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Dive computers and Haldanian sets of parametres : how to manage repetitive dives ?

Alain Foret*
Plongée Plaisir, Worldivers Research & Reports, Montpellier, France.
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Haldane's model do not take into account the possibility of making several dives a day. This was not part of the Royal Navy's requirement [1]. Consequently, the management of repetitive dives using a set of Haldanian parameters (U.S. Navy and variants such as RDP-PADI, PDIC, Huggins, Bassett... ; Bühlmann, Hahn, MN90, COMEX, RGBM [2], VPM [3]...) requires an additional procedure, with dive tables as with dive computers.

HISTORY

The Haldane model defines parallel compartments that do not communicate with each other. The overall coherence is ensured by the logic of the controlling compartment : during the ascent, at each stop, the most restrictive compartment (the deepest and/or longest stop ; the lowest No Deco Limit[1]) dictates its conditions to all the others.

Calculations show that for most recreational dives, the controlling compartments have short half-times of the order of 5, 10, 12 or 18 minutes depending on the set of parameters used, for a first dive as well as for a repetitive dive.

After a surface interval of 6 times these half-times (30, 60, 72, 108 minutes), the controlling compartments are practically reset. During repetitive dives, these short compartments remain controlling desaturation and do not require significant more stops than in a single dive, whereas the long compartments have not completed their desaturation between the two dives. Ignoring this level of saturation in the longest compartments is a limitation of the Haldane model that can lead to decompression sickness (DCS).

Haldane was fully aware of this limitation : "A diver has often to descend twice or oftener at short intervals. At the beginning of the second descent the more slowly desaturating parts of the body will not have had time to lose their excess of nitrogen, and consequently they will be more highly saturated at the end of the second descent than would otherwise have been the case." [4] This means that, when managing repetitive dives, it is not enough to simply consider the residual neutral gas (nitrogen) in the compartments at the end of the surface interval time [7].

Historically, the first procedure proposed was to add the duration of the first dive to the second dive. Haldane states : "To meet the increased risk in decompression it is desirable, in calculating the proper stoppages, to add together the two periods of exposure" [4]. The US-Navy adopted the Haldane tables in 1916, then created its own tables (1935) and maintained this procedure : "A safe rule is to take the total combined time of the two dives and use a table for that exposure, at the pressure at which the diver was working." [5]

This method remained in place from 1908 to 1948, but was replaced by the "Repetitive Group" (RG) method (French Navy, Jean Alinat [6]), which calculates a fictitious time (Residual Nitrogen Time - RNT) to over-penalise repetitive dives [8] [9]. All the dive tables in the world have adopted this approach.

IN THE AGE OF DIVE COMPUTERS

With the first dive computers, it was realised that the RG method could not be implemented directly, as it required prior knowledge of the depth of the repetitive dive, which is not the case with real-time calculations.

Faced with this difficulty, manufacturers are reacting in different ways. Some are considering no longer applying over-penalisation, while others think this would be dangerous. The debate is quickly settled[2].

Brent Goetzl, Project Engineer, Oceanic Dive Computers states : "For those who question the conservatism of these designs [over-penalisation, RG method], we refer to the experiments of both the U.S. Navy (Thalmann [12]) and the Royal Navy (Leitch and Barnard [13]) that demonstrate unrestricted Haldanian models for repetitive

1. The term is inappropriate, although it is widely used. Each ascent phase causes decompression (reduction in pressure) and desaturation (nitrogen off-gasing). These are dives where no stops are required (No-Stop Limit).

2. A. A. Bühlmann himself applied over-penalisation to computer algorithms (UWATEC) developed [10] with sets of parameters ZH-L 16, 8 and 6

dive control can produce an unacceptable incidence of decompression sickness." [11]

In this context, Oceanic Dive Computers is unveiling a method [11] that is an adaptation of the RG method. Based on the choice of a controlling compartment on the surface (e.g. 120 min), the desaturation level of this compartment at the end of the surface interval is calculated (e. g. 15%, 20%, 50%...) and applied to all the compartments whose half-time is less than that of the compartment chosen. The desaturation level is calculated using the classic Haldane equation :

$$D_L = 1 - (0,5)^{\frac{S_{IT}}{T_{1/2}}}, \quad (1)$$

where :
D_L is the desaturation level
S_{IT} is the surface interval time in minutes
$T_{1/2}$ is the half-time of the controlling compartment at the surface, in minutes

S_{IT}	Compartments (half-time in min), examples						
(min)	5	10	15	20	60	80	120
30	−98%	−88%	−75%	−65%	−29%	−23%	−16%
60	−100%	−98%	−94%	−88%	−50%	−41%	−29%
90	−100%	−100%	−98%	−96%	−65%	−54%	−41%
120	−100%	−100%	−100%	−98%	−75%	−65%	−50%
150	−100%	−100%	−100%	−99%	−82%	−73%	−58%
180	−100%	−100%	−100%	−100%	−88%	−79%	−65%
240	−100%	−100%	−100%	−100%	−94%	−88%	−75%

TABLE I. Examples of surface desaturation levels according to different compartments and surface intervals times (S_{IT}). The short compartments are given for information only ; they are never considered as controlling compartments at the surface. In order to apply an over-penalisation to all the compartments, it has historically been chosen to use a long half-time of the 120 min type (C_{120} [11], for "sport dives", with required stops) or 60 min (C_{60} [17], recreational dives, No Deco Limit).

Assuming that the controlling compartment at the surface is 120 min (C_{120}), for a surface interval of 90 min, its desaturation level (−41%) is applied to all the compartments (whose half-time is shorter than that of the controlling compartment). In the example given in the table I, compartments 5, 10, 15, 20, 60 and 80 min are all considered to be desaturated at 41% instead of 100, 100, 98, 96, 65, 54%.

Calculation example using the Bühlmann ZH-L 16 C set of parameters

Let's consider a dive with a residual nitrogen on arrival at the surface given in column C of the table II. For a surface interval time (S_{IT}) of 90 min, column D gives the residual nitrogen at the end of the S_{IT} without using the surface controlling compartment logic ; columns E and F give the residual nitrogen considering a controlling compartment of 60 and 120 min.

A	B	C	D	E	F
N°	$t_{1/2}$ (min)	Residual N_2 on arrival at the surface	Residual N_2 at the end of the surface interval (90 min) No controlling compartment	C_{60}	C_{120}
1	4	1,458	0,800	1,030	1,188
2	8	1,888	0,800	1,181	1,443
3	12,5	2,018	0,808	1,226	1,519
4	18,5	1,980	0,840	1,213	1,496
5	27	1,840	0,903	1,164	1,414
6	38,3	1,668	0,970	1,104	1,312
7	54,3	1,492	1,019	1,042	1,208
8	77	1,332	1,037	1,037*	1,114
9	109	1,200	1,026	1,026*	1,036
10	146	1,111	1,003	1,003*	1,003*
11	187	1,049	0,978	0,978*	0,978*
12	239	0,998	0,953	0,953*	0,953*
13	305	0,956	0,929	0,929*	0,929*
14	390	0,925	0,907	0,907*	0,907*
15	498	0,899	0,887	0,887*	0,887*
16	635	0,878	0,871	0,871*	0,871*

TABLE II. Example of residual nitrogen calculation (unit : bar) with the Bühlmann ZH-L 16 C set of parameters. The controlling compartment can be chosen from within or outside the set of parameters. The values marked with a star* are those of greater duration than that of the controlling compartment.

The table III presents the decompression stops calculated for several repetitive dives. It can be seen that there are few differences for "recreational" dives (No Deco Limits, shallow dives), up to a Q factor or PrT Index[3] of 120, but that there are significant differences for "sport" dives (required stops, deep dives).

3. In 1952, Hempleman [14] developed the *Q factor* or *PrT index*, an approximation, using a single compartment, of the charge of neutral gas (nitrogen) as a function of time (Δt) in minutes and depth (p) in meters :

$$PrT = p\sqrt{\Delta t} \quad (2)$$

For example, for a 40-minute dive to 30 m, $PrT = 30\sqrt{40} = 190$. A probability of DCS may be associated with it [15] [16].

Depth (m)	Duration (min)	Q Factor (PrT)	Stops No OverP.	Stops OverP. C_{60}		Stops OverP. C_{120}	
			3 m	6 m	3 m	6 m	3 m
12 m	60 min	92	0		0		0
15 m	60 min	116	0		0		0
18 m	45 min	120	0		0		6
18 m	60 min	139	3		7		14
20 m	45 min	134	1		6		12
20 m	60 min	154	13		15		23
25 m	30 min	136	1		6		15
25 m	45 min	167	20		21	2	29
30 m	15 min	116	0		1		5
30 m	30 min	164	13	1	18	4	24

TABLE III. Comparison according to whether or not over-penalisation is applied to repetitive dives (ZH-L 16 C set of parameters, using Table II data).

CONCLUSION

This method makes it possible to apply an over-penalisation whatever the set of Haldane parameters, while modulating the level of this over-penalisation by the choice of controlling compartment on the surface.

In a dive computer, it might be possible to make this over-penalisation fixed or configurable, for example by allowing the user to activate it or not, or even to choose the controlling compartment on the surface.

Historical analysis shows that for shallow dives without required stops (No Deco Limits), the 60 min half-time [17] can be used, whereas for more sporty dives, with required decompression stops, as practised in Europe[4], it is better to choose a half-time of around 120 min [11]. Technical divers (helium divers) may have different needs, because of the stops made with pure oxygen at the end of the dive.

In this context, three types of dives should be considered in dive computers :

- Recreational dives (shallow dives, no required stops), with an over-penalisation based on the compartment C_{60} ;
- Sport dives, with required stops and deep dives, for which the over-penalisation should be based on the compartment C_{120} ;
- Technical dives for which there could be a free choice, from no over-penalisation (justifying this choice) to over-penalisation based on the compartment C_{120} or other.

In all cases, dive computer manufacturers should indicate the choices made in their instructions for use.

4. Diving is practised differently in different countries. In Europe, for example, some countries (France, Belgium, etc.) train recreational divers to dive with air, with required decompression stops, to depths of up to 50 or 60 metres.

* Corresponding author : alain.foret@worldivers.com

[1] Royal Navy, Admiralty, S.W., C.N. 11713/19049, 8th August 1905.

[2] The RGBM uses a set of Haldanian parameters : B. Wienke, *Reduced Gradient Bubble Model in Depth*, Best Publishing Company, 2003, p. 34.

[3] The VPM uses a set of Haldanian parameters, that of Bühlmann : "This program uses the sixteen (16) half-time compartments of the Buhlmann ZH-L16 model", VPM Fortran source code, Erik C. Baker, 2003.

[4] Haldane J.-S. et coll., *The Prevention of decompression air Illness*, J. Hyg., 1908, pp. 369-370.

[5] *US-Navy Diving Manual*, 1916, chapitre X, p. 84.

[6] GRS, PV Essais et recherches n° 41 du 12 mai 1948, PV n° 47 et note n° 84 GRS du 16 mars 1949. Note n° 218 GERS du 9 août 1952.

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[15] B. Gardette et M. Plutarque *Comex, 50 ans de recherches et d'innovations*, Comex, 2012, pp. 142-143.

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[17] *Development and validation of no-stop decompression procedures for recreational diving*, The DSAT Recreational Dive Planner, 1994, p. 22