www.scuba-clinic.com service@scuba-clinic.com

Tech talk #8: “Under pressure – feeling and filling in control” part 2

In our last tech talk we had a look at some safe filling procedures and I promised there would be more to come. In part 2, let’s have a look at filling rates, overfilling and water baths.

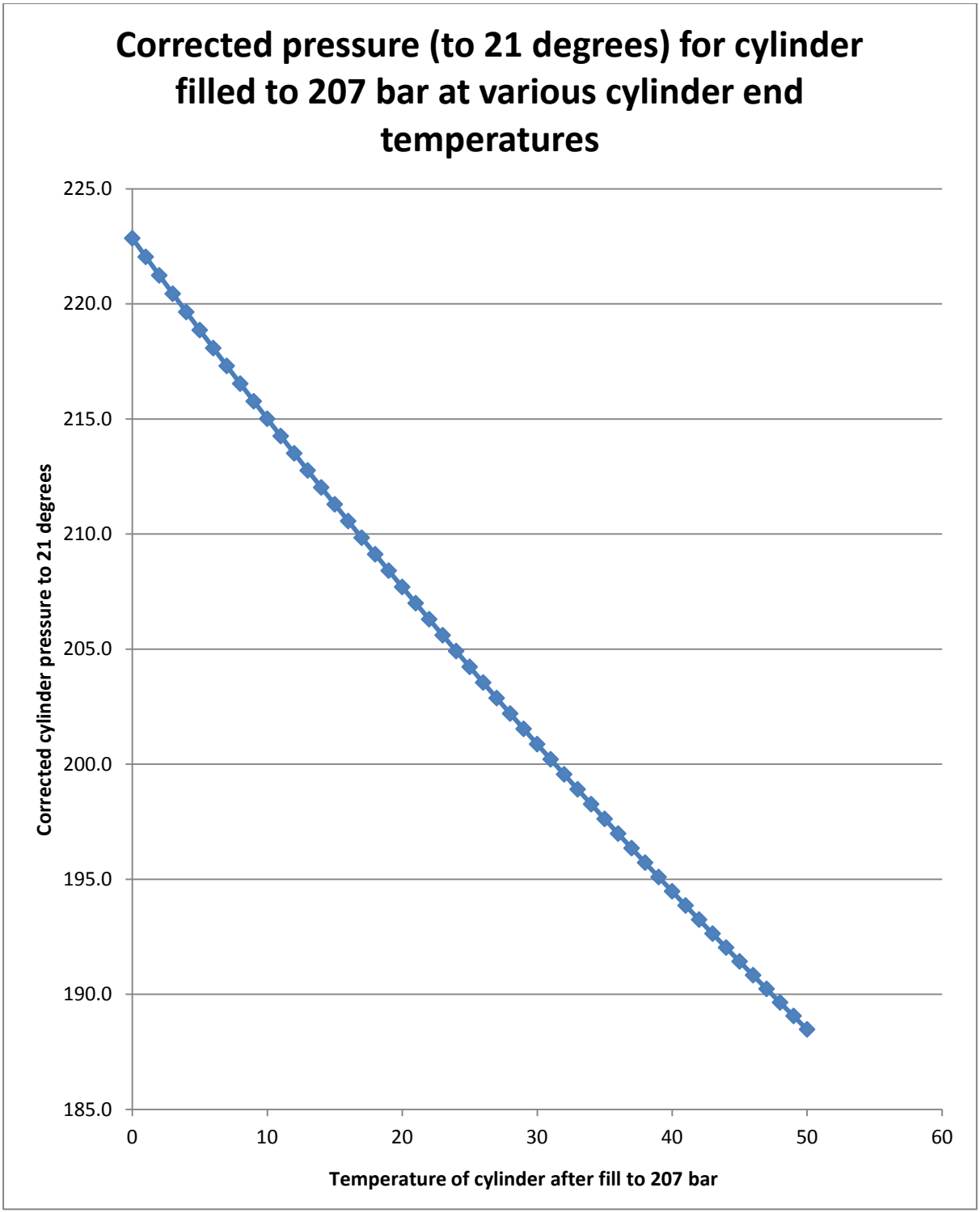
Firstly I doubt that for anyone who has filled cylinder it’s a secret that as the cylinder is being filled its temperature rises. As to why this exactly happens, I’m afraid there’s no easy explanation without referring to thermodynamics of a flow process. We’ll not go into details; a reasonable explanation in a nutshell, without complicated formulae I found would be: the enthalpy of the gas which you are filling adds to the internal energy of the gas in the cylinder, and because the internal energy is positively correlated to temperature, the temperature in of the gas in the cylinder rises.

So the quicker cylinders get filled, the greater the temperature rise. In order to keep this temperature rise acceptable, the scuba industry accepted filling rate for air is 300 to 600 PSI or 21 to 41 bar per minute. So in order to fill any empty cylinder from 0 to 207 bar, the recommended time required would be around 5 to 9.8 minutes. Anything less than 5 minutes is just a little too or way too fast. A practical example, let’s say you have a compressor with an output of 550 litres/min and you wish to fill a 12 l cylinder to 200 bar. In this case you would need 2400 litres of air, a volume delivered by your compressor in 4.36 minutes too fast in other words as 5 minutes would be the minimum. So how to get around this problem: simply increase the number of cylinders to be filled simultaneously (increasing the number of fill whips). In this case doubling the number of fill whips, would increase the filling time to 8.72 minutes, definitely more acceptable.

It doesn’t stop just there yet; any fill station operator will have experienced the fact that despite having filled the cylinder to its working pressure, as the cylinder cools down the cylinder pressure will drop. Back to physics 101: I hope that the relationship between temperature and pressure in the form of Gay-Lussac’s or Amontons law of pressure-temperature still rings a bell (? – if not so -): if a gas's temperature increases, then so does its pressure if the mass and volume of the gas are held constant. This relationship states that pressure over temperature (P/T) is a constant. So if the

temperature of a container is increased, the pressure increases and if the temperature of a container is decreased, the pressure decreases.

The latter will happen to filled scuba cylinders, once filled and exposed to the ambient temperature, the pressure can rise or fall depending on the cylinder temperature and the ambient temperature. A good approximation of how much increase/decrease of pressure is involved can be estimated by the ratio of 0.6 bar per degree Celsius of temperature change on a full scuba cylinder. The graph (graph 1) illustrates what would happen to the cylinder pressure of a cylinder filled to 207 bar and being cooled down or heated up to 21 degrees C.

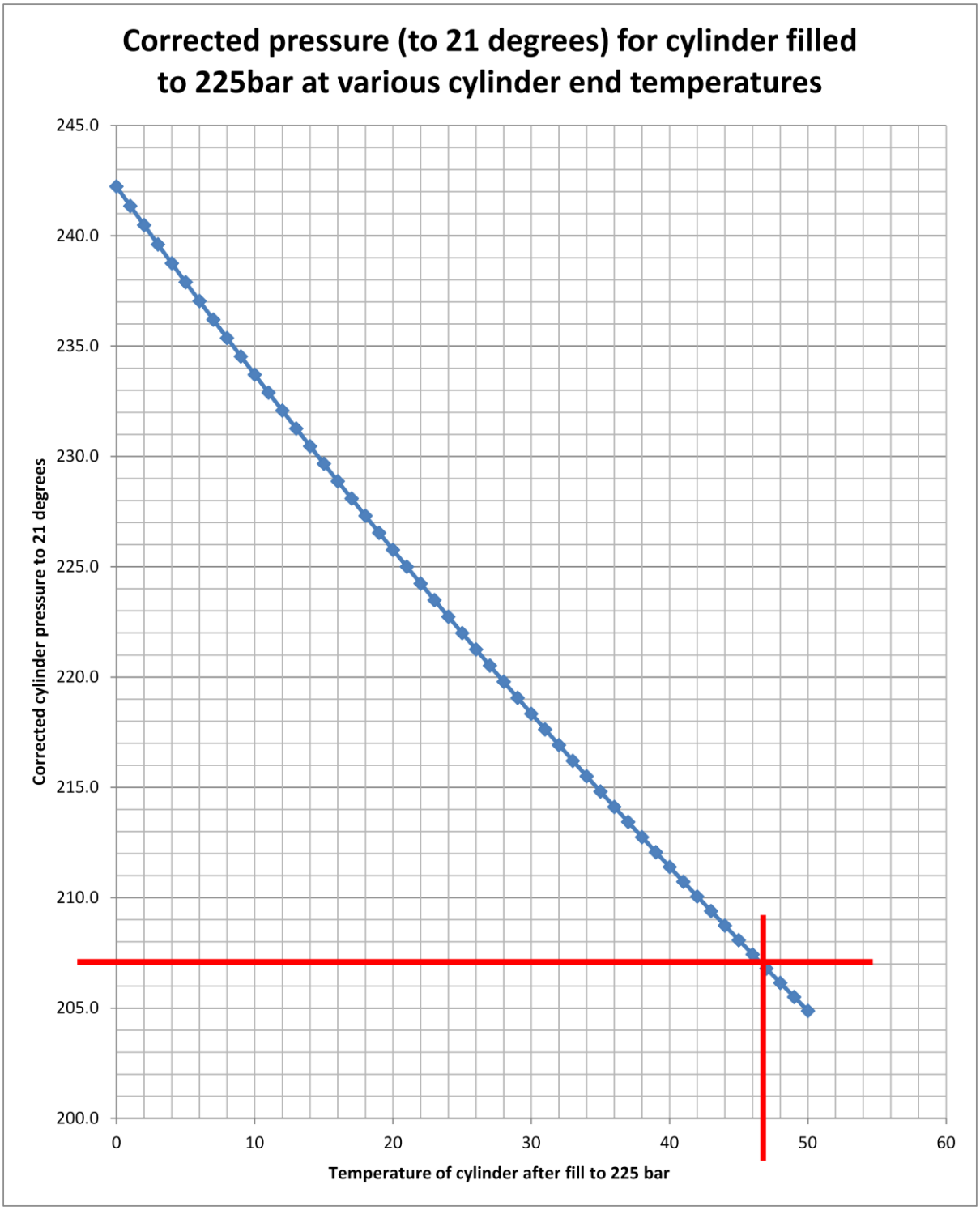


So having established that cylinder will cool down after filling and this is accompanied by a pressure drop, how to keep our customers happy? Let's say you fill a cylinder to 207 bar and the end fill temperature is 50 degrees. In Asia, Thailand more specifically, ambient temperatures are often 35 degrees. So if this cylinder cools down, the remaining pressure would be 197.4 bar at 35 degrees and customers complaining that their cylinder is not full. It's easy to imagine that the latter would be more pronounced if the ambient temperature would be less.

One school of clever fill station operators came up with the idea of simply overfilling the cylinders so that as they would cool down, the end pressure would be sufficient to keep the customer happy. Not a bad idea at first sight. However other considerations come into play. When talking about the service pressure it is related to a reference temperature, and hence has to be taken into account what local regulations say. For the DOT-3AL3000 cylinders, most frequently used in the Asia region (and of course the US), this temperature is 21 degrees Celsius and 3000 PSI or 207 bar. So if a cylinder is filled to 207 bar and has an end filling temperature of 40 degrees Celsius it pressure would be 194.5 bar if cooled down to 21 degrees. Not a problem there at all.

It's not an uncommon practise to overfill the cylinders till the safety valves blows off. On a lot of compressors this is safety valve is set at 225 bar. If the cylinder end temperature is 50 degrees, at an ambient temperature of 35 degrees, the cylinder would be 214.6 bar and at the reference temperature of 21 degrees 204.9 bar; within the limits, not a problem. However, if cylinder end temperatures are lower than 50 degrees, let's say 45 degrees end filling temperature, at ambient of 35 degrees, the cylinder pressure would be 217.9 bar and at the reference temperature of 21 degrees, 208 bar. A clear case of overfilling beyond the allowable limits. Not only is there risk of overfilling the cylinder, safety valves are not really designed to operate continuously and will wear out more quickly. If the safety valves now fails, doesn't blow off, there's a real risk of getting into serious trouble. A much safer option is attentive operators, watching the pressure gauge and shutting the system down when the desired pressure is reached. On a side note here, operators running 300 bar compressors will likely benefit from using pressure reducers and or additional safety valves as not to allow cylinders to reach pressures above the allowable limits.

The graph (graph 2) illustrates what would happen to the cylinder pressure of a cylinder filled to 225 bar (blowing off of the safety valve) and being cooled down or heated up to 21 degrees C. Any end cylinder temperature above 46.7 degrees would be an overfill.



The other school of clever operators came up with the idea of cooling the cylinder down during the fill process and the birth of the well internet-forum-discussed infamous ‘water-bath’ was born. Not only would the water-bath cool the cylinders down, it also would protect the operator in case of a catastrophic cylinder explosion. Is this really so? Just some thoughts to draw up your own conclusion for this practise:

- As explained in previous articles, the energy contained in a full scuba cylinder is enormous. A water bath, often a large plastic bin, under no circumstances will be able to contain the

explosive force of the blast; it will just add some more shrapnel to potentially injure the operator. Let's not forget that water is incompressible and therefore will transfer the force of the explosion in full onto the container.

- Most likely cylinder will be removed from the bath immediately after the fill, not giving enough time to dissipate the heat. Add to this the most likely the water bath is already at ambient temperature, so especially in hot climates the heat transfer and gradient will be minimal. Let not forget that unless that water is changed, if will absorb heat, increasing its own temperature and making the cooling less and less effective over time.
- Not always will cylinders be gently placed into the water bath and droplets of water could find their way onto the cylinder valves. As well, there's a risk of dropping the fill whip into the bath. Both scenarios could lead to water being injected directly into the cylinder once the pressure is applies. And water inside the cylinder will inevitably lead to internal corrosion. On top of that, how often is the water changed? Most likely water entering the cylinder will be contaminated water. Oh well, this contaminated water will likely not rinse the cylinder as well as you hoped for.
- Maybe a bit 'far fetched' wet and dripping cylinders around the filling area could lead to a potential slip-hazzard ☺

I rest my case. When filling cylinders an increase in temperature is inevitable. Instead of resorting to 'over-filling' or 'water-baths', the best alternative to keep the temperature under control is to slow fill. This can be easily achieved by using more fill whips simultaneously. Fill to the working pressure, let the cylinder cool down and top them up. They will now have the required pressure and you're customers will be happy. Safe filling.