

HYDRA 10 : A 701 MSW ONSHORE RECORD DIVE USING "HYDRELIOX"

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SUMMARY

Following the Comex "Hydra" research program on hydrogen-helium-oxygen (HYDRELIOX), Hydra 10 was performed in the Comex hydrogen hyperbaric facilities in Marseilles by three professional divers.

The dive protocol included : 4 weeks of pre-dive period, 2 days of confinement at 10 msw, 13 days of compression to 675 msw, 3 days of bottom stage between 650 and 675 msw with an excursion dive at 701 msw, 24 days of decompression with 8 working dives in wet chamber.

The results of this record dive confirmed :

- The ability of divers to operate at depths of 300 to 650 msw with Hydreliox breathing mixture.

- The good adaptation of human being to long residence times at very great depths with 9 days below 600 msw and 5 days below 650 msw.

By limiting the effects of the high pressure syndrome and without hydrogen narcosis, the Hydreliox not only enhances the diver's effectiveness and working capabilities, but also provides for improved safety.

Hydrogen is truly the key to extreme depths and oil companies can now count on human technical assistance at depths far exceeding the limits of conventional helium diving.

Keywords : Hydrogen, gas mixture, working capabilities, safety, onshore record dive.

INTRODUCTION

HYDRA 10 experimental dive is the next phase of the ongoing Comex "HYDRA" Research Program related to the use of hydrogen in high pressure breathing gas mixture. Comex HYDRA program was launched in 1968 with HYDRA 1 and continued until HYDRA 10 in 1992. In 1990, after HYDRA 9, we concluded :

- 1) Hydrogen has narcotic effects but which are completely reversible without long-term effects on the organism.
- 2) The admissible hydrogen pressure is in the 2.4 to 2.5 MPa range. However, this threshold has to be lowered to 2 MPa for long duration dives.
- 3) Mixed with helium (Hydreliox), hydrogen reduces High Pressure Syndrome (HPS) : Decreasing the High Pressure Nervous Syndrome (HPNS), enhancing diver confort with respect to respiratory function (High Pressure Respiratory Syndrome - HPRS) and articular function (High Pressure Articular Syndrome - HPAS).

These data and the results obtained from hydrogen and helium monkeys saturation dives (HYDRA 10 monkeys - 1992) indicate the Hydreliox would enable dives to be achieved effectively and safety at depths between 600 and 700 msw. To demonstrate that divers can operate effectively at these extreme depths with Hydreliox was the purpose of HYDRA 10 onshore experimental dive. This dive was performed in Comex Marseilles by three selected professional divers of Comex and Stolt Comex Seaway Companies in November - December 1992.

METHODS

HYDRA 10 experimental facilities

The Comex facilities used for HYDRA 10 included four chambers of Experimental Hyperbaric Center in Marseilles, France :

- A set of three spheres (EMS 800) of 7 m³ each (internal diameter : 2.5 m) with one used as a dry lab, one as a diving bell one as a diving pool.

- A 35 m³ cylindrical chamber (internal diameter : 2.3 m - length : 9.35 m) with living area and sleeping quarters and sanitaires. It can house-up to 6 divers but was designed for three during HYDRA 10.

The chambers are provided with two life support units and an audio-TV communication System.

Dive protocol

HYDRA 10 total dive time lasted five months (October 5th 1992 to March 1st 1993), with 42 days inside the chambers (November 2nd to December 14th 1992). HYDRA 10 included different phases :

Pre-dive : 4 weeks duration

Dive (Fig. 1) : 42 days duration with :

- Confinement :
 - . Pressure : 2 MPa (10 msw)
 - . Gas mixture : Heliox (He - O₂)
 - . PO₂ : 40 kPa
 - . Duration : 2 days

- Compression :
 - . Pressure : From 2 to 6.85 MPa (10 - 675 msw)
 - . Gas mixtures : Heliox (then Hydreliox).
 - . Compression with He between 10 and 200 msw,
 - . H₂ : 200 - 400 msw and He : 400 - 675 msw
 - . PO₂ = 40 kPa
 - . Duration : 13 days

- Bottom stage :
 - . Pressures : 6.85 - 6.6 - 7.11 - 6.85 MPa
(675 - 650 - 701 - 675 msw)
 - . Gas mixture : Hydreliox (PH₂ = 2 MPa)
 - . PO₂ = 40 kPa
 - . Duration : 3 days

- Decompression :
 - Pressure : from 7.11 to 1 MPa (701 - 0 msw)
 - Gas mixtures : Hydreliox (675 - 280 msw)
then Heliox (280 - 0 msw)
 - PO₂ = 50 kPa (675 - 120 msw) then 60 kPa (120 - 15 msw)
then 24 % (15 - 0 msw)
 - Duration : 24 days

The gas temperature of the chambers was maintained during Hydreliox period between 30°C and 33°C depending on pressure and corresponding to thermally neutral condition. The relative humidity was about 50 %.

Post-dive : 2 months and half.

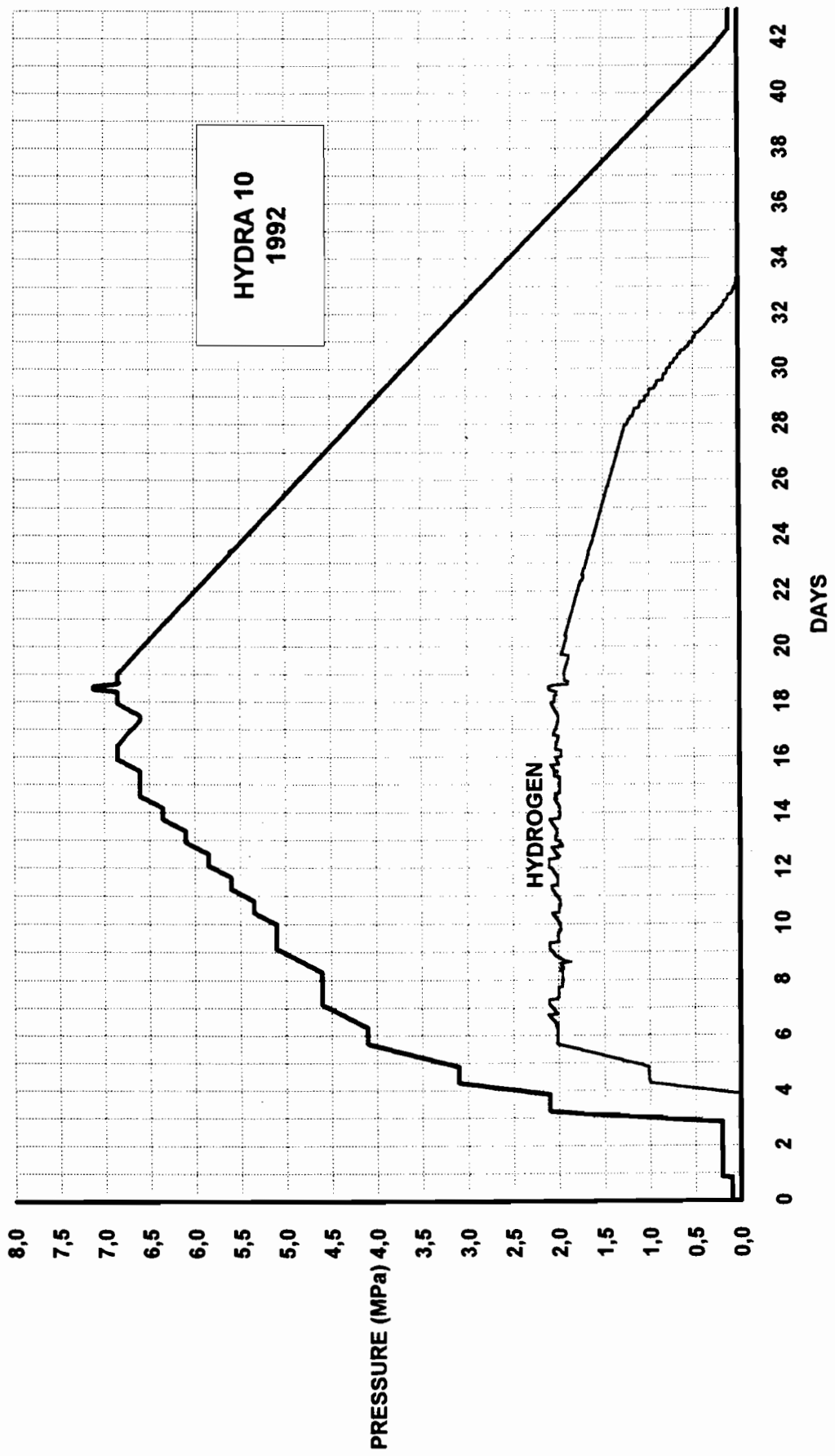


FIGURE 1

Scientific Program

Medical follow-up

COMEX Medical Service :

- Selection of divers.
- Hygiene.
- Nutrition and Dietetics.

Pre and post-dive health evaluation

- Clinical examination : Comex Medical Service.
- Breathing function : Ste Marguerite Hospital/Marseilles.
- Cardiology : Les Alpilles Clinic/Marseilles.
- NMR Imagery : Timone Hospital/Marseilles.
- Ophthalmology : Hotel-Dieu Hospital/Marseilles.
- Psychology : Timone Hospital/Marseilles.
- Kinesitherapy and Osteopathy : COMEX Medical Service.

Neurophysiology

- Tremor : CNRS/Marseilles.
- EEG (Electroencephalography) : CNRS/Marseilles.

Psychology

- Sensitive - motor and cognitive tests : AMF/Aubagne.
- Clinical Psychology : Timone Hospital/Marseilles.
- Taste analysis : SOPAD-NESTLE/Paris.

Cardio-vascular and breathing functions

- ECG/TA at rest and during exercise : Les Alpilles Clinic and North Hospital/Marseilles.
- Cardiac out-put at rest and during exercise : North Hospital/Amiens.
- Transcutaneous PO₂/PCO₂ at rest and during exercise : North Hospital/Amiens, Calmette Hospital/Lille.
- Electromyography (EMG) of diaphragm and skeletal muscle : North Hospital and CNRS/Marseilles.
- Somesthetic and breathing sensorial analysis : CNRS/Marseilles.
- Detection of circulating bubbles (Doppler) : COMEX Medical Service.

Biochemistry

Blood and urine biology pre and post-dive (and urine biology during dive) : COMEX Medical Service, Purpan Hospital/Toulouse, Salvator Hospital/Marseilles.

Others

- Hyperbaric voice unscrambling : ENSSAT-LASTI/Lannion, CYBERNETIX/Marseilles.
- Diving individual equipment : COMEX PRO.
- Underwater monitoring of the diver : COMEX, North Hospital/Amiens.
- Underwater ergonomics : COMEX, North Hospital/Amiens.

Divers

Three professional deep divers (and one substitute) from COMEX and STOLT COMEX SEAWAY companies performed HYDRA 10. The divers were selected among very experienced (10 - 15 years) divers who had participated before to deep COMEX experimental dives (450 msw or deeper) including hydrogen program dives.

The divers' team was trained during one month of pre-dive period with medical follow-up and health evaluation.

RESULTS AND DISCUSSION

The High Pressure Syndrome was reduced during HYDRA 10. The three divers were able to reach 675 msw (6.85 MPa) and one of them 701 msw (7.11 MPa).

Up to 650 msw, during compression phase, no symptoms appeared and the three divers were in excellent shape to perform all programmed tasks.

At 650 msw (6.6 MPa) and deeper, we particularly observed :

- An increasing HPNS with : slight tremor, myoclonia, dysmetria which induced psychometric and intellectual performance decrease.
- A dyskinesia associated to proprioception troubles with muscular weakness.
- A decrease in appetite which required a change in the divers nutrition.
- Sleep disturbance with decrease of deep sleep phases.
- A slight ventilatory impairment without dyspnea or nasal respiratory difficulty.
- No articular pain or no juice joint syndrome.

When the divers reached 675 msw (6.85 MPa), due to these impairments and a general fatigue, the Scientific Board decided after one night at this depth to return to 650 msw (6.6 MPa).

After a short stage at 650 msw (6.6 MPa), the divers recovered good physical conditions and a new compression to 675 msw (6.85 MPa), was decided.

Friday November 20th, 1993, one diver, the least sensitive of the three to HPS, entered in the "EMS 800" for 7 hour-excursion dive to 701 msw (7.11 MPa). During the three hours spent at that record depth, he performed a variety of scientific tests including a calibrated effort test on arm-ergometer. At 701 msw (7.11 MPa), the diver presented no ventilatory impairment or dyspnea, no nasal respiratory difficulty, no articular pains and no dizziness or dysmetria but only a slight postural distal tremor. ECG as strictly normal and EEG not much modified.

During the decompression to 675 msw (6.85 MPa) and during the 9 hours stop at this depth, no circulating bubble was detected by Doppler method.

The 2.0 MPa hydrogen partial pressure used in HYDRA 10 limited the hydrogen narcotic effect observed in HYDRA 6 and 9. So these symptoms were slight with mainly some psychodysleptic effects and mental and emotional changes.

During decompression Hydreliox phase, we observed a progressive improvement of divers, with few bubbles detected after moving. When the hydrogen was selectively removed from Hydreliox and for PH₂ lower than 12 b (1.2 MPa), the divers recovered their Heliox feeling : ventilatory impairment with nasal respiratory difficulty and arthralgia.

Eight working dives in the wet chamber (EMS 800) were carried out during decompression at depths of 660, 640, 635, 580, 550, 490, 460 msw on Hydreliox and at 145 msw on Heliox. The three divers demonstrated their effectiveness and working capacity during each dive as they performed exercise on arm-ergometer and assembled COMEX pipe puzzle according to an isometric drawing in a remarkably short time.

We noted no difference in ventilatory rate and heart rate between work in water, on the surface and at different depths. We concluded that an appropriate and stable cardio-ventilatory adaptation was monitored on the three divers and for different amounts of work imposed.

CONCLUSIONS

All the HYDRA 10 objectives were met. The use of hydrogen breathing mixture, Hydreliox, not only enhances the divers' effectiveness and working capabilities, but also provides improved safety. The increased comfort can be used to ensure greater reliability for human intervention on undersea oil production facilities. By optimization of following parameters : compression rate, hydrogen partial pressure, selection and training of divers and chamber comfort, depths of 300 to 650 msw can be considered accessible to a large number of professional divers.

In addition to the adaptation to long residence times at very great depths with more than 9 days below 600 msw and more than 5 days below 650 msw with one excursion dive at 701 msw record depth, was now demonstrated.

Oil companies can now count on human technical assistance at depths far exceeding the limits of conventional helium dive (200 - 300 msw). Hydrogen is truly the key to extreme depths.

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