore, everything else being equal, an "empty" tank really contains 20.9% O_2 at 14.7 psi (1 bar).

Part 2: Blending A Nitrox Tank

This section will introduce *partial pressure blending*, one of the most common ways in which Nitrox gas is blended. Using the basics of Dalton's Law, as described in Part 1, we will derive the formulas necessary to understand how to mix oxygen and air -- or any combination of gases -- to prepare a desired Nitrox blend.

2.1. Partial Pressure Blending

Nitrox -- more formally known as Enhanced Air Nitrox -- is a SCUBA gas blend containing more oxygen -- and, therefore, less nitrogen -- than ordinary air.[6] For a number of reasons beyond the scope of this paper, Nitrox blends for recreational divers are limited to 40% oxygen (i.e., F_{O2} = 0.4, aka EAN40).

Although there are several ways in which a Nitrox tank can be prepared, one of the most common ways is called *partial pressure blending (PPB)*. Understanding Dalton's Law is essential to understanding PPB, which basically works as follows:

1. Measure the pressure and fraction of oxygen of the gas currently in the tank. This is called the starting pressure (P_S) and starting mix (M_S), respectively.
2. Determine the pressure and fraction of oxygen of the gas to be in the tank after filling; this is the desired pressure (P_D) and desired mix (M_D), respectively. These values are supplied to the gas blender by the diver who, in turn, determines these values based upon their dive plan.
3. The gas blender will employ two gases, called the *fill gas* and *top-off gas*, in order to prepare the desired Nitrox mix. The fill and top-off gases will contain a fixed fraction of oxygen, denoted M_F and M_T, respectively. The most common fill gas is pure oxygen (M_F = 100% = 1.0) and the most common top-off gas is air (M_T = 20.9% = 0.209).
4. The blender adds some amount of fill gas followed by some amount of top-off gas to the tank; the pressure of the two gases is denoted P_F and P_T, respectively. The blending formulas tell the blender how much fill gas to add to the tank.
5. The blender adds the top-off gas to the tank to achieve the proper desired pressure and mix.

This exercise in Dalton's Law -- and algebra! -- is shown in Figure 2.1. The tank containing the desired gas mixture (M_D) at the desired tank pressure (P_D) is prepared by measuring the fractional pressure of the gas in the tank at the start (i.e., $P_S \bullet M_S$) and then calculating the necessary fractional pressures of the fill gas (i.e., $P_F \bullet M_F$) and the top-off gas (i.e., $P_T \bullet M_T$).

[6] Nitrox allows divers with a longer no-decompression dive time at a given depth than air because it contains less nitrogen. The depth, however, is limited by the amount of oxygen due to potential oxygen toxicity. Details in the use of nitrox, its limitations, and dive planning are covered in Nitrox certification courses. This paper just touches on how the gas is prepared.

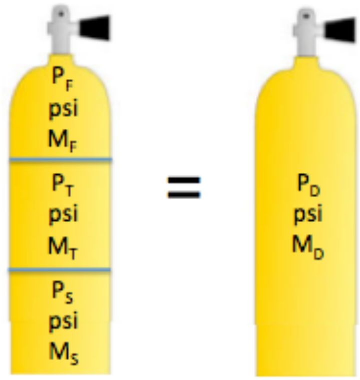


Figure 2.1. *The desired gas mixture (D) is a combination of the gas at the start (S) plus the top-off gas (T) and fill gas (F).*

2.2. A Formula For Blending EANx

The discussion above showed how oxygen and air can be combined to form a desired EANx mix. Real tanks, however, have to add the mixing gases to whatever is currently in the tank. To create a formula for EANx, then, we need to accommodate the starting pressure and mix of the tank prior to filling (denoted P_S and M_S, respectively). The total pressure of the desired mix, then, is the sum of the fractional pressures of the starting, fill, and top-off gases:

$$P_D \bullet M_D = P_S \bullet M_S + P_F \bullet M_F + P_T \bullet M_T$$

As before, we have a formula with a bunch of variables. Since we know the starting pressure and mix (i.e., P_S and M_S), the desired pressure and mix (i.e., P_D and M_D), and the mix of the fill and top-off gases (i.e., M_F and M_T), we have only two unknowns, namely the pressure of the fill gas (P_F) and the pressure of the top-off gas (P_T). And, as before, those two values are related to each other since we know the desired total pressure and starting pressure:

$$P_S + P_F + P_T = P_D$$
$$P_T = P_D - P_S - P_F$$

Our blending formula is slightly more complicated than the mixing formula discussed above because a) we need to deal with the starting gas and b) our fill and top-off gases might not be air and oxygen. Nevertheless, the new formula is just as straight-forward (don't worry, we'll use actual numbers later!):

$$P_S \bullet M_S + P_F \bullet M_F + P_T \bullet M_T = P_D \bullet M_D$$

$$P_S \bullet M_S + P_F \bullet M_F + (P_D - P_S - P_F) \bullet M_T = P_D \bullet M_D$$

$$P_S \bullet M_S + P_F \bullet M_F + P_D \bullet M_T - P_S \bullet M_T - P_F \bullet M_T = P_D \bullet M_D$$

$P_F \bullet M_F - P_F \bullet M_T = P_D \bullet M_D - P_S \bullet M_S - P_D \bullet M_T + P_S \bullet M_T$

$P_F \bullet (M_F - M_T) = P_D \bullet (M_D - M_T) - P_S \bullet (M_S - M_T)$

$$P_F = \frac{P_D \bullet (M_D - M_T) - P_S \bullet (M_S - M_T)}{(M_F - M_T)}$$

Again, now that we know the fill gas pressure, we can calculate the top-off gas pressure:

$P_T = P_D - P_S - P_F$

As before, the formulas will make more sense with real values so we'll look at three examples.

2.3. Example 1: M_D Greater Than M_S

In this example, the desired gas mixture (M_D) has a higher percentage of oxygen than the starting mix (M_S). Suppose an EAN32 tank currently at 425 psi (29 bar) needs to be filled with an EAN34 mix to 3200 psi (218 bar). In this case, we know (Figure 2.2):

P_S = 425 psi = 29 bar
P_D = 3200 psi = 218 bar
M_F = 100% = 1.0

M_S = 32% = 0.32
M_D = 34% = 0.34
M_T = 20.9% = 0.209

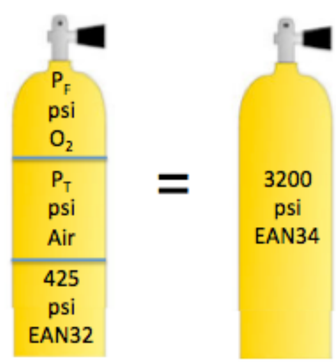


Figure 2.2. *Tank at 425 psi of EAN32 needs to be filled to 3200 psi of EAN 34.*

Calculate the required pressure of fill gas using the formula above:

$$P_F = \frac{P_D \bullet (M_D - M_T) - P_S \bullet (M_S - M_T)}{(M_F - M_T)}$$

IMPERIAL

$$P_F = \frac{3200 \bullet (0.34-0.209) - 425 \bullet (0.32-0.209)}{(1.0 - 0.209)}$$

$$= \frac{(3200 \bullet 0.131) - (425 \bullet 0.111)}{0.791}$$

$$= (419.2 - 47.175) / 0.791$$

$$= 372.025 / 0.791$$

$$= 470 \text{ psi}$$

METRIC

$$P_F = \frac{218 \bullet (0.34-0.209) - 29 \bullet (0.32-0.209)}{(1.0 - 0.209)}$$

$$= \frac{(218 \bullet 0.131) - (29 \bullet 0.111)}{0.791}$$

$$= (28.558 - 3.219) / 0.791$$

$$= 25.339 / 0.791$$

$$= 32 \text{ bar}$$

$$P_T = P_D - P_S - P_F$$

$P_T = 3200 - 425 - 470$
$= 2305$ psi

$P_T = 218 - 29 - 32$
$= 157$ bar

The pressure/mix product of the desired gas is ($P_D \bullet M_D$), yielding a value of 1088 psi (74 bar). Check the calculated fill pressure by summing the partial pressure/mix products of the start, fill, and top-off gases (Figure 2.3):

$$(P_S \bullet M_S) + (P_F \bullet M_F) + (P_T \bullet M_T)$$

IMPERIAL

$= (425 \bullet 0.32) + (470 \bullet 1.0) + (2305 \bullet 0.209)$
$= 136 + 470 + 482$
$= 1088$ psi

METRIC

$= (29 \bullet 0.32) + (32 \bullet 1.0) + (157 \bullet 0.209)$
$= 9 + 32 + 33$
$= 74$ bar

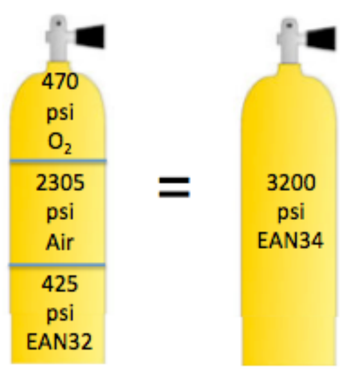


Figure 2.3. *Adding 470 psi of oxygen and 2305 psi of air to a starting tank of 425 psi of EAN32 will create a 3200 psi EAN34 blend.*

2.4. Example 2: M_D Less Than M_S

In this example, the desired gas mixture has a lower percentage of oxygen than the starting mix. Nothing actually changes here with respect to the use of the formulas or the process; that's all the same. Suppose an EAN36 tank currently at 375 psi (26 bar) needs to be filled with an EAN32 mix to 3000 psi (204 bar). In this case, we know (Figure 2.4):

P_S = 375 psi = 26 bar
P_D = 3000 psi = 204 bar
M_F = 100% = 1.0

M_S = 36% = 0.36
M_D = 32% = 0.32
M_T = 20.9% = 0.209

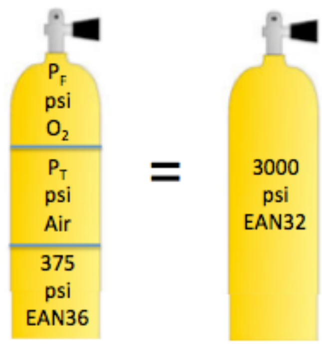


Figure 2.4. *Tank at 375 psi of EAN36 needs to be filled to 3000 psi of EAN 32.*

Calculate the required pressure of fill gas using the blending formula:

$$P_F = \frac{P_D \bullet (M_D - M_T) - P_S \bullet (M_S - M_T)}{(M_F - M_T)}$$

IMPERIAL

$$P_F = \frac{3000 \bullet (0.32-0.209) - 375 \bullet (0.36-0.209)}{(1.0 - 0.209)}$$

$$= \frac{(3000 \bullet 0.111) - (375 \bullet 0.151)}{0.791}$$

$$= (333.0 - 56.625) / 0.791$$

$$= 276.375 / 0.791$$

$$= 349 \text{ psi}$$

METRIC

$$P_F = \frac{204 \bullet (0.32-0.209) - 26 \bullet (0.36-0.209)}{(1.0 - 0.209)}$$

$$= \frac{(204 \bullet 0.111) - (26 \bullet 0.151)}{0.791}$$

$$= (22.644 - 3.926) / 0.791$$

$$= 18.718 / 0.791$$

$$= 24 \text{ bar}$$

$P_T = P_D - P_S - P_F$

$P_T = 3000 - 375 - 349$
$= 2276$ psi

$P_T = 204 - 26 - 24$
$= 154$ bar

The pressure/mix product of the desired gas is (P_D • M_D), yielding a value of 960 psi (65 bar). Check the calculated fill pressure by summing the partial pressure/mix products of the start, fill, and top-off gases (Figure 2.5):

$(P_S \bullet M_S) + (P_F \bullet M_F) + (P_T \bullet M_T)$

IMPERIAL

= (375•0.36) + (349•1.0) + (2276•0.209)
= 135 + 349 + 476
= 960 psi

METRIC

= (26•0.36) + (24•1.0) + (154•0.209)
= 9 + 24 + 32
= 65 bar

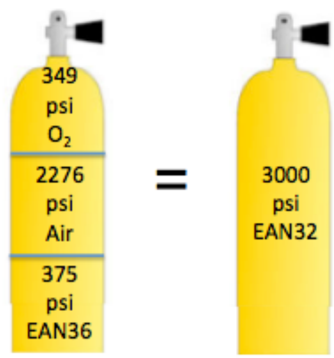


Figure 2.5. *Adding 349 psi of oxygen and 2276 psi of air to a starting tank of 375 psi of EAN36 will create a 3000 psi EAN32 blend.*

2.5. Example 3: Bleeding The Tank

It is sometimes necessary to remove gas from the tank in order to obtain the desired blend; this is usually necessary when the desired mix is much lower than the starting mix and the tank pressure is relatively high. In this example, suppose an EAN36 tank currently at 1500 psi (102 bar) needs to be filled to 3000 psi (204 bar) with an EAN28 mix. In this case, we know (Figure 2.6):

P_S = 1500 psi = 102 bar
P_D = 3000 psi = 204 bar
M_F = 100% = 1.0

M_S = 36% = 0.36
M_D = 28% = 0.28
M_T = 20.9% = 0.209

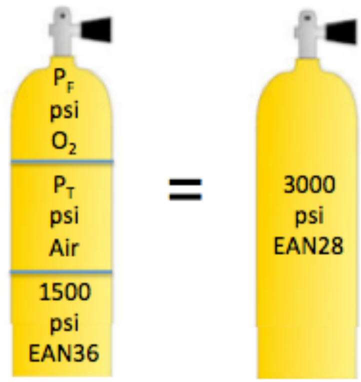


Figure 2.6. *Tank at 1500 psi of EAN36 needs to be filled to 3000 psi of EAN 28.*

Calculate the required pressure of fill gas using the standard blending formula:

$$P_F = \frac{P_D \bullet (M_D - M_T) - P_S \bullet (M_S - M_T)}{(M_F - M_T)}$$

IMPERIAL

$$P_F = \frac{3000 \bullet (0.28-0.209) - 1500 \bullet (0.36-0.209)}{(1.0 - 0.209)}$$

$$= \frac{(3000 \bullet 0.071) - (1500 \bullet 0.151)}{0.791}$$

$$= (213.0 - 226.5) / 0.791$$

$$= -13.5 / 0.791$$

$$= -17 \text{ psi}$$

METRIC

$$P_F = \frac{204 \bullet (0.28-0.209) - 102 \bullet (0.36-0.209)}{(1.0 - 0.209)}$$

$$= \frac{(204 \bullet 0.071) - (102 \bullet 0.151)}{0.791}$$

$$= (14.484 - 15.402) / 0.791$$

$$= -0.918 / 0.791$$

$$= -1 \text{ bar}$$

A negative P_F value indicates that the starting mix/pressure is too high to be able to obtain the desired mix/pressure using the fill gas that we have. Therefore, some of the gas in the tank must be removed -- or *bled off* -- prior to blending the desired mix.

We need a new formula in order to determine how much gas to bleed off in order to find the correct starting pressure (P_S) of the current mix. In the general blending formula that we are using, we can only get a negative value for P_F when:

$$P_S \bullet (M_S - M_T) > P_D \bullet (M_D - M_T)$$

When that situation occurs, it is necessary to balance the two terms (i.e., make the two terms equal). The two sides in the equation will be equal only if the term on the left is made smaller or the term on the right is made larger. Of the five variables in the formula, the only one that can actually be changed is the starting pressure; to compute a new P_S value:

$$P_S \bullet (M_S - M_T) = P_D \bullet (M_D - M_T)$$

$$P_S = \frac{P_D \bullet (M_D - M_T)}{(M_S - M_T)}$$

Using the numbers from this example:

IMPERIAL	**METRIC**
$P_S = \frac{3000 \bullet (0.28 - 0.209)}{(0.36 - 0.209)}$	$P_S = \frac{204 \bullet (0.28 - 0.209)}{(0.36 - 0.209)}$
$= (3000 \bullet 0.071) / 0.151$	$= (204 \bullet 0.071) / 0.151$
= 1411 psi	= 96 bar

This means that the tank needs to be bled off to 1411 psi (96 bar) and then filled only with the top-off gas; no fill gas will be needed after the tank is bled down. Thus, in this example, the tank would be filled with 1589 psi (108 bar) of air.

The values can be checked as before. The pressure/mix product of the desired gas is ($P_D \bullet M_D$), yielding a value of 840 psi (57 bar). Check the calculated fill pressure by summing the partial pressure/mix products of the start, fill, and top-off gases (Figure 2.7):

$$(P_S \bullet M_S) + (P_F \bullet M_F) + (P_T \bullet M_T)$$

IMPERIAL	**METRIC**
$= (1411 \bullet 0.36) + (0 \bullet 1.0) + (1589 \bullet 0.209)$	$= (96 \bullet 0.36) + (0 \bullet 1.0) + (108 \bullet 0.209)$
= 508 + 0 + 332	= 35 + 0 + 23
= 840 psi	= 58 bar[7]

[7] The difference between the expected and actual values is due to rounding error.

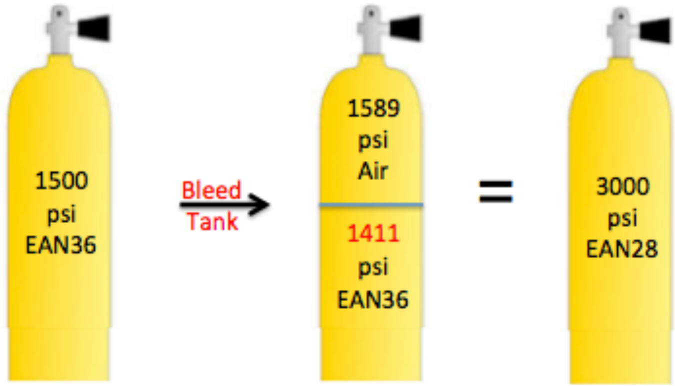


Figure 2.7. *Tank at 1500 psi of EAN36 needs to be bled down to 1411 psi and then filled with air to create a 3000 psi blend of EAN 28.*

Part 3: A Spreadsheet for Blending

The intent of this paper is to provide a basis for the mathematics behind gas blending calculations, whether done in the blender's head, using tables, or employing software. The calculations are a straight-forward application of Dalton's Law although one can argue that life-giving -- and potentially life-threatening -- gases should not be mixed using arithmetic that is not being checked! And just as Nitrox-certified divers are trained to check the mix in their tanks prior to diving, perhaps they should also know how the blending is accomplished and calculated.

To that end, this section will introduce a spreadsheet for calculating Nitrox gas mixes using the partial pressure blending method.

3.1. Downloading The Spreadsheet

The gas blending spreadsheet described here can be downloaded from:

http://www.garykessler.net/software/index.html#scuba

Scroll down to the EAN Gas Mix Calculator to obtain the latest version of the software (v3.1 as of this writing). The software is distributed in a ZIP file containing the spreadsheet and license. The spreadsheet is a regular Excel spreadsheet and works in the Mac OS X and Windows versions of Microsoft Excel.

3.2. Opening The Spreadsheet

Open the spreadsheet by doubling-clicking the .xlsx file, as you would any spreadsheet. By default, the sheet will open to the *Gas Mix Calculator (PSI)* tab, showing calculations in psi (Figure 3.1).

The bottom of the page is the **Parameters** section and has five cells with a yellow background. With these cells, the user can define:

- The minimum pO_2 (i.e., minimum M_S and M_D), as a percent. The default is 20.9%, or air.
- The maximum pO_2 (i.e., maximum M_S and M_D), as a percent. The default is 40%, the highest recreational Nitrox mix.
- The fill gas pO_2 (M_F), as a percent. The default is 100% oxygen.
- The top-off gas pO_2 (M_T), as a percent. The default is 20.9% (air).
- The maximum tank pressure (P_D), in psi. The spreadsheet default is 4000 psi.

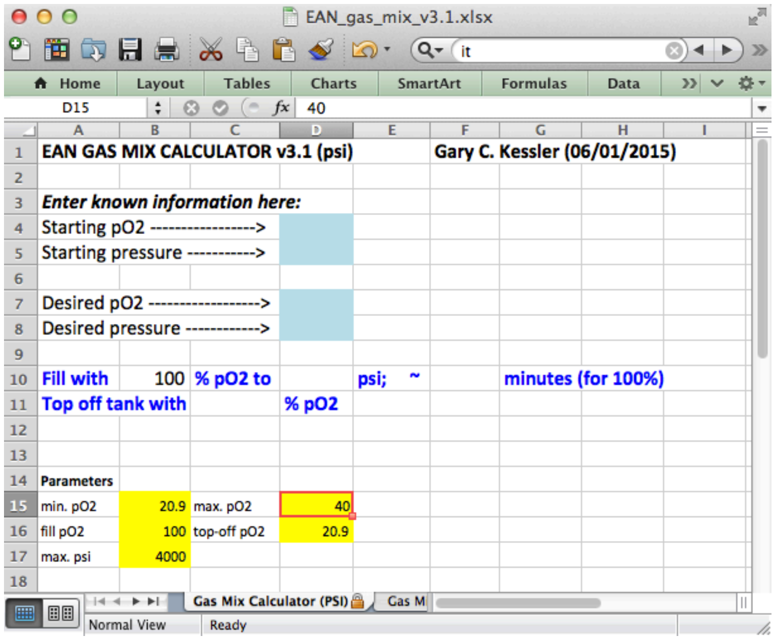


Figure 3.1. *Gas Mix Calculator (psi) tab.*

There are also four data entry fields with a light blue background where the starting pO2 (M_S), starting pressure (P_S), desired pO2 (M_D), and desired pressure (P_D) can be entered. More on data entry below.

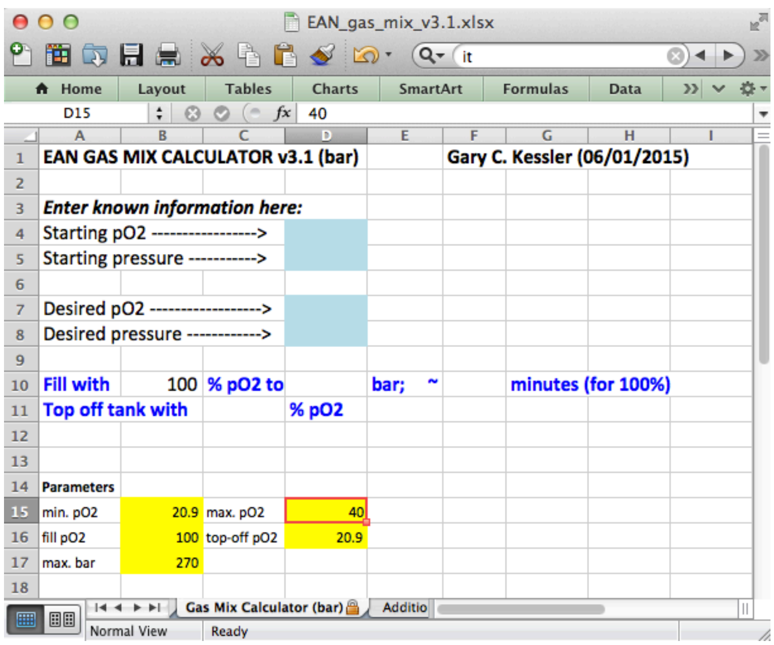


Figure 3.2. *Gas Mix Calculator (bar) tab.*

The *Gas Mix Calculator (bar)* tab is an identical spreadsheet page for metric calculations (Figure 3.2). The only difference between the metric and imperial pages is that pressure values are expressed in bar rather than psi.

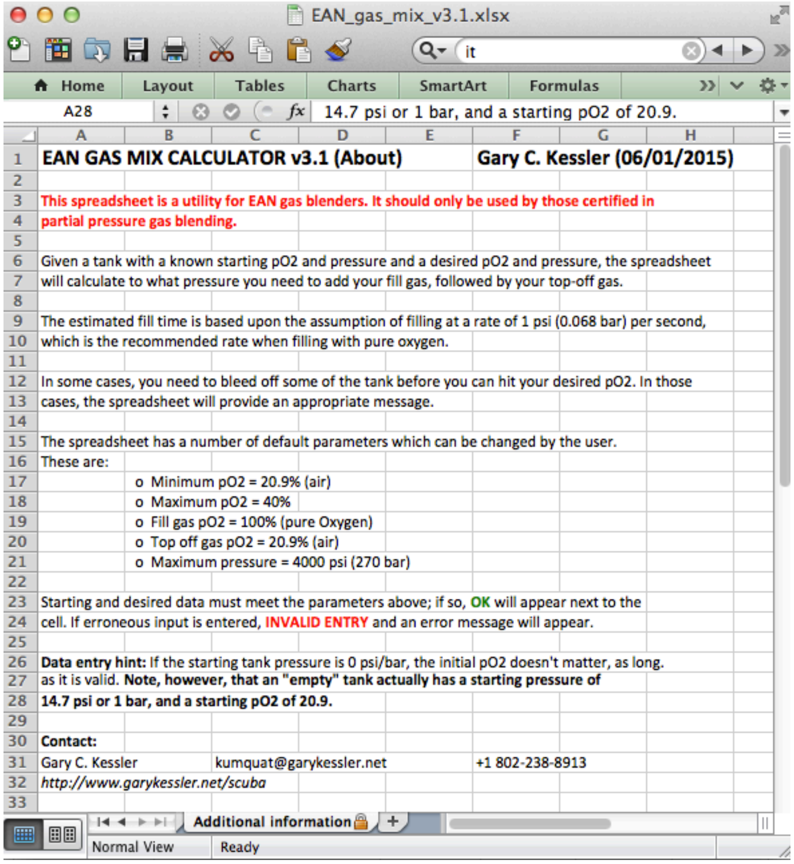


Figure 3.3. *Additional information tab.*

Finally, the *Additional information* tab provides summary information about the spreadsheet as well as contact information for comments, suggestions, etc. (Figure 3.3).

3.3. Data Entry

Data entry in the spreadsheet is straight-forward and no different from entering data into cells in any other type of spreadsheet. Merely enter the starting and desired pressure and O_2 mix, and the pressure of the tank after adding the fill gas will be displayed. Do note that all spreadsheet cells are locked except the four data entry cells and five parameter cells.

Some notes are worth mentioning. Data values entered into the four fields must pass a number of tests to be considered valid:

- The *Starting pO2* and *Desired pO2* values -- entered as a percentage -- must not be less than the *min. pO2* parameter or greater than the *max. pO2* parameter.

- The *Starting pressure* value -- entered in psi or bar -- must not be less than 0 or greater than the *max. psi/max. bar* parameter.

- The *Desired pressure* value -- entered in psi or bar -- must not be less than the *Starting pressure* value or greater than the *max. psi/max. bar* parameter.

3.4. Data Entry Examples

Example 1: Normal Data Entry

An EAN32 tank with 360 psi (25 bar) needs to be filled to 3200 psi (218 bar) with an EAN36 blend (Figure 3.4).

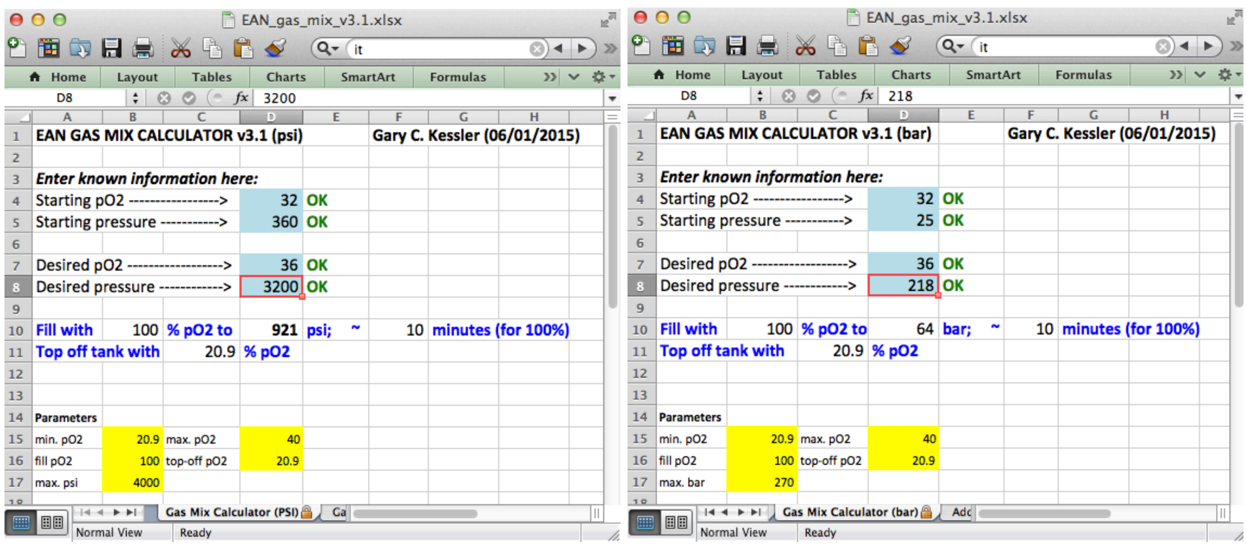


Figure 3.4. *Normal data entry (psi and bar).*

The spreadsheet indicates that this tank should be filled with 100% oxygen (the fill gas) to 921 psi (64 bar), which should take about 10 minutes at the safe fill rate for 100% O_2. The tank should then be topped off to the desired pressure (i.e., 3200 psi or 218 bar) with air.

NOTE that the information here is ***not*** indicating that 921 psi (64 bar) be added to the tank but that the tank should be filled to that pressure. In other words, we actually *add* 561 psi (32 bar) to the starting pressure to get to the proper total pressure after the fill gas is added.

Example 2: Common Errors

The spreadsheet will provide an error message if data is entered that either doesn't make sense or cannot result in a valid result. For example, Figures 3.5 and 3.6 show the error messages that would appear if the start or desired pO2, respectively, are out of range (i.e., if the pO2 value is less than the *min. pO2* parameter or greater than the *max. pO2* parameter).

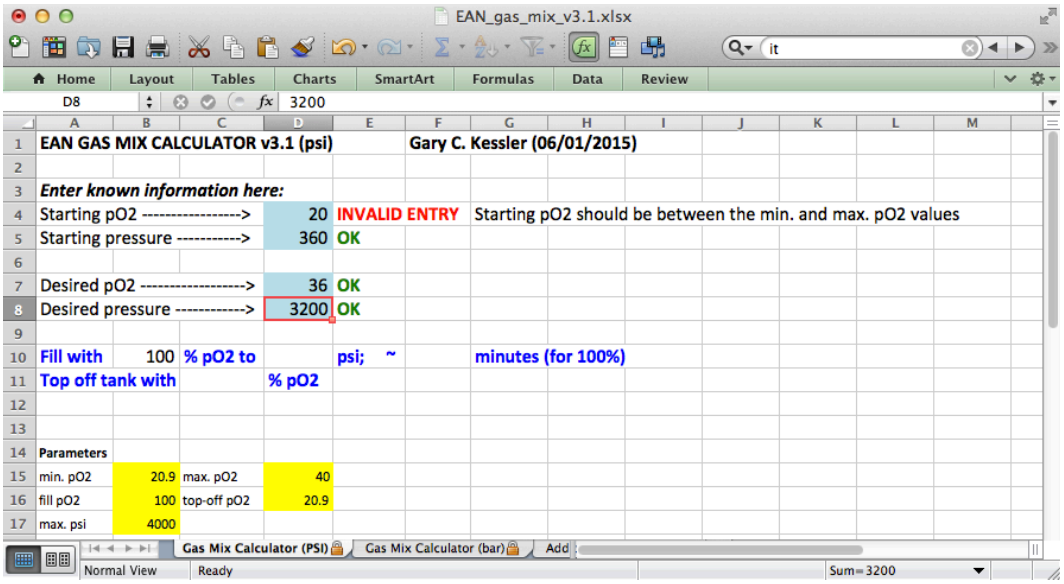


Figure 3.5. *Starting pO2 entry out of range (psi).*

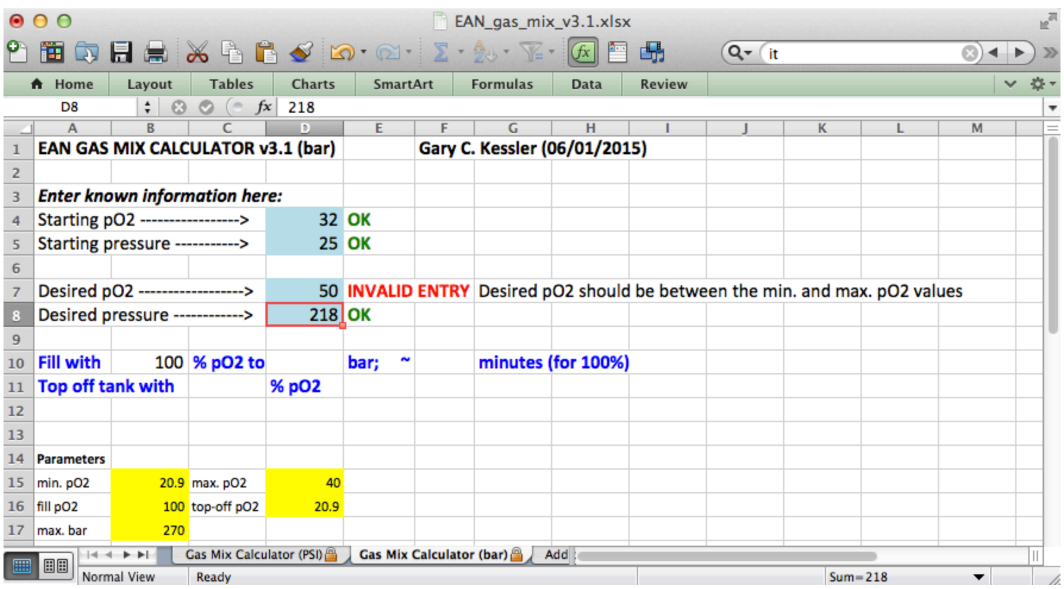


Figure 3.6. *Starting pO2 entry out of range (bar).*

Figure 3.7 shows the error message that will appear if the starting pressure value is out of range; i.e., if the starting pressure is less than 0 or greater than the *max psi* or *max bar* parameter. Note that if the starting pressure is out of range by being too high, it is likely that the desired pressure will also get flagged as an error even though it is valid (Figure 3.8). The second error message will disappear when the starting pressure value is fixed.

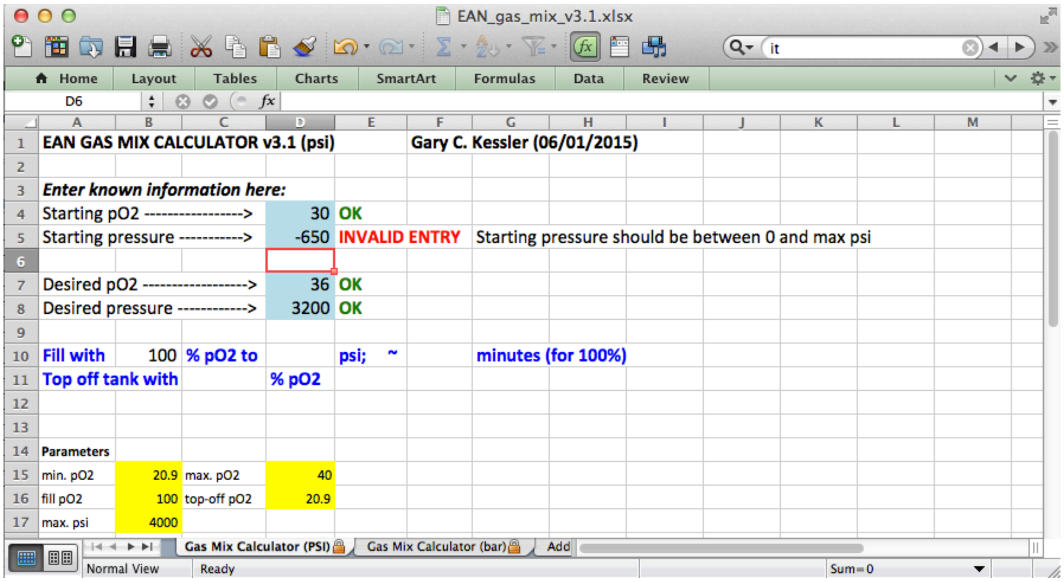


Figure 3.7. *Starting pressure entry less than 0 (psi).*

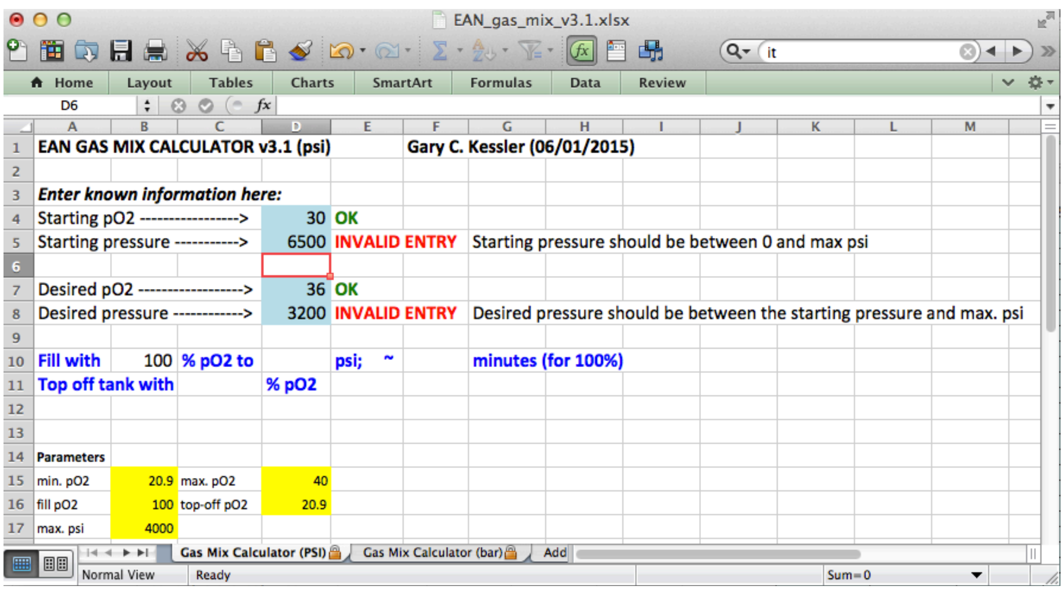


Figure 3.8. *Starting pressure entry greater than the* max. psi *parameter value, causing the (valid) desired pressure entry to be flagged as an error (psi).*

Figure 3.9 shows the error message when the desired pressure is invalid, in this case with a value greater than that of the starting pressure.

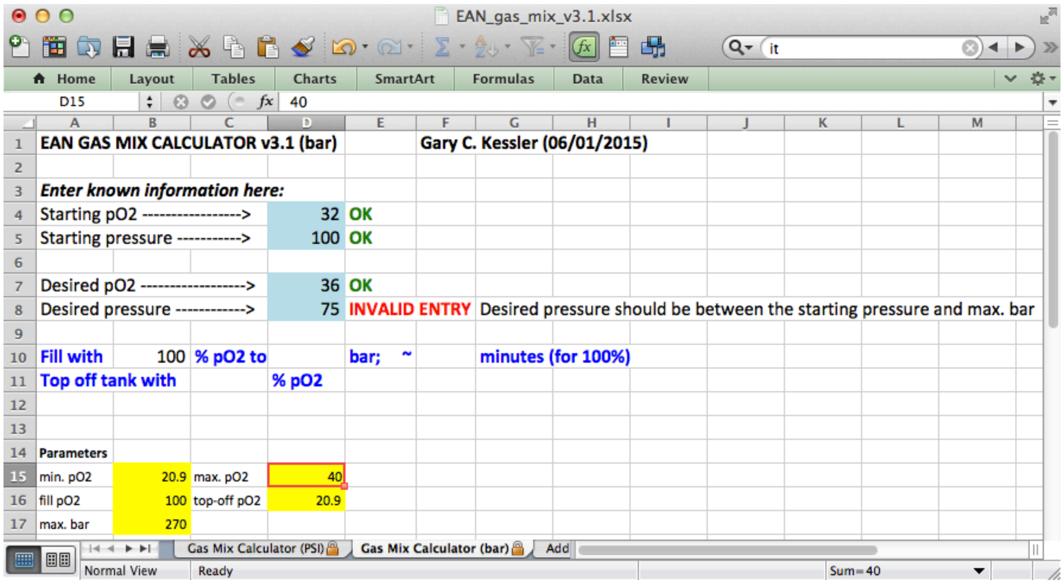


Figure 3.9. *Desired pressure entry less than starting pressure entry (bar)*

Example 3: Bleeding a Tank

Having a situation where the tank needs to be bled is not an error condition, but provides information in a slightly different way than previous valid data entry screenshots have shown.

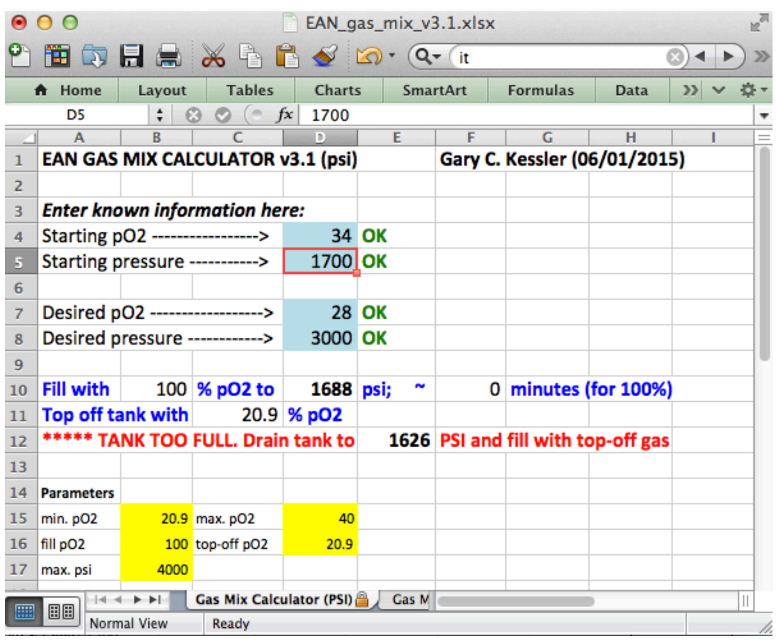


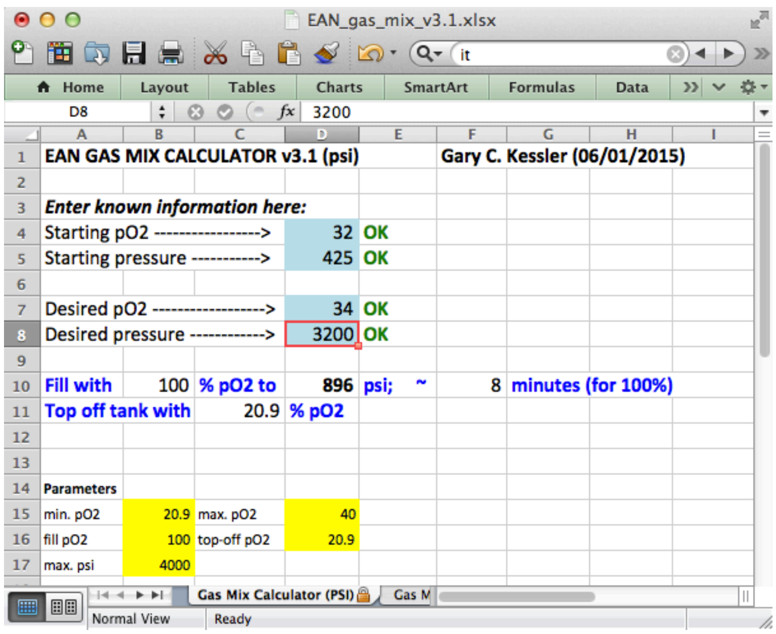
Figure 3.10. *Achieving the proper blend requires bleeding the tank (psi).*

Figure 3.10 shows a situation where the tank needs to be drained of gas. In this case, the starting tank already contains an EAN34 blend at 1700 psi and the diver wants a new blend of EAN28 at 3000 psi. The spreadsheet is only solving an equation for which there is an answer -- a *wrong* answer! Therefore, the spreadsheet also makes it pretty clear that the tank needs to be first bled to 1626 psi and then filled only with the top-off gas (i.e., no fill gas will be required in this circumstance).

APPENDIX A:
The Spreadsheet and Examples

This Appendix shows spreadsheet screenshots for solving the sample problems given in Section 1.

In Example 1, we start with a 425 psi (29 bar) tank of EAN32 and wish to fill it to 3200 psi (218 bar) of EAN34. The formula shows that 470 psi (32 bar) of fill gas needs to be added to the tank followed by 2305 psi (157 bar) of top-off gas needs to be added. The spreadsheet does not show these values explicitly but does the additional for you. In particular, if the tank started at 425 psi (29 bar) and needs 470 psi (32 bar) to be added, then the blender is merely using fill gas to get the pressure up to ~895 psi (~62 bar), as shown in Figures A.1 and A.2, respectively.



	A	B	C	D	E	F	G	H	I
1	EAN GAS MIX CALCULATOR v3.1 (psi)					Gary C. Kessler (06/01/2015)			
2									
3	*Enter known information here:*								
4	Starting pO2 ----------------->			32	OK				
5	Starting pressure ----------->			425	OK				
6									
7	Desired pO2 ------------------>			34	OK				
8	Desired pressure ------------>			3200	OK				
9									
10	Fill with	100	% pO2 to	896	psi;	~	8	minutes (for 100%)	
11	Top off tank with		20.9	% pO2					
12									
13									
14	Parameters								
15	min. pO2	20.9	max. pO2	40					
16	fill pO2	100	top-off pO2	20.9					
17	max. psi	4000							

Figure A.1. *Example 1 calculation (psi).*

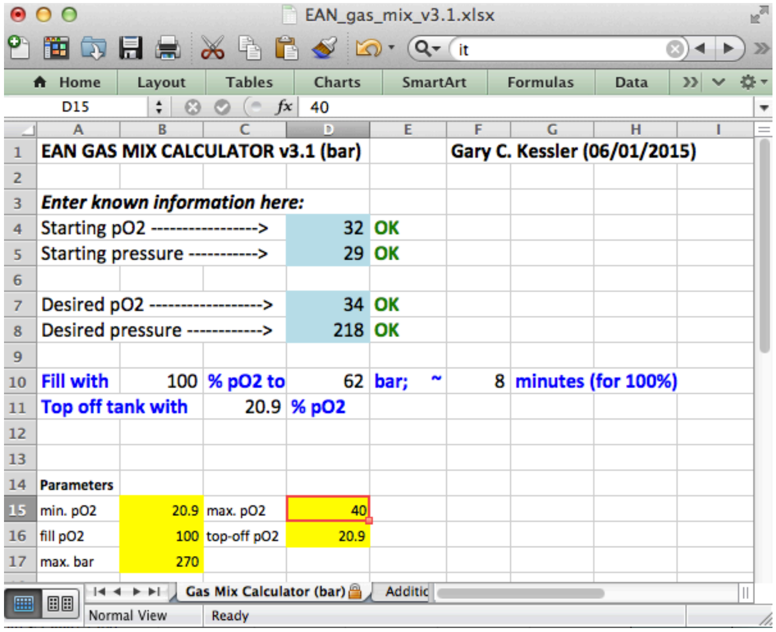


Figure A.2. *Example 1 calculation (bar).*

In Example 2, we start with a 375 psi (26 bar) tank of EAN36 and wish to fill it to 3000 psi (204 bar) of EAN32. The formula shows that 349 psi (24 bar) of fill gas needs to be added to the tank, yielding a tank pressure of ~725 psi (50 bar) after adding the fill gas, as shown in Figures A.3 and A.4, respectively.

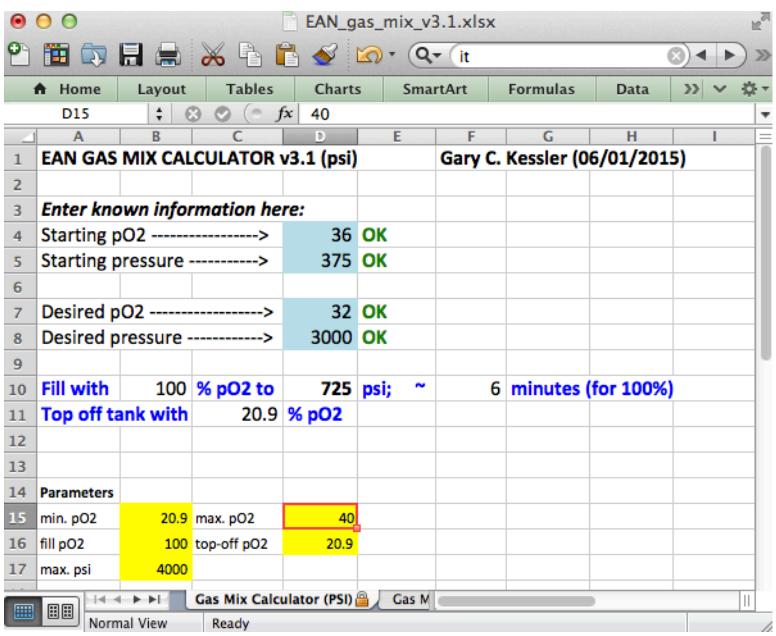


Figure A.3. *Example 2 calculation (psi).*

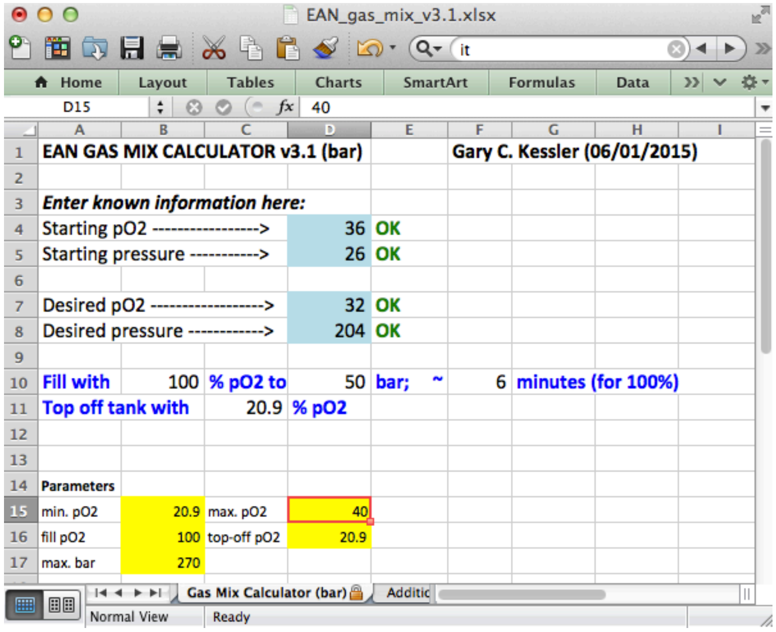


Figure A.4. *Example 2 calculation (bar).*

Finally, we start with a 1500 psi (102 bar) tank of EAN36 and wish to fill it to 3000 psi (204 bar) of EAN28 in Example 3. The formula here shows that we need to bleed the tank to 1411 psi (96 bar) and just add top-off gas to the tank. This is shown in Figures A.5 and A.6, respectively.

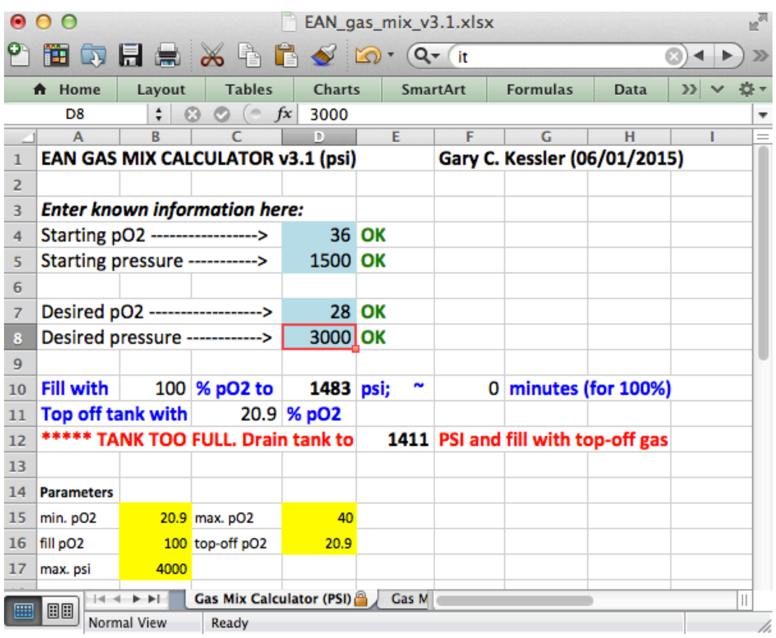


Figure A.5. *Example 3 calculation (psi).*

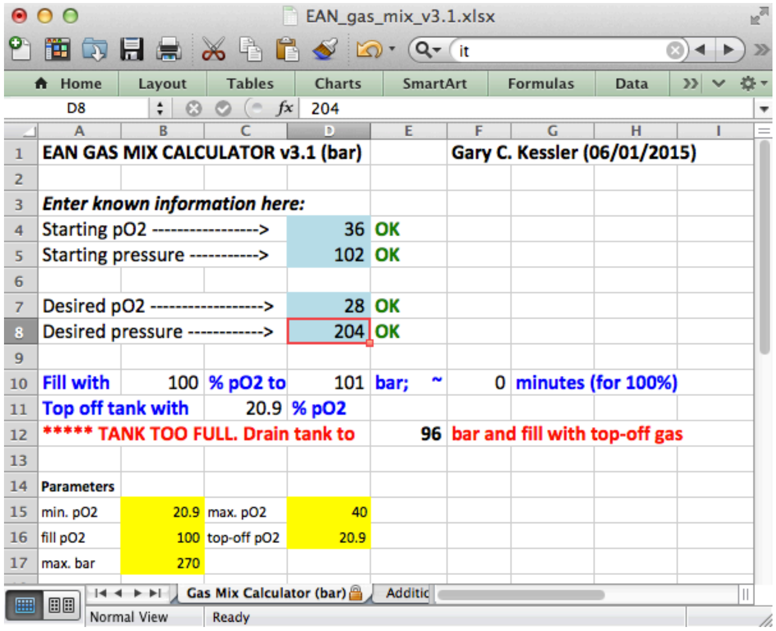


Figure A.6. *Example 3 calculation (bar).*

Acronyms and Abbreviations

bar	One atmosphere of pressure (14.7 psi)
F_X	Fractional portion of gas X in a gas mixture (%)
M	F_{O2} in a gas blend (%)
N_2	Nitrogen
O_2	Oxygen
P	Pressure (psi or bar)
psi	Pounds per square inch

	Pressure (psi/bar)	**F_{O2} in Mix (%)**
Start	P_S	M_S
Desired	P_D	M_D
Fill gas	P_F	M_F
Top-off gas	P_T	M_T

References and Further Reading

EnviroDive. (2007). *Diving & Nitrox Gas Blending FAQ*. Retrieved from http://www.envirodive.com/faq.html

NitroxMadeEasy. (2009, July 23). *Nitrox Made Easy*. Retrieved from http://www.nitroxmadeeasy.com/

Richardson, D. (Ed.). (2007, May). *DSAT Gas Blender Manual*, v1.02. Rancho Santa Margarita, CA: Professional Association of Dive Instructors (PADI).

Wikipedia. (2015, February 21). *Gas blending*. Retrieved from http://en.wikipedia.org/wiki/Gas_blending

About the Author

Gary C. Kessler was certified as a SCUBA diver as a teenager in southern California in 1967. He was later certified as an Open Water Diver, Advanced Open Water Diver, and Rescue Diver by the Professional Association of Dive Instructors (PADI) as part of the Colchester (Vermont) Rescue Dive Team in 1991. In 2009, Gary became a PADI Divemaster and Open Water Instructor, becoming a Master SCUBA Diver Trainer in 2011, Tec Gas Blender in 2014, and Tec Gas Blender Instructor in 2015.

Living on Lake Champlain (the sixth largest fresh water lake in the U.S.) and wanting to dive whenever he wanted, Gary bought his first boat in 1994. He received his USCG Captain's license in 2012. He currently lives in Ormond Beach, Florida.

In his other life, Gary is a professor at Embry-Riddle Aeronautical University in Daytona Beach, where he teaches cybersecurity. He is also an information security and digital forensics consultant, educator, and practitioner. Gary holds a B.A. in Mathematics, M.S. in Computer Science, and Ph.D. in Computing Technology in Education.