Rules for gas-management with the use of stage tank(s)

A mathematical analysis

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Introduction

A very common configuration in technical and cave diving is a double set of primary tanks, either carried backmount or sidemount) and one stage tank.
The reasons for carrying more gas are numerous:

- To further enhance the penetration distance or the dive time or both
- For having more reserve gas for the same penetration/dive time
- If different mixtures are used (travel gas / bottom gas)
- For tasks which may require an elevated gas consumption (SAC rate/RMV)
- As bailout tank(s) when using CCR
- As a pure safety tank in case of unforeseen emergencies, which is not included in the standard gas-management calculation

Due to different initial gas contents (tank size, initial pressure, type of gas), a proper gas management may be quite demanding.
For ease of use, the diver normally tries to use tanks of identical size, initial pressure…and sometimes also identical type of gas. Standard sizes are 7, 8, 10,12l for steel and 40, 60, 80cft for Aluminum tanks. Speleo divers also use 5-7l / 300bar small tanks for very confined spaces.

Different approaches for usage

There are 3 standard approaches of how stage tanks are used:

1. **Rule of Thirds (or more restrictive) for all tanks**

- In this case, the rule of thirds (or a more restrictive one) is applied to all tanks in use, including the stage tanks, such as the stage tank(s) would just be another (3^{rd} or 4th) primary tank.
- In an ideal case, all the mixtures and initial gas volumes are identical for all tanks in use.
- In case of different gas mixtures and initial volumes, this must be taken into account accordingly.
- If different gases (mixtures) are in use, the sequence of usage is determined by the individual mixture and the actual diver position within the profile (travel gas, bottom gas, CCR bailout) and their operation depths (MinOD, MOD).
- With this protocol, it doesn't make sense to add some additional safety pressure.

2. **50% rule for stage tank alone (+reserve)**

- For the case of 3 identical tanks/initial gas volumes, we can calculate as follows: if there is but one stage and one would like to apply the rule of 50% (+ 5-10 bar additional safety pressure) then the rule of forth (¼) must be applied to the two primary tanks. At the end, this results in achieving a rule of thirds overall (on the total initial gas volume).
- If under the same premises, one wishes to apply the rule of fourth (¼) on the overall initial gas volume, then the rule of eighth (1/8) must be applied to the two primary tanks!

- In case that primary tanks and stage tanks have different initial gas volumes, the gas rule to be applied on both primary tanks has to be calculated physically and mathematically correct (s. below).

3. **50% rule(+reserve) for stage tank as only gas supply for 1st dive only**
   - Will often be used if there is no possibility for a refill of the primary tanks between 1st and 2nd dive (or no 2nd set available). 1st dive is then carried out with stage tank alone as source of gas.
   - Normally the stage tank will be used down to 50% on the way in (plus a safety margin of +5 – 10 bar). *The two primaries are left alone as a reserve*.
   - For the case that all 3 tanks (2 primary, 1 stage) have identical initial gas volumes, this means the application of the rule of sixth.
   - This protocol is secure as long as the initial gas volume of the stage tank used is less or at maximum twice the one of both primary tanks. However, due to the physical dimensions and imposed limitations, such a configuration is most unlikely.

General considerations

As it has been shown above, there are more than just one solutions for the gas-management.

When handling with stage tanks, especially in the overhead environment, one must also consider:

- *Increased drag (and physical effort) and allocated increased gas consumption, reduced swimming speed, increased travel- and bottom times*
- *Buoyancy and trim, especially with almost empty aluminum tanks or with very heavy steel tanks*
- *The question of how far one should take an already used stage tank further in, after having reached its "return pressure"*
- *When using different gas mixtures, it is imminent to carefully select the tanks to always stay within MinOD and MOD*
- *The potential physical impact (damage) that any non-streamlined object, such as stage tanks are (!) can have on the cave environment*
- *The potential danger of a silt-out or getting stuck with a bunch of stage tanks around you*
- *Special consideration is requested when installing stage tank depots (when, where, procedures for dropping and taking up on return, time needed,…)*
- *From which point on is it more advisable to travel with DPVs instead of swimming?*
- *The condition that you should always have enough gas to share it during the return to the exit with a buddy whose gas supply just "vanished" by some catastrophic failure at the point of return (=maximum penetration).*

As a summary:

Stage tank diving does not just mean to attach one or more stage tank on some D-rings! Many parameters have to be seriously considered and a well-balanced gas-management can be quite challenging.

There is never a one and only solution as some agencies try to make us believe. Gas-management was and will always be a well-balanced compromise of sometimes diverging requirements and boundary conditions.

Question to be answered

The question to clarify is: with a given set of tanks (primary and stage) with their initial gas contents and a predetermined *overall usage ratio* (gas rule) as well as another (or identical) *ratio for the stage*, how can we correctly and mathematically determine the required usage *ratio for the primary tanks*?

A simplified example without any big math

Let us suppose that we have a set of 2 primary tanks and 1 stage tank. All tanks have the same size and identical initial pressure and gas. Thus, V_PT1-init = V_PT2-init = V_ST-init.

On the way in, we wish to breathe down the stage to 50%, the other 50% for the way out. *For simplification only (!), we assume that we do not keep any reserve in the stage tank!*

THIS IS AN ASSUMPTION TO SIMPLIFY THE CALCULATION! NEVER DO THIS IN REAL LIFE!

We also wish to apply the rule of thirds to our OVERALL initial gas volume. This means that from the 3 * 3/3 = 9/3 we can use 3/3 (=1 full tank) for in and another 3/3 (=another full tank) for out. This leaves us with one full tank (3/3) at the end or one third of the initial gas volume.

This remaining gas volume is equally distributed between the two primary tanks (=1/2 ea.), because our stage tank will be empty at the end.

Usage protocol: we start with the stage tank, breathe it down to 50% and switch then to the primary tanks. At the switch point, we can either drop the stage tank or keep it with us.

We proceed further in on the primaries until we reach the return point (return pressure). We call the dive, still breathing from the primaries until reaching a 2nd switch point on the way back. Here we go back to the stage and breathe from it until reaching the exit.

Yet unknown so far: return pressure and 2nd switch point pressure.

From the above we know that after the first switch point we can use 50% (1/2) of the initial original gas volume of the primaries.

Half of it (=1/4) for going further in until reaching the return point, half of it (=1/4) for returning to the 2nd switch point where we go back to the stage tank, and stay on it until we reach the exit.

In other words, by using the stage to 50% on the way in (and another 50% out), with NO reserve for the stage tank, we have to apply at least the rule of fourth onto the primary tanks for maintaining an overall rule of thirds.

A practical application with some realistic numbers:
With 220bar initial pressure on all tanks (a good fill!), this means that the 1st switch point is (latest!!!) at 110bar on the stage. We now have ¼ of 220bar = 55bar for further going in on the primaries until reaching the return pressure (220bar – 55bar = 165bar). After the turning point we breathe the primaries down to the pressure for the 2nd switch point (165bar – 55bar = 110bar). There we switch to the stage tank, which still holds the remaining 50% of its initial volume.

You see: no formulas, just common sense!

List of terms used

Before going into the mathematical formulation of the problem and its algebraic solution, and to enhance your understanding, we present to you a list of the terms used:

term	description	unit
PT1/2	primary tank 1/2	
v_PT1/2	tank volume PT1/2	l
p_PT1/2-init	initial pressure PT1/2	bar
V_PT1/2-init	initial gas volume (content) PT1/2	bar*l
ST1/2	stage tank 1/2	
v-ST1/2	volume stage tank1/2	l
p_ST1/2-init	initial pressure ST1/2	bar
V-ST1/2-init	initial gas volume (content) ST1/2	bar*l
ratio_ST-1way-basic	basic 1way gas usage ratio for ST (without reserve)	---
ratio_ST-1way-eff	effective 1way gas usage ratio for ST (with reserve)	---
dp_ST-Res	reserve pressure each stage tank (1 way)	bar
V_ST-Res	reserve gas volume stage tanks (1 way)	bar*l
V_tot-init	initial total volume of gas	bar*l
V_tot-disp-init	initial total volume of gas at our disposition	bar*l
V_tot-ret	total gas volume for return	bar*l
V_tot-disp-ret	total gas volume for return at our disposition	bar*l
ratio_V_tot-disp-ret-init	V_tot-disp-ret / V_tot-disp-init	---
ratio_1way-overall	gas usage ratio (rule) 1way for total gas volume	---
ratio_PT-both-1way	gas usage ratio (rule) 1way for both PT	---

Mathematical analysis

The classic configuration in overhead diving from cave zone 2 on consists of a minimum of two (2) primary tanks of equal size and (whenever possible) of equal initial pressure and gas mixture.
These two primary tanks may be carried as a backmount connected twin set (or two independent tanks) or as a sidemount independent double tank set

Depending many parameters (s. above), one or more stage tanks, sometimes with different size, initial pressures and gas mixtures are also taken “onboard”. Using more than just one stage tank is quite common. To carry more than two stage tanks is not easy and has a number of disadvantages. In addition, if one tries to use tanks of identical size and initial filling pressure, this is not always possible, making proper calculation quite challenging.

We assume that the desired ratio_ST-1way-basic and dp_ST-Res are equal for both stage tanks! Different values for each tank would be unpractical if not even dangerous.

The following calculations apply for the case that the gas in all tanks can be used throughout the dive at any time.

The volume of gas contained in a pressurized tank under the assumption of an ideal gas can be calculated as follows:
V = v * p E1
For our 2 primary tanks and for the initial state:
V_PT1-init=v_PT1 * p_PT1-init E2a
V_PT2-init=v_PT2 * p_PT2-init E2b

and for the total initial primary tanks gas volume:
V_PT-tot-init = V_PT1-init +° V_PT2-init E2c

For our stage tanks:
V_ST1-init = v_ST1 * p_ST1-init E3a
V_ST2-init = v_ST2 * p_ST2-init E3b

and for the total initial stage tank gas volume:
V_ST-tot-init = V_ST1-init +° V_ST2-init E3c

The total amount of initial gas (primary tanks + stage tanks) is:
V_tot-init = V_PT1-init + V_PT2-init + V_ST1-init +° V_ST2-init E4a
or = V_PT-tot-init + V_ST-tot-init E4b

However, if we consider not touching on either way the “reserve volume” in the stage tanks, then we can write:
V_tot-disp-init = V_ST-tot-init - 2 * dp_ST-Res * (v_ST1 + v_ST2) E4c

For ONE way (way in or way out) and applying the selected rules for the overall gas usage (=at our disposition) we can write:
V_tot-disp-1way = ratio_1way-overall * V_tot-disp-init E5

Usually this ratio_1way-overall is more commonly known as rule of thirds, rule of fourths etc.. Thus, a ratio_1way-overall = 0.25 means ¼, a ratio_1way-overall=0.333 means 1/3 etc.

This ratio_1way-overall (1/3, ¼, 1/6,…) is normally predetermined before the dive and depends on many parameters, which are not to be discussed here.

However, as the different approaches for usage presented above show, primary tanks and stage tank(s) may have applied different rules for their gas-management.
There are many reasons for using different ratios for the primary tanks and for the stage tank(s).
The important thing is that the overall ratio is maintained as determined during the dive planning!

Under the assumption that the usage ratio is identical for both primary tanks (regardless whether they are connected or independent), we can write:
V_PT1_used-1way = ratio_PT-both-1way * V_PT1-init E6a
V_PT2_used-1way = ratio_PT-both-1way * V_PT2-init E6b
and thus:
V_PT-both_used-1way = ratio_PT-both-1way * (V_PT1-init + V_PT2-init) E6c

On the other side, we have seen that the stage tank(s) may be used in different roles and – depending on that – different rules for the stage tank(s) usage may apply.

In a general form, we can write:
V_ST_used-1way = ratio_ST-1way * V_ST-tot-init E7
The range here of ratio_ST-1way can extend from 0.5 (max.) down to 0.25 or even less.

However the situations gets a bit more complex if an additional small amount of gas is kept as a reserve. The stage tank is not used down to 50% (or whatever %) but we stop using it some 5, 10 or more bars above (dp_ST-Res). In other words, the gas volume *at our disposition* is further diminished by keeping (= not touching) this additional reserve.

Therefore, we have to distinguish between the ratio_ST-1way-basic (without reserve) and ratio_ST-1way-eff (final, effective, with reserve, at our disposition).
For the effective gas volume to be used (= at our disposition) for 1 way (in or out), we can now write:
V_ST_used-1way = ratio_ST-1way-eff * V_ST-tot-init E8

Now, by including dp_ST-Res (1 way), which must not be touched:
V_ST_used-1way = ratio_ST-1way-basic * V_ST-tot-init – dp_ST-Res * (v_ST1+v_ST2) E9

By using Eq. 8 and 9, solving for the yet unknown ratio_ST-1way-eff we get:

$$\text{ratio\_ST-1way-eff} = \frac{(\text{ratio\_ST-1way-basic} * \text{V\_ST-tot-init} - \text{dp\_ST-Res} * (\text{v\_ST1}+\text{v\_ST2}))}{\text{V\_ST-tot-init}} \qquad \text{E10a}$$

or “cleaned up”:

$$\text{ratio\_ST-1way-eff} = \text{ratio\_ST-1way-basic} - \frac{\text{dp\_ST-Res} * (\text{v\_ST1} + \text{v\_ST2})}{\text{V\_ST-tot-init}} \qquad \text{E10b}$$

We see that the greater dp_ST-Res becomes, the smaller gets the usage ratio ratio_ST-1way-eff of the stage tank (we have less gas at *our disposition* for 1 way).

Finally we can write for one way (in or out) for the volume of gas at *our disposition*:

$$\text{V\_tot-disp-1way} = \text{ratio\_PT-both-1way} * (\text{V\_PT1-init} + \text{V\_PT2-init}) + \text{ratio\_ST-1way-eff} * \text{V\_ST-tot-init} \qquad \text{E11}$$

The only unknown term left is *ratio_PT-both-1way*; we also replace V_tot-disp-1way by Eq. 5; finally, we solve Eq. 11 for ratio_PT-both-1way :

$$\text{ratio\_PT-both-1way} = \frac{(\text{ratio\_1way-overall} * \text{V\_tot-disp-init} - \text{ratio\_ST-1way-eff} * \text{V\_ST-tot-init})}{(\text{V\_PT1-init} + \text{V\_PT2-init})} \qquad \text{E12}$$

This *ratio_PT-both-1way* is the gas rule we have to apply for the two (both) primary tanks and what we have been looking for at the beginning of this analysis.

Practical application 1

Let's take a very simple example:

- all tank sizes are equal, including the two primary tanks and the one stage tank
- initial pressure are also equal for all tanks
  v_PT1 = v_PT2 = v_ST = v_Fl
  p_PT1-init = p_PT2-init = p_ST-init = p_Fl-init
  V_PT1-init = V_PT2-init = V_ST-init = V_Fl-init
  V_tot-init = 3 * V_Fl-init
- on the way in, stage tank should be used down to 50% (ratio_ST-1way-basic=0.5)
- no reserve pressure for stage tank (dp_ST-Res = 0 bar); ratio_ST-1way-eff = 0.5)
- we want to achieve an overall usage ratio of 1/3 (ratio_1way-overall=0.3333)

Then we can write:

$$\text{ratio\_PT-both-1way} = \frac{(1/3 * 3\ \text{V\_Fl-init} - 0.5 * \text{V\_Fl-init})}{(2 * \text{V\_Fl-init})}$$

$$\text{ratio\_PT-both-1way} = \frac{0.5}{2} = \boxed{\frac{1}{4}}$$

Conclusion

In other words, if we want to keep an overall usage ratio of 1/3 and a ratio of 50% (**1/2**) with zero reserve for the (single) stage tank, then we MUST apply a usage ratio of 0.25 (**1/4**) on both primary tanks. (→ ***have a look on the "common sense" example on page 4)***

Practical application 2

With the same initial data, we want to maintain an overall usage ratio_1way-overall of **¼** (0.25).

$$\text{ratio\_PT-both-1way} = \frac{(1/4 * 3\ \text{V\_Fl-init} - 0.5 * \text{V\_Fl-init})}{(2 * \text{V\_Fl-init})}$$

$$\text{ratio\_PT-both-1way} = \frac{0.25}{2} = \boxed{\frac{1}{8}}$$

Conclusion

In this case, we must even apply a ratio of **1/8** (0.125) on both primary tanks!

Practical application 3

Now let’s take a much more complex example:
V_PT1 = 7 l
V_PT2 = 7 l
p_PT1-init = 300 bar
p_PT2-init = 220 bar

v_ST = 11.1 l
p_ST = 206 bar
dp_ST-Res = 10 bar
ratio_ST-1way-basic = 0.50 (50%)

Overall gas ratio for one way (ratio_1way-overall) should be **0.33333** (1/3)

Numerical calculation:
V_PT1-init = 7l * 300 bar = **2100 bar*l**
V_PT2-init = 7l * 220 bar = **1540 bar*l**

V_ST-init = 11.1 l * 206 bar = **2286.6 bar*l**

V_tot-init = 2100 bar*l + 1540 bar*l + 2286.6 bar*l = **5926 bar*l (ABgerundet)**

V_tot-disp-1way = 0.3333 * 5926 bar*l = **1976 bar*l**

$$\text{ratio\_ST-1way-eff} = \frac{(0.50 * 2286\ \text{bar*l} - 11.1\text{l} * 10\ \text{bar})}{2286\ \text{bar*l}} = \mathbf{0.4514}\ (45,..\%)$$

$$\text{ratio\_PT-both-1way} = \frac{(0.3333 * 5926\ \text{bar*l} - 0.4514 * 2286\ \text{bar*l})}{(2100\ \text{bar*l} + 1540\ \text{bar*l})} = \mathbf{0.2591}\ (¼\ \text{or}\ 26\%)$$

p_PT1-return = 300bar – 0.2591 * 300bar = **222 bar**
p_PT2-return = 220 bar – 0.2591 * 220 bar = **163 bar**
p_ST-return = 0.5 * 206bar + 10 bar = **113 bar**

V_PT1-return + V_PT2-return = 7 l * 222 bar + 7 l * 163 bar = **2697 bar*l**
V_ST-return = 11.1 l * 113 bar = **1254 bar*l**
V_tot-return = 2697 bar*l + 1254 bar*l= **3951 bar*l**

X-Check: ratio_1way-overall should be = **0.3333** (s. above)

We check: ratio_1way-overall = (5927bar*l – 3951bar*l) / 5927bar*l = **0.3333 (=OK)**

Practical application 4

Now let’s take a much more complex example:
V_PT1 = 10 l
V_PT2 = 10 l
p_PT1-init = 230 bar
p_PT2-init = 210 bar
v_ST1 = 11.1 l
p_ST1 = 210 bar
v_ST2 = 11.1 l
p_ST2 = 210 bar
dp_ST-Res = 10 bar
ratio_ST-1way-basic = 0.50 (50%)
Overall gas ratio for one way (ratio_1way-overall) should be **0.333…** (1/3)

Numerical calculation:
V_PT1-init = 10l * 230 bar = **2300 bar*l**
V_PT2-init = 10l * 220 bar = **2100 bar*l**
V_PT-tot-init = 2300 bar*l + 2100 bar*l = **4400 bar*l**
V_ST1-init = 11.1 l * 210 bar = **2331 bar*l**
V_ST2-init = 11.1 l * 210 bar = **2331 bar*l**
V_ST-tot-init = 2331 bar*l + 2331 bar*l = **4662 bar*l**

V_tot-init = 2300 bar*l + 2100 bar*l + 2331 bar*l + 2331 bar*l = **9062 bar*l (rounded)**
V_tot-disp-init = 2300 bar*l + 2100 bar*l + 2331 bar*l + 2331 bar*l = **8618 bar*l (rounded)**
V_tot-disp-1way = 0.3333 * 9062 bar*l = **2873 bar*l**

(0.50 * 4662 bar*l – 10 bar *(11.1l + 11.1l))
ratio_ST-1way-eff = --- = **0.4524** (45,..%)
4662 bar*l

(0.3333 * 8618 bar*l – 0.4524 * 4662 bar*l)
ratio_PT-both-1way = --- = **0.1736** (17.4%)
(2300 bar*l + 2100 bar*l)

p_PT1-ret = 230bar – 0.1736 * 230bar = **190 bar**
p_PT2-ret = 210 bar – 0.1736 * 210 bar = **174 bar**
p_ST1-ret = 0.5 * 210bar + 10 bar = **115 bar**
p_ST2-ret = 0.5 * 210bar + 10 bar = **115 bar**

V_PT-tot-ret = V_PT1-ret + V_PT2-ret = 10l * 190 bar + 10 l * 174 bar = **3636 bar*l (rounded)**
V_ST1-disp-ret = V_ST2-disp-ret = 11.1 l * 115 bar – 2 * 10bar * 11.1l = **1055 bar*l**
V_ST-tot-disp-ret = V_ST1-disp-ret + V_ST2-disp-ret = **2109 (rounded)**
V_tot-disp-ret = 3636 bar*l + 2109 bar*l= **5745 (rounded) bar*l**

X-Check: ratio_1way-overall should be = **0.3333** (s. above)

We check: ratio_1way-overall = (8618bar*l – 5745bar*l) / 8618bar*l = **0.3334 (=OK)**

Appendix: Sample calculations

Overview of attached Samples

1. Application of 1/3 Rule overall with 50% stage tank (1) usage and no reserve
2. Application of 1/4 Rule overall with 50% stage tank (1) usage and no reserve
3. Application of 1/3 Rule on all tanks (incl. 1 stage tank)
4. Application of 1/3 Rule overall with 50% stage tank (1) usage with NO reserve AND individual gas volumes for each tank
5. Application of 1/3 Rule overall with 50% stage tank (1) usage minus reserve AND individual gas volumes for each tank
6. Sample calculation with 2 Stage Tanks, 50% stage tank usage minus reserve and individual gas volumes

Appendix: Sample calculations

1. Application of 1/3 Rule overall with 50% stage usage and no reserve

Gas-Management with Stage Tank(s)

(calculations under the assumption of ideal gas behaviour)

Configuration: 2 Primary Tanks and 1-2 Stage Tanks; all tanks may have individual (different) volumes and initial pressures
Mode of use: all 3 tanks can be used at any time during the dive
Assumption: stage tank(s) used by ratio_ST-1way-basic= 50.00% of the initial pressure + dp_ST-Res on the way in (Maximum = 50%).
Caution: calculation performed under application of ideal gas laws

Input date
Output data

Question to be answered: which rule must be equally applied to the 2 primary tanks to observe a given (desired) overall gas rule ?

Gas-Tanks

a) Primary Tanks			
volume PT1	v_PT1	10	l
initial pressure PT1	p_PT1-init	210	bar
volume PT2	v_PT2	10	l
initial pressure PT2	p_PT2-init	210	bar
b) Stage Tank(s)			
volume ST1	v_ST1	10.0	l
initial pressure ST1	p_ST1-init	210	bar
volume ST2	v_ST2	0.0	l
initial pressure ST2	p_ST2-init	0	bar
reserve pressure ST (1 way); for all stages identical	dp_ST-Res	0	bar

Note: This reserve MUST NOT be used, except in an unexpected GAA.
Therefore, this volume (for both ways) does NOT belong to the gas volume at DISPOSTION.
GAA: greates assummed accident

Contents

initial gas volume (content) PT1	V_PT1-init	2100	bar*l
initial gas volume (content) PT2	V_PT2-init	2100	bar*l
total initial gas-volume (content) PT1+PT2	V_PT-tot-init	4200	bar*l
initial gas volume (content) ST1	V_ST1-init	2100	bar*l
initial gas volume (content) ST2	V_ST2-init	0	bar*l
total inital gas-volume (content) of ST1 + ST2	V-ST-tot-init	2100	bar*l
total reserve gas volume of all ST (1 way)	V_ST-Res-tot	0	bar*l
total volume of consumed stage tank gas 1way	V-ST-1way-cons	1050	bar*l
effective 1way gas usage ratio for ST1	ratio_ST1-1way-eff	50.0%	
effective 1way gas usage ratio for ST2	ratio_ST2-1way-eff	0.0%	
effective gas usage ratio for all ST (1 way)	ratio_ST-1way-eff	50.00%	

Applicable rules and consequences

total initial volume of gas (incl. reserve volume)	V_tot-init	6300	bar*l	
total initial gas volum at DISPOSITION (w/o 2* reserve)	V_tot-disp-init	6300	bar*l	
desired rule for TOTAL initial gas VOLUME at DISPOSITION	1 /	3	---	*)
ratio_V_tot-disp-desired		33.3%		
total volume of gas at DISPOSITION 1 way	**V_tot-disp-1way**	**2100**	**bar*l**	

WHAT WE WOULD LIKE TO KNOW:
rule to apply for the PRIMARY TANKS (both equally)

ratio_PT-both-1way; calculated value	1 /	4.00	---	*)
ratio_PT-both-1way; FINALLY CHOSEN value	1 /	4.0	---	OK
ratio_PT-both-1way		25.00%		

resulting return pressures and gas volume Primary Tanks:

return pressure for PT1	p_PT1-ret	158	bar
return pressure for PT2	p_PT2-ret	158	bar
return gas-volume (content) in PT1	V_PT1-ret	1575.0	bar*l
return gas-volume (content) in PT2	V_PT2-ret	1575.0	bar*l
total return gas-volume (content) of all PT	V_PT-tot-ret	3150	bar*l

resulting return pressures and gas volume Stage Tanks:

return pressure ST1 (of which dp_ST-Res MUST NOT be used)	p_ST1-ret	105	bar
return pressure ST2 (of which dp_ST-Res MUST NOT be used)	p_ST2-ret	0	bar
return gas-volume (content) in ST1 - 2 * reserve volume	V_ST1-disp-ret	1050.0	bar*l
return gas-volume (content) in ST2 - 2 * reserve volume	V_ST2-disp-ret	0.0	bar*l
total return gas-volume (content) at DISPOSITION of all ST	V_ST-tot-disp-ret	1050	bar*l
total gas volume at DISPOSITION for return (excl. reserve)	**V_tot-disp-ret**	**4200**	**bar*l**

X-Check: V_tot-disp-ret / V_tot-disp-init — ratio_V_tot-disp-ret-init 0.6667 --- OK

Legend:

PT1/2	primary tank 1 /2
v_PT1 /2	tank volume PT1 /2
p_PT1 /2-init	initial pressure PT1 /2
V_PT1 /2-init	initial gas volume (content) PT1 /2
V_PT-tot-init	total initial gas volume (content) PT1+PT2
ST1 / ST2	stage tank1 /2
v-ST1 /2	volume stage tank 1 /2
p_ST1 /2-init	initial pressure ST 1 /2
V_ST1 /2-init	initial gas volume (content) ST1 /2
V-ST-tot-init	total initial gas volume (content) all stage tanks
dp_ST-Res	reserve pressure stage tank(s) 1 way; equal for all stages
V_ST-Res-tot	total reserve gas volume all stage tank(s) 1 way
ratio_ST1/2-1way-basic	basic 1way gas usage ratio (rule) for ST1 /2 (without reserve)
ratio_ST1/2-1way-eff	effective 1way gas usage ratio (rule) for ST1 /2
V_tot-init	total initial volume of gas (PT+ST)
V_tot-disp-init	total initial volume of gas (PT+ST) at our DISPOSITION
V_tot-disp-ret	total gas volume for return at our DISPOSITION
ratio_V_tot-disp-desired	desired gas usage ratio 1way for total volume at DISPOSITION
ratio_V_tot-disp-ret-init	V_tot-disp-ret / V_tot-disp-init
ratio_PT-both-1way	gas usage ratio (rule) 1way for both PT
V_tot-disp-1way	total volume of gas at DISPOSITION 1 way

Caution: **If Primary Tanks have different initial pressures, one must strive to equalize both pressures underway asap by alternatively breathing from the tanks. This to make sure that there is always enough gas for a buddy for the event of a worst case gas szenario (catastrophic failure of the buddy's both PT, followed by air-sharing exit.**

***) rule of thirds (3),**
rule of forths (4),
rule of fifths (5),
etc.

Example with identical initial volumes, 50% stage use (1 stage), 33.3% overall gas usage and with 0 reserve.

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Appendix: Sample calculations

2. Application of 1/4 Rule overall with 50% stage usage and no reserve

Gas-Management with Stage Tank(s)

(calculations under the assumption of ideal gas behaviour)

Configuration: 2 Primary Tanks and 1-2 Stage Tanks; all tanks may have individual (different) volumes and initial pressures
Mode of use: all 3 tanks can be used at any time during the dive
Assumption: stage tank(s) used by ratio_ST-1way-basic= 50.00% of the initial pressure + dp_ST-Res on the way in (Maximum = 50%).
Caution: calculation performed under application of ideal gas laws

Input date	
Output data	

Question to be answered: which rule must be equally applied to the 2 primary tanks to observe a given (desired) overall gas rule?

Gas-Tanks

a) Primary Tanks			
volume PT1	v_PT1	10	l
initial pressure PT1	p_PT1-init	210	bar
volume PT2	v_PT2	10	l
initial pressure PT2	p_PT2-init	210	bar
b) Stage Tank(s)			
volume ST1	v_ST1	10.0	l
initial pressure ST1	p_ST1-init	210	bar
volume ST2	v_ST2	0.0	l
initial pressure ST2	p_ST2-init	0	bar
reserve pressure ST (1 way); for all stages identical	dp_ST-Res	0	bar

Note: This reserve MUST NOT be used, except in an unexpected GAA.
Therefore, this volume (for both ways) does NOT belong to
the gas volume at DISPOSTION.
GAA: greates assummed accident

Contents

initial gas volume (content) PT1	V_PT1-init	2100	bar*l
initial gas volume (content) PT2	V_PT2-init	2100	bar*l
total initial gas-volume (content) PT1+PT2	V_PT-tot-init	4200	bar*l
initial gas volume (content) ST1	V_ST1-init	2100	bar*l
initial gas volume (content) ST2	V_ST2-init	0	bar*l
total inital gas-volume (content) of ST1 + ST2	V-ST-tot-init	2100	bar*l
total reserve gas volume of all ST (1 way)	V_ST-Res-tot	0	bar*l
total volume of consumed stage tank gas 1way	V-ST-1way-cons	1050	bar*l
effective 1way gas usage ratio for ST1	ratio_ST1-1way-eff	50.0%	
effective 1way gas usage ratio for ST2	ratio_ST2-1way-eff	0.0%	
effective gas usage ratio for all ST (1 way)	ratio_ST-1way-eff	50.00%	

Applicable rules and consequences

total initial volume of gas (incl. reserve volume)	V_tot-init	6300	bar*l	
total initial gas volum at DISPOSITION (w/o 2* reserve)	V_tot-disp-init	6300	bar*l	
desired rule for TOTAL initial gas VOLUME at DISPOSITION		1 / 4	---	*)
ratio_V_tot-disp-desired		25.0%		
total volume of gas at DISPOSITION 1 way	**V_tot-disp-1way**	**1575**	**bar*l**	
WHAT WE WOULD LIKE TO KNOW:				
rule to apply for the PRIMARY TANKS (both equally)				
ratio_PT-both-1way; calculated value		1 / 8.00	---	*)
ratio_PT-both-1way; FINALLY CHOSEN value		1 / 8.0	---	OK
ratio_PT-both-1way		12.50%		
resulting return pressures and gas volume Primary Tanks:				
return pressure for PT1	p_PT1-ret	184	bar	
return pressure for PT2	p_PT2-ret	184	bar	
return gas-volume (content) in PT1	V_PT1-ret	1837.5	bar*l	
return gas-volume (content) in PT2	V_PT2-ret	1837.5	bar*l	
total return gas-volume (content) of all PT	V_PT-tot-ret	3675	bar*l	
resulting return pressures and gas volume Stage Tanks:				
return pressure ST1 (of which dp_ST-Res MUST NOT be used)	p_ST1-ret	105	bar	
return pressure ST2 (of which dp_ST-Res MUST NOT be used)	p_ST2-ret	0	bar	
return gas-volume (content) in ST1 - 2 * reserve volume	V_ST1-disp-ret	1050.0	bar*l	
return gas-volume (content) in ST2 - 2 * reserve volume	V_ST2-disp-ret	0.0	bar*l	
total return gas-volume (content) at DISPOSITION of all ST	V_ST-tot-disp-ret	1050	bar*l	
total gas volume at DISPOSITION for return (excl. reserve)	**V_tot-disp-ret**	**4725**	**bar*l**	
X-Check: V_tot-disp-ret / V_tot-disp-init	ratio_V_tot-disp-ret-init	0.7500	---	OK

Legend:

PT1/2	primary tank 1 /2
v_PT1 /2	tank volume PT1 /2
p_PT1 /2-init	initial pressure PT1 /2
V_PT1 /2-init	initial gas volume (content) PT1 /2
V_PT-tot-init	total initial gas volume (content) PT1+PT2
ST1 / ST2	stage tank1 /2
v-ST1 /2	volume stage tank 1 /2
p_ST1 /2-init	initial pressure ST 1 /2
V_ST1 /2-init	initial gas volume (content) ST1 /2
V-ST-tot-init	total initial gas volume (content) all stage tanks
dp_ST-Res	reserve pressure stage tank(s) 1 way; equal for all stages
V_ST-Res-tot	total reserve gas volume all stage tank(s) 1 way
ratio_ST1/2-1way-basic	basic 1way gas usage ratio (rule) for ST1 /2 (without reserve)
ratio_ST1/2-1way-eff	effective 1way gas usage ratio (rule) for ST1 /2
V_tot-init	total initial volume of gas (PT+ST)
V_tot-disp-init	total initial volume of gas (PT+ST) at our DISPOSITION
V_tot-disp-ret	total gas volume for return at our DISPOSITION
ratio_V_tot-disp-desired	desired gas usage ratio 1way for total volume at DISPOSITION
ratio_V_tot-disp-ret-init	V_tot-disp-ret / V_tot-disp-init
ratio_PT-both-1way	gas usage ratio (rule) 1way for both PT
V_tot-disp-1way	total volume of gas at DISPOSITION 1 way

Caution: **If Primary Tanks have different initial pressures, one must strive to equalize both pressures underway asap by alternatively breathing from the tanks. This to make sure that there is always enough gas for a buddy for the event of a worst case gas szenario (catastrophic failure of the buddy's both PT, followed by air-sharing exit.**

***) rule of thirds (3),**
rule of forths (4),
rule of fifths (5),
etc.

Example with identical initial volumes, 50% stage use (1 stage), 25% overall gas usage and with 0 reserve.

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Appendix: Sample calculations

3. Application of 1/3 Rule on all tanks (incl. stage)

Gas-Management with Stage Tank(s)

(calculations under the assumption of ideal gas behaviour)

Configuration: 2 Primary Tanks and 1-2 Stage Tanks; all tanks may have individual (different) volumes and initial pressures
Mode of use: all 3 tanks can be used at any time during the dive
Assumption: stage tank(s) used by ratio_ST-1way-basic= 33.33% of the initial pressure + dp_ST-Res on the way in (Maximum = 50%).
Caution: calculation performed under application of ideal gas laws

Input date
Output data

Question to be answered: which rule must be equally applied to the 2 primary tanks to observe a given (desired) overall gas rule?

Gas-Tanks				Contents			
a) Primary Tanks							
volume PT1	v_PT1	10	l	initial gas volume (content) PT1	V_PT1-init	2100	bar*l
initial pressure PT1	p_PT1-init	210	bar				
volume PT2	v_PT2	10	l	initial gas volume (content) PT2	V_PT2-init	2100	bar*l
initial pressure PT2	p_PT2-init	210	bar				
				total initial gas-volume (content) PT1+PT2	V_PT-tot-init	4200	bar*l
b) Stage Tank(s)							
volume ST1	v_ST1	10.0	l	initial gas volume (content) ST1	V_ST1-init	2100	bar*l
initial pressure ST1	p_ST1-init	210	bar				
volume ST2	v_ST2	0.0	l	initial gas volume (content) ST2	V_ST2-init	0	bar*l
initial pressure ST2	p_ST2-init	0	bar				
				total inital gas-volume (content) of ST1 + ST2	V-ST-tot-init	2100	bar*l
reserve pressure ST (1 way); for all stages identical	dp_ST-Res	0	bar	total reserve gas volume of all ST (1 way)	V_ST-Res-tot	0	bar*l
				total volume of consumed stage tank gas 1way	V-ST-1way-cons	699.93	bar*l
				effective 1way gas usage ratio for ST1	ratio_ST1-1way-eff	33.3%	
				effective 1way gas usage ratio for ST2	ratio_ST2-1way-eff	0.0%	
				effective gas usage ratio for all ST (1 way)	ratio_ST-1way-eff	33.33%	

Note: This reserve MUST NOT be used, except in an unexpected GAA.
Therefore, this volume (for both ways) does NOT belong to the gas volume at DISPOSTION.
GAA: greates assummed accident

Applicable rules and consequences

total initial volume of gas (incl. reserve volume)	V_tot-init	6300	bar*l
total initial gas volum at DISPOSITION (w/o 2* reserve)	V_tot-disp-init	6300	bar*l
desired rule for TOTAL initial gas VOLUME at DISPOSITION		1 / 3	--- *)
	ratio_V_tot-disp-desired	33.3%	
total volume of gas at DISPOSITION 1 way	V_tot-disp-1way	2100	bar*l
WHAT WE WOULD LIKE TO KNOW:			
rule to apply for the PRIMARY TANKS (both equally)			
	ratio_PT-both-1way; calculated value	1 / 3.00	--- *)
	ratio_PT-both-1way; FINALLY CHOSEN value	1 / 3.0	--- OK
	ratio_PT-both-1way	33.33%	
resulting return pressures and gas volume Primary Tanks:			
return pressure for PT1	p_PT1-ret	140	bar
return pressure for PT2	p_PT2-ret	140	bar
return gas-volume (content) in PT1	V_PT1-ret	1400.0	bar*l
return gas-volume (content) in PT2	V_PT2-ret	1400.0	bar*l
total return gas-volume (content) of all PT	V_PT-tot-ret	2800	bar*l
resulting return pressures and gas volume Stage Tanks:			
return pressure ST1 (of which dp_ST-Res MUST NOT be used)	p_ST1-ret	140	bar
return pressure ST2 (of which dp_ST-Res MUST NOT be used)	p_ST2-ret	0	bar
return gas-volume (content) in ST1 - 2 * reserve volume	V_ST1-disp-ret	1400.1	bar*l
return gas-volume (content) in ST2 - 2 * reserve volume	V_ST2-disp-ret	0.0	bar*l
total return gas-volume (content) at DISPOSITION of all ST	V_ST-tot-disp-ret	1400	bar*l
total gas volume at DISPOSITION for return (excl. reserve)	V_tot-disp-ret	4200	bar*l
X-Check: V_tot-disp-ret / V_tot-disp-init	ratio_V_tot-disp-ret-init	0.6667	--- OK

Legend:

PT1/2	primary tank 1 /2	V_tot-init	total initial volume of gas (PT+ST)
v_PT1 /2	tank volume PT1 /2	V_tot-disp-init	total initial volume of gas (PT+ST) at our DISPOSITION
p_PT1 /2-init	initial pressure PT1 /2	V_tot-disp-ret	total gas volume for return at our DISPOSITION
V_PT1 /2-init	initial gas volume (content) PT1 /2	ratio_V_tot-disp-desired	desired gas usage ratio 1way for total volume at DISPOSITION
V_PT-tot-init	total initial gas volume (content) PT1+PT2	ratio_V_tot-disp-ret-init	V_tot-disp-ret / V_tot-disp-init
		ratio_PT-both-1way	gas usage ratio (rule) 1way for both PT
ST1 / ST2	stage tank1 /2	V_tot-disp-1way	total volume of gas at DISPOSITION 1 way
v-ST1 /2	volume stage tank 1 /2		
p_ST1 /2-init	initial pressure ST 1 /2		
V_ST1 /2-init	initial gas volume (content) ST1 /2		
V-ST-tot-init	total initial gas volume (content) all stage tanks		
dp_ST-Res	reserve pressure stage tank(s) 1 way; equal for all stages		
V_ST-Res-tot	total reserve gas volume all stage tank(s) 1 way		
ratio_ST1/2-1way-basic	basic 1way gas usage ratio (rule) for ST1 /2 (without reserve)		
ratio_ST1/2-1way-eff	effective 1way gas usage ratio (rule) for ST1 /2		

Caution: **If Primary Tanks have different initial pressures, one must strive to equalize both pressures underway asap by alternatively breathing from the tanks. This to make sure that there is always enough gas for a buddy for the event of a worst case gas szenario (catastrophic failure of the buddy's both PT, followed by air-sharing exit.**

***) rule of thirds (3), rule of forths (4), rule of fifths (5), etc.**

Example with identical initial volumes, 33% stage use (1 stage), 33% overall gas usage and 0 (extra) reserve.

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Appendix: Sample calculations

4. Application of 1/3 Rule overall with 50% stage usage and no reserve AND individual gas volumes or each tank

Gas-Management with Stage Tank(s)

(calculations under the assumption of ideal gas behaviour)

Configuration: 2 Primary Tanks and 1-2 Stage Tanks; all tanks may have individual (different) volumes and initial pressures
Mode of use: all 3 tanks can be used at any time during the dive
Assumption: stage tank(s) used by ratio_ST-1way-basic= 50.00% of the initial pressure + dp_ST-Res on the way in (Maximum = 50%).
Caution: calculation performed under application of ideal gas laws

Input date
Output data

Question to be answered: which rule must be equally applied to the 2 primary tanks to observe a given (desired) overall gas rule ?

Gas-Tanks

a) Primary Tanks

volume PT1	v_PT1	10	l
initial pressure PT1	p_PT1-init	230	bar
volume PT2	v_PT2	10	l
initial pressure PT2	p_PT2-init	210	bar

b) Stage Tank(s)

volume ST1	v_ST1	11.1	l
initial pressure ST1	p_ST1-init	206	bar
volume ST2	v_ST2	0.0	l
initial pressure ST2	p_ST2-init	0	bar
reserve pressure ST (1 way); for all stages identical	dp_ST-Res	0	bar

Note: This reserve MUST NOT be used, except in an unexpected GAA.
Therefore, this volume (for both ways) does NOT belong to the gas volume at DISPOSTION.
GAA: greates assummed accident

Contents

initial gas volume (content) PT1	V_PT1-init	2300	bar*l
initial gas volume (content) PT2	V_PT2-init	2100	bar*l
total initial gas-volume (content) PT1+PT2	V_PT-tot-init	4400	bar*l
initial gas volume (content) ST1	V_ST1-init	2287	bar*l
initial gas volume (content) ST2	V_ST2-init	0	bar*l
total inital gas-volume (content) of ST1 + ST2	V-ST-tot-init	2287	bar*l
total reserve gas volume of all ST (1 way)	V_ST-Res-tot	0	bar*l
total volume of consumed stage tank gas 1way	V-ST-1way-cons	1143.3	bar*l
effective 1way gas usage ratio for ST1	ratio_ST1-1way-eff	50.0%	
effective 1way gas usage ratio for ST2	ratio_ST2-1way-eff	0.0%	
effective gas usage ratio for all ST (1 way)	ratio_ST-1way-eff	50.00%	

Applicable rules and consequences

total initial volume of gas (incl. reserve volume)	V_tot-init	6687	bar*l
total initial gas volum at DISPOSITION (w/o 2* reserve)	V_tot-disp-init	6686.6	bar*l
desired rule for TOTAL initial gas VOLUME at DISPOSITION		1 / 3 ---	*)
	ratio_V_tot-disp-desired	33.3%	
total volume of gas at DISPOSITION 1 way	**V_tot-disp-1way**	2229	bar*l

WHAT WE WOULD LIKE TO KNOW:
rule to apply for the PRIMARY TANKS (both equally)

ratio_PT-both-1way; calculated value	1 / 4.05 ---	*)
ratio_PT-both-1way; FINALLY CHOSEN value	1 / 4.05 ---	OK
ratio_PT-both-1way	24.69%	

resulting return pressures and gas volume Primary Tanks:

return pressure for PT1	p_PT1-ret	173	bar
return pressure for PT2	p_PT2-ret	158	bar
return gas-volume (content) in PT1	V_PT1-ret	1732.1	bar*l
return gas-volume (content) in PT2	V_PT2-ret	1581.5	bar*l
total return gas-volume (content) of all PT	V_PT-tot-ret	3314	bar*l

resulting return pressures and gas volume Stage Tanks:

return pressure ST1 (of which dp_ST-Res MUST NOT be used)	p_ST1-ret	103	bar
return pressure ST2 (of which dp_ST-Res MUST NOT be used)	p_ST2-ret	0	bar
return gas-volume (content) in ST1 - 2 * reserve volume	V_ST1-disp-ret	1143.3	bar*l
return gas-volume (content) in ST2 - 2 * reserve volume	V_ST2-disp-ret	0.0	bar*l
total return gas-volume (content) at DISPOSITION of all ST	V_ST-tot-disp-ret	1143	bar*l
total gas volume at DISPOSITION for return (excl. reserve)	**V_tot-disp-ret**	4457	bar*l

X-Check: V_tot-disp-ret / V_tot-disp-init ratio_V_tot-disp-ret-init 0.6665 --- OK

Legend:

PT1/2	primary tank 1 / 2
v_PT1 /2	tank volume PT1 / 2
p_PT1 /2-init	initial pressure PT1 / 2
V_PT1 /2-init	initial gas volume (content) PT1 / 2
V_PT-tot-init	total initial gas volume (content) PT1+PT2
ST1 / ST2	stage tank1 / 2
v-ST1 / 2	volume stage tank 1 / 2
p_ST1 /2-init	initial pressure ST 1 / 2
V_ST1 /2-init	initial gas volume (content) ST1 / 2
V-ST-tot-init	total initial gas volume (content) all stage tanks
dp_ST-Res	reserve pressure stage tank(s) 1 way; equal for all stages
V_ST-Res-tot	total reserve gas volume all stage tank(s) 1 way
ratio_ST1/2-1way-basic	basic 1way gas usage ratio (rule) for ST1 / 2 (without reserve)
ratio_ST1/2-1way-eff	effective 1way gas usage ratio (rule) for ST1 / 2
V_tot-init	total initial volume of gas (PT+ST)
V_tot-disp-init	total initial volume of gas (PT+ST) at our DISPOSITION
V_tot-disp-ret	total gas volume for return at our DISPOSITION
ratio_V_tot-disp-desired	desired gas usage ratio 1way for total volume at DISPOSITION
ratio_V_tot-disp-ret-init	V_tot-disp-ret / V_tot-disp-init
ratio_PT-both-1way	gas usage ratio (rule) 1way for both PT
V_tot-disp-1way	total volume of gas at DISPOSITION 1 way

Caution: **If Primary Tanks have different initial pressures, one must strive to equalize both pressures underway asap by alternatively breathing from the tanks. This to make sure that there is always enough gas for a buddy for the event of a worst case gas szenario (catastrophic failure of the buddy's both PT, followed by air-sharing exit.**

***) rule of thirds (3), rule of forths (4), rule of fifths (5), etc.**

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Example with different initial volumes, 50% stage use (1 stage), 33% overall gas usage and with 0 reserve.

Appendix: Sample calculations

5. Application of 1/3 Rule overall with 50% stage usage minus reserve AND

Gas-Management with Stage Tank(s)

(calculations under the assumption of ideal gas behaviour)

Configuration: 2 Primary Tanks and 1-2 Stage Tanks; all tanks may have individual (different) volumes and initial pressures
Mode of use: all 3 tanks can be used at any time during the dive
Assumption: stage tank(s) used by ratio_ST-1way-basic= 50.00% of the initial pressure + dp_ST-Res on the way in (Maximum = 50%).
Caution: calculation performed under application of ideal gas laws

Input date
Output data

Question to be answered: which rule must be equally applied to the 2 primary tanks to observe a given (desired) overall gas rule ?

Gas-Tanks

a) Primary Tanks			
volume PT1	v_PT1	10	l
initial pressure PT1	p_PT1-init	230	bar
volume PT2	v_PT2	10	l
initial pressure PT2	p_PT2-init	210	bar
b) Stage Tank(s)			
volume ST1	v_ST1	11.1	l
initial pressure ST1	p_ST1-init	206	bar
volume ST2	v_ST2	0.0	l
initial pressure ST2	p_ST2-init	0	bar
reserve pressure ST (1 way); for all stages identical	dp_ST-Res	10	bar

Note: This reserve MUST NOT be used, except in an unexpected GAA.
Therefore, this volume (for both ways) does NOT belong to
the gas volume at DISPOSTION.
GAA: greates assummed accident

Contents

initial gas volume (content) PT1	V_PT1-init	2300	bar*l
initial gas volume (content) PT2	V_PT2-init	2100	bar*l
total initial gas-volume (content) PT1+PT2	V_PT-tot-init	4400	bar*l
initial gas volume (content) ST1	V_ST1-init	2287	bar*l
initial gas volume (content) ST2	V_ST2-init	0	bar*l
total inital gas-volume (content) of ST1 + ST2	V-ST-tot-init	2287	bar*l
total reserve gas volume of all ST (1 way)	V_ST-Res-tot	111	bar*l
total volume of consumed stage tank gas 1way	V-ST-1way-cons	1032.3	bar*l
effective 1way gas usage ratio for ST1	ratio_ST1-1way-eff	45.1%	
effective 1way gas usage ratio for ST2	ratio_ST2-1way-eff	0.0%	
effective gas usage ratio for all ST (1 way)	ratio_ST-1way-eff	45.15%	

Applicable rules and consequences

total initial volume of gas (incl. reserve volume)	V_tot-init	6687	bar*l	
total initial gas volum at DISPOSITION (w/o 2* reserve)	V_tot-disp-init	6464.6	bar*l	
desired rule for TOTAL initial gas VOLUME at DISPOSITION		1 / 3	---	*)
	ratio_V_tot-disp-desired	33.3%		
total volume of gas at DISPOSITION 1 way	V_tot-disp-1way	2155	bar*l	

WHAT WE WOULD LIKE TO KNOW:
rule to apply for the PRIMARY TANKS (both equally)

ratio_PT-both-1way; calculated value	1 / 3.92	---	*)
ratio_PT-both-1way; FINALLY CHOSEN value	1 / 3.92	---	OK
ratio_PT-both-1way	25.51%		

resulting return pressures and gas volume Primary Tanks:

return pressure for PT1	p_PT1-ret	171	bar
return pressure for PT2	p_PT2-ret	156	bar
return gas-volume (content) in PT1	V_PT1-ret	1713.3	bar*l
return gas-volume (content) in PT2	V_PT2-ret	1564.3	bar*l
total return gas-volume (content) of all PT	V_PT-tot-ret	3278	bar*l

resulting return pressures and gas volume Stage Tanks:

return pressure ST1 (of which dp_ST-Res MUST NOT be used)	p_ST1-ret	113	bar
return pressure ST2 (of which dp_ST-Res MUST NOT be used)	p_ST2-ret	0	bar
return gas-volume (content) in ST1 - 2 * reserve volume	V_ST1-disp-ret	1032.3	bar*l
return gas-volume (content) in ST2 - 2 * reserve volume	V_ST2-disp-ret	0.0	bar*l
total return gas-volume (content) at DISPOSITION of all ST	V_ST-tot-disp-ret	1032	bar*l
total gas volume at DISPOSITION for return (excl. reserve)	V_tot-disp-ret	4310	bar*l

X-Check: V_tot-disp-ret / V_tot-disp-init — ratio_V_tot-disp-ret-init 0.6667 --- OK

Legend:

PT1/2	primary tank 1 /2
v_PT1 /2	tank volume PT1 /2
p_PT1 /2-init	initial pressure PT1 /2
V_PT1 /2-init	initial gas volume (content) PT1 /2
V_PT-tot-init	total initial gas volume (content) PT1+PT2
ST1 / ST2	stage tank1 /2
v-ST1 /2	volume stage tank 1 /2
p_ST1 /2-init	initial pressure ST 1 /2
V_ST1 /2-init	initial gas volume (content) ST1 /2
V-ST-tot-init	total initial gas volume (content) all stage tanks
dp_ST-Res	reserve pressure stage tank(s) 1 way; equal for all stages
V_ST-Res-tot	total reserve gas volume all stage tank(s) 1 way
ratio_ST1/2-1way-basic	basic 1way gas usage ratio (rule) for ST1 /2 (without reserve)
ratio_ST1/2-1way-eff	effective 1way gas usage ratio (rule) for ST1 /2

V_tot-init	total initial volume of gas (PT+ST)
V_tot-disp-init	total initial volume of gas (PT+ST) at our DISPOSITION
V_tot-disp-ret	total gas volume for return at our DISPOSITION
ratio_V_tot-disp-desired	desired gas usage ratio 1way for total volume at DISPOSITION
ratio_V_tot-disp-ret-init	V_tot-disp-ret / V_tot-disp-init
ratio_PT-both-1way	gas usage ratio (rule) 1way for both PT
V_tot-disp-1way	total volume of gas at DISPOSITION 1 way

Caution: If Primary Tanks have different initial pressures, one must strive to equalize both pressures underway asap by alternatively breathing from the tanks. This to make sure that there is always enough gas for a buddy for the event of a worst case gas szenario (catastrophic failure of the buddy's both PT, followed by air-sharing exit.

*) rule of thirds (3),
rule of forths (4),
rule of fifths (5),
etc.

Example with different initial volumes, 50% stage use (1 stage), 33% overall gas usage and with reserve.

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Appendix: Sample calculations

6. Sample calculation with 2 Stage Tanks, reserve and individual gas volumes

Gas-Management with Stage Tank(s)

(calculations under the assumption of ideal gas behaviour)

Configuration: 2 Primary Tanks and 1-2 Stage Tanks; all tanks may have individual (different) volumes and initial pressures
Mode of use: all 3 tanks can be used at any time during the dive
Assumption: stage tank(s) used by ratio_ST-1way-basic= 50.00% of the initial pressure + dp_ST-Res on the way in (Maximum = 50%).
Caution: calculation performed under application of ideal gas laws

Input date
Output data

Question to be answered: which rule must be equally applied to the 2 primary tanks to observe a given (desired) overall gas rule ?

Gas-Tanks

a) Primary Tanks

volume PT1	v_PT1	10	l
initial pressure PT1	p_PT1-init	230	bar
volume PT2	v_PT2	10	l
initial pressure PT2	p_PT2-init	210	bar

b) Stage Tank(s)

volume ST1	v_ST1	11.1	l
initial pressure ST1	p_ST1-init	206	bar
volume ST2	v_ST2	11.1	l
initial pressure ST2	p_ST2-init	220	bar
reserve pressure ST (1 way); for all stages identical	dp_ST-Res	10	bar

Note: This reserve MUST NOT be used, except in an unexpected GAA.
Therefore, this volume (for both ways) does NOT belong to
the gas volume at DISPOSTION.
GAA: greates assummed accident

Contents

initial gas volume (content) PT1	V_PT1-init	2300	bar*l
initial gas volume (content) PT2	V_PT2-init	2100	bar*l
total initial gas-volume (content) PT1+PT2	V_PT-tot-init	4400	bar*l
initial gas volume (content) ST1	V_ST1-init	2287	bar*l
initial gas volume (content) ST2	V_ST2-init	2442	bar*l
total inital gas-volume (content) of ST1 + ST2	V-ST-tot-init	4729	bar*l
total reserve gas volume of all ST (1 way)	V_ST-Res-tot	222	bar*l
total volume of consumed stage tank gas 1way	V-ST-1way-cons	2142.3	bar*l
effective 1way gas usage ratio for ST1	ratio_ST1-1way-eff	45.1%	
effective 1way gas usage ratio for ST2	ratio_ST2-1way-eff	45.5%	
effective gas usage ratio for all ST (1 way)	ratio_ST-1way-eff	45.31%	

Applicable rules and consequences

total initial volume of gas (incl. reserve volume)	V_tot-init	9129	bar*l	
total initial gas volum at DISPOSITION (w/o 2* reserve)	V_tot-disp-init	8684.6	bar*l	
desired rule for TOTAL initial gas VOLUME at DISPOSITION		1 / 3	---	*)
	ratio_V_tot-disp-desired	33.3%		
total volume of gas at DISPOSITION 1 way	**V_tot-disp-1way**	2895	bar*l	

WHAT WE WOULD LIKE TO KNOW:
rule to apply for the PRIMARY TANKS (both equally)

ratio_PT-both-1way; calculated value	1 / 5.85	---	*)
ratio_PT-both-1way; FINALLY CHOSEN value	1 / 5.85	---	OK
ratio_PT-both-1way	17.09%		

resulting return pressures and gas volume Primary Tanks:

return pressure for PT1	p_PT1-ret	191	bar
return pressure for PT2	p_PT2-ret	174	bar
return gas-volume (content) in PT1	V_PT1-ret	1906.8	bar*l
return gas-volume (content) in PT2	V_PT2-ret	1741.0	bar*l
total return gas-volume (content) of all PT	V_PT-tot-ret	3648	bar*l

resulting return pressures and gas volume Stage Tanks:

return pressure ST1 (of which dp_ST-Res MUST NOT be used)	p_ST1-ret	113	bar
return pressure ST2 (of which dp_ST-Res MUST NOT be used)	p_ST2-ret	120	bar
return gas-volume (content) in ST1 - 2 * reserve volume	V_ST1-disp-ret	1032.3	bar*l
return gas-volume (content) in ST2 - 2 * reserve volume	V_ST2-disp-ret	1110.0	bar*l
total return gas-volume (content) at DISPOSITION of all ST	V_ST-tot-disp-ret	2142	bar*l
total gas volume at DISPOSITION for return (excl. reserve)	**V_tot-disp-ret**	5790	bar*l

X-Check: V_tot-disp-ret / V_tot-disp-init   ratio_V_tot-disp-ret-init 0.6667 --- OK

Legend:

PT1/2	primary tank 1 /2
v_PT1 /2	tank volume PT1 /2
p_PT1 /2-init	initial pressure PT1 /2
V_PT1 /2-init	initial gas volume (content) PT1 /2
V_PT-tot-init	total initial gas volume (content) PT1+PT2
ST1 / ST2	stage tank1 /2
v-ST1 /2	volume stage tank 1 /2
p_ST1 /2-init	initial pressure ST 1 /2
V_ST1 /2-init	initial gas volume (content) ST1 /2
V-ST-tot-init	total initial gas volume (content) all stage tanks
dp_ST-Res	reserve pressure stage tank(s) 1 way; equal for all stages
V_ST-Res-tot	total reserve gas volume all stage tank(s) 1 way
ratio_ST1/2-1way-basic	basic 1way gas usage ratio (rule) for ST1 /2 (without reserve)
ratio_ST1/2-1way-eff	effective 1way gas usage ratio (rule) for ST1 /2
V_tot-init	total initial volume of gas (PT+ST)
V_tot-disp-init	total initial volume of gas (PT+ST) at our DISPOSITION
V_tot-disp-ret	total gas volume for return at our DISPOSITION
ratio_V_tot-disp-desired	desired gas usage ratio 1way for total volume at DISPOSITION
ratio_V_tot-disp-ret-init	V_tot-disp-ret / V_tot-disp-init
ratio_PT-both-1way	gas usage ratio (rule) 1way for both PT
V_tot-disp-1way	total volume of gas at DISPOSITION 1 way

Caution: If Primary Tanks have different initial pressures, one must strive to equalize both pressures underway asap by alternatively breathing from the tanks. This to make sure that there is always enough gas for a buddy for the event of a worst case gas szenario (catastrophic failure of the buddy's both PT, followed by air-sharing exit.

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Example with different initial volumes, 50% stage use (2 stage), 33% overall gas usage and with reserve.

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