The Case For Dry-Filling Scuba Tanks

by Fred Calhoun, PE

Wet-filling doesn't work and can be harmful to scuba tanks! Read on. One of scuba's lingering myths is that a scuba tank must be immersed in a bath of water while it is being filled. Many of us think we know the reason why – to cool the tank in order to get a "good fill." This article will consider the principal elements of the procedure in a once-and-for-all effort to put a halt to the practice.

The fact is that immersing a scuba tank in a bath of water while filling it can do harm while accomplishing little else (very little measurable cooling takes place during the process).

Although we all want a "good fill," we all must abide by the safety regulation which prohibits the overfilling of a scuba cylinder. What that means is what it says – we must not allow our scuba tank to be overfilled. Period.

For the purpose of example, we shall discuss a so-called "aluminum 80" rated at 3,000 psig (the numbers are nice and even and easy to use and it's the predominant tank nowadays). What we're going to say applies to all scuba cylinders, however.

Let's consider the numerous variables involved in the filling process. Each will have an effect on the tank's final temperature and pressure. Take the list to your dive store to see which items apply there.

The Water Bath

A) There might not be a water bath (the store operator is an informed person).

B) There is a bath and it's a barrel of standing water (probably at "room temperature"- a typical installation and messy).

C) The bath is of mechanically chilled water (there is little chance that you'll find this situation, and that's good).

D) The bath is of flowing water (it's tap water, flowing or spraying, and going to drain – another typical installation, messy and wasteful).

The Tank

(before filling begins)

A) It's completely "empty" or nearly so (has the potential of being the "warmest" after the filling process).

B) It's partly full (has the potential for not getting as warm as in "A" above).

The Tank

(during the filling process)

A) It's not immersed but gets a spray of water.

B) It's partially immersed (and does, or does not, get a spray of water).

C) It's fully immersed.

The Filling

(this is the action which most affects the final temperature and pressure of the tank)

A) It's fast (an irresponsible act – tank, surroundings and people are in jeopardy when this is done and a water bath won't help).

B) It's slow (the only right way – the action of an informed and responsible operator).

C) After filling, the tank sits for a while in the bath to be cooled and is then "topped off" (usually not the case, because everyone is in a hurry).

D) The tank is plucked from the bath as soon as it's been filled (which means that it got wet, but didn't get cooled).

Next let's consider the several environmental conditions through which the tank may pass as it makes its way from the dive store to the dive site.

1. The air temperature outside the store is cooler (or

warmer) than the tank's temperature.

2. The tank heats up in the sunbaked trunk of a car.
3. The tank lies in the sun (or the shade).
4. The dive is in cold, cool, or warm water (usually it's at least cool).

All the preceding features (bath vs. no bath, standing water vs. running water, fast fill vs. slow fill, etc.) will have an effect on the pressure of the air in the tank. Eventually, the tank will find itself in a reasonably stable environment (in the water of the dive site) and its pressure will stabilize.

Let's determine the greatest possible range of temperatures a tank might experience, that is, from a fast hot fill to the coldest possible dive site water. A tank brought to a temperature of 115 degrees by a fast fill would be painfully hot to touch...this will be our upper limit. Remember, such a fast fill would be an irresponsible act – we're using 115 degrees as our limit for example purpose only. The coldest water that a tank could be taken into might be 30 degrees or so (the temperature of sea water slush). A temperature drop of 85 degrees (115 degrees minus 30 degrees) will produce a pressure drop of about 445 psig (you can trust my mathematics on this). The point of the preceding extreme example is to show that even considering the worst possible range of conditions, the pressure in the tank would drop by only 15%. A more likely example would be the following: an informed and responsible dive store operator slowly fills the aluminum 80 to 3,000 psig (maximum, because tanks must not be over-filled). The tank experiences a rise in temperature to 95 degrees...it's warm and that's fine. The dive is in water at a temperature of 60 degrees will produce a pressure drop of about 190 psig...a change of only 6% (you can still trust my mathematics).

If water baths "worked" (they don't, by the way – and the whole purpose of this treatise is to point that out to you) so that the aluminum 80 at a pressure of 3,000 psig could leave the dive store "cool" it would then have to be protected from any subsequent temperature rise because such a temperature rise would cause the pressure to go over 3,000 psig and that would be irresponsible and against regulations.

Why don't water baths work? (I thought you'd never ask!). Because the water isn't cold enough and the tank isn't in the water long enough. Although the difference isn't anything to get all excited about, steel tanks do better in water baths than do aluminum tanks. The amount of heat required to warm aluminum is abouttwo times what it takes to warm steel. Comparing our 3,000 psig aluminum 80 to an older 2,250 psig steel 70, the weight of the aluminum is about 1.5 times the weight of the steel. What the above means is that it will take about three times as much heat to warm the aluminum tank as it will take to warm the steel tank. Because the transmission ability of the metal of the two tanks is about the same, the differences noted above are reflected in time. It will take longer for the aluminum tank to be warmed by the air inside it, and it will take longer for the aluminum tank to give up that heat to its surroundings. The aluminum tank has a higher "storage factor". What this means is that typically (because we're all in a hurry) the aluminum tank is out of the bath and out of the dive store before all the heat gets to the outside surface. The preceding describes the principal components relative to the difficulty in "cooling" aluminum tanks versus steel tanks. This is not a serious problem, it is simply another ingredient supporting the fact that water baths do not work. They especially don't work for aluminum tanks.

Is there any problem associated with filling tanks immersed in a water bath?

Scuba tanks should leave the dive store warm and not over-filled. Those conditions will produce a safe situation where the only way for the tank's pressure to go is "down" (which is good), rather than "up" which is bad).

Now I've told you that there's no measurable "good" associated with filling a scuba tank in a bath of water. Let me wipe away one more misconception. The purpose of the water bath is not to provide protection in case of an explosion – it simply couldn't do that.

One final issue. Is there any problem associated with filling tanks immersed in a water bath? (I'm glad you asked.). The primary way in which water enters most scuba tanks is through careless handling at air stations during the filling process where a water bath is used. This happens because:

1 - Water enters the tank valve, having been transferred there by peoples' wet hands,

2 - Water enters the tank valve from splashing of water as the tank is put in the bath,

3 - Water enters the filler attachment, as in 1 and 2 above, prior to its being hooked up to the tank valve,

4 - Pressurized air drives the water into the tank as filling begins.

The hardly measurable amount of cooling which a water bath might provide in no way compensates for the potential harm which can be done to a scuba tank by the wetfilling process.

Here's an experiment for you. Take two identical 3,000 psig aluminum 80 scuba tanks which are "empty". Don't "empty" them for the experiment, use two that have stood "empty" overnight (to simulate real conditions). Fill both of them at the same time, in the same way, to 3,000 psig (max.)...except...one is to be immersed and the other is not to be immersed. When filling an aluminum 80, the process should take at least five minutes (no tank should be filled faster than that). After filling, don't leave the immersed tank in the bath any longer than is typically the case for a dive store's regular business day (my experience s that most operators will lift a tank from its bath as soon as it's been filled...so do that). Allow both tanks to sit for as long as you like (an hour anyway) and then compare their pressures. If there's a significant difference, I will eat the dry tank.

Whether a tank has been dryfilled or wet-filled, there will always be some cooling down that will occur. Following the cool-down, the difference in pressure between a dry-filled tank and a wet-filled tank will be less than 10% (all other things being equal, and the procedures being typical). We must not feel that we have been cheated when a 3,000 psig tank cools to 2,700 psig. That's life! It isn't "wrong." It's the way the physics of the situation works. Any mad attempts (a water bath is a mad attempt) to offset nature will cost far more than they're worth, are potentially harmful to the tank and, quite frankly, accomplish so little that it's safe to say they accomplish nothing.

In Summary

1 - Filling a tank immersed in a water bath is potentially harmful to it (that's how the water gets in).

2 - If the water bath worked, the tank would have to be protected from warming up later on.

3 - The water bath doesn't work, as we've shown here, and whether dryfilled or wetfilled, the only result of the filling process is that one can expect about a 10% pressure drop.

4 - Over-filling a scuba tank to compensate for the inevitable cool down is irresponsible, jeopardizing the tank, the store and other friendly things around it.

The above article was reviewed by Bill High, founder of PSI, who had the following comments for the author:

I appreciate your allowing me to view your dry-filling article and am pleased to see you address the issue. The subject needs the attention of someone such as yourself.

A water bath does have one merit. With the present aluminum cylinder cracking problem and an occasional deeply pitted steel cylinder, the fill station operator occasionally sees bubbles coming from the apparently good metal. This has alerted several of my inspectors to cracks in Luxfer tanks. Two other thoughts came to mind as I read the report. The gas industry and OSHA publish 120° F. as the upper limit for h.p. cylinders while they are in service. Is there a reason for the difference between this and your 115?

According to my understanding of the gas industry protocol, they say the pressure is to reach maximum service pressure at 70° F. Therefore, when the temperature is less, the cylinder correctly filled (to its maximum) will read somewhat less (5 psi for each one degree Fahrenheit). With the temperature of a stable cylinder above 70, but no more than 120, the pressure can read higher by the same 5 psi for each degree. If this is all true then, perhaps, it should be somehow addressed with the realization that the pressure changes are so small that the gauges in use are less accurate than allowable change that we might see.

When you get your paper published, I will gladly reprint it for my inspectors. They and everyone else need to know the bad effect of that water which sneaks into the tank by the route you mention. They also need to hear from you and others the point I strongly make in class about slow filling. Somewhere I read that in the gas industry that 300 psi per minute was the standard. Anything less than the present 3,000 per minute would be good!

Bill High, NAUI #0175

The Case For Dry-Filling Scuba Tanks (Part II)

by Fred Calhoun, PE

I have had some very interesting responses to the original article (Nov./Dec. 988 *NDA News*, Ed.). Some people felt that I should have included all the mathematics (included here) in the proof. Many dive shop operators stated that they have to overfill their customers' tanks in order to keep them happy (that boggles the mind). My counter has been that if we can convince people to use fins with holes in them, or to always carry two mouthpieces on their regulators, we can certainly talk them out of wanting dive shop operators to break the law. Many shop operators declared that it is legal to overfill all tanks by 10%, and quoted with confidence "DOT regulations." The "DOT regulation" which disproves this is included here, as well.

The Mathematics

Considering the aluminum 80 with the service pressure rating of 3000 psig: we had established that the greatest temperature differential which it might experience would be from 115° F (too hot to handle) to 30 ° F (sea water slush). That's a difference of 85° F. Charles' Law, which will allow us to calculate the final pressure and which is accurate to within 2% at 3,000 psig, is set up as follows:

(3,000 psig + 15 psi)/(115° F + 460 degrees F.) = (final pressure + 15 psi)/(30° F. + 460° F).

Combining terms yields:

3,015 psig/575° R = (final press. + 15 psi)/490° F.

Eliminating the unite to simplify the expression yields:

3015/575-(final pressure + 15)/ 490.

Cross multiply and divide out and you get:

(final pressure + 15) = 2,569 (a gauge pressure of 2,554).

2,554 psig/3000 psig = 0.85. The "cold" pressure will be 85% of the "hot" pressure...a loss of 15%...the probably-never-happen, worst case drop in pressure due to cooling.

Plug in the more reasonable numbers and do it again:

3,015/(460 + 95) = (final pressure + 15)/(460 + 60).

Cross multiply and divide out and you get:

(final pressure + 15) = 2825 (a gauge pressure of 2810).

2810 psig/3000 psig = 0.94. The "cold" pressure will be 94% of the "hot" pressure...a loss of 6%...the more usual (and unavoidable) drop in pressure due to cooling.

Keeping Them Happy

If shop operators want to keep their customers happy, they should just quote the law. Here it is: DOT 49 CFR 173.302 (Charging of cylinders...), (b) Filling limits (Ref. 173.301 (e)): "Container pressure. The pressure in the container at 70° F. must not exceed the service pressure for which the container is marked...". That's straightforward enough and no one should have any trouble understanding it.

What DOT Really Says About 10% In Excess: DOT 49 CFR 173.302 (c) (Special filling limits...) specifies the conditions under which certain cylinders may be filled to pressures 10% in excess of their marked service pressures. The first thing it says is that the only cylinders to which the regulation applies are 3A, AX, 3AA, 3AAX, and 3T cylinders. Aluminum cylinders (3AL) are not included and must not be filled to pressures beyond their marked service pressures. The next thing it says is that those cylinders which have been tested for the 10% in excess will have a plus sign following the date stamp. No one should have any trouble understanding this.

More On Dry-Filling

by Fred Calhoun, PE

Ed. Note: Last year, Bill High and Fred Calhoun corresponded on the subject of dry-filling tanks, a topic which has stirred some interest. Excerpts from a letter Bill sent to Fred appeared in the Nov/Dec '88 NDA News with Fred's article on the subject. The following is Fred's response to Bill's comments.

The use of 115° F as an upper limit for a "hot fill", rather than 120° F is simple. On a temperature rise, one reaches 115° F first, and 115° F is too hot to handle. D.O.T. regulations specify that one of the "filling limits" for cylinders is 70° F (the other "limit" is the stamped pressure). D.O.T. regulations also specify that one of the "transportation limits" is 130° F (they recognize that a cylinder might get warm during transit). What does the above mean? It means that when filling a cylinder, the filling pressure limit is the pressure stamped on the cylinder and the filling temperature limit is 70° F. When transporting that same cylinder, its temperature may be allowed to increase to no more than 130° F. No one should be troubled by these "limits"...don't let anyone over-fill or over-heat your scuba tank in the shop and you won't have any trouble with it in the trunk of your car.

From time to time, I come across the "5-to-l" pressure change per degree F ratio and wish to "correct" it. In the vicinity of 3,000 psig, the ratio is about 5.7 psig per degree F change. In the vicinity of 2,500 psig, the ratio is about 4.8 psig per degree F change. In the vicinity of 2,000 psig, the ratio is about 3.8 psig per degree F change. Suppose we consider a properly filled aluminum 80 (3,000 psig at 70° F) leaving a dive shop and getting heated to 130° F in the trunk of a car. The pressure of the air in the cylinder will have increased to about 3,342 psig (quite acceptable and well within regulations). The "mathematics" looks like this: 3,000 psig + (60 x 5.7) = 3,342 psig.

The other two issues in Bill's letter had to do with the accuracy of pressure gauges (the ones we use are notoriously inaccurate) and the filling rate of 300 psig per minute (imagine that). There isn't much that can be done about the accuracy of pressure gauges...and there isn't much that needs to be done. The gauges are small, so there isn't much usable space for a scale to start with. The graduations are relatively close together and the pointers are "fat" (the pointer on my submersible pressure gauge is "30 psig" wide, for example). At best, for the typical dial face gauge, one needs to interpolate between the "major marks." Usually, there are "major marks" at 500, 1,000, 1,500, 2,000, 2,500, and 3,000 psig, etc., with some gauges sporting intermediate smaller marks representing 100 psig increments. Pressure gauges on dive shop filling apparatus may be larger than described above and, as a result, may tend to seem to be more accurate. What's important to remember is that the rated working pressures of most cylinders we use in scuba diving are expressed in easy to deal with numbers (like 2,250, 2,400, 3,000 psig, etc.). It's easy to fill up to these marks. Which brings me to the last item...how fast should tanks be filled? It's the speed with which tanks can be filled that determines, in part, how many tanks a shop can fill, as well as how long a customer has to stand around waiting. The filling rate should be 300 psig per minute (wet or dry...and, we hope that everyone's savvy enough at this point to realize that wet fills aren't doing them or their tank any good).