NUI Diving Seminar 2017 – Evolution session
Deep Hydreliox Diving

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Summary of presentation

• A Brief History of Hydreliox Diving
• Benefits to the diver – Hydreliox vs Heliox
• Obstacles to commercialisation of Hydreliox
• Hydrogen acceptance & use in current times
• Technology enhancements in commercial diving
• Justification for using Hydreliox?
• Safety & risk concerns and mitigation
• Thoughts for the future...
Apologies & acknowledgements

Dr. Jean-Yves Massimelli – UDS
(ex-Comex diving doctor for HYDRA Project)

Théo Mavroostomos – ex Comex
(deepest man in the world – HYDRA 10 Project – 701m)

Ben Sharples – JFD
(Business Execution Director)
a brief history of hydreliox diving

Comex ‘HYDRA’ Research Programme
Started in 1968 with HYDRA 1 and continued for 28 years to HYDRA 12 in 1996

Comex founder (1961)
Henri Germain Delauze
a brief history of hydreliox diving

HYDRA objectives were to study alternative breathing gases for deep diving – especially hydrogen

Comex headquarters
Marseille France
a brief history of hydreliox diving

It was hoped that hydrogen would help alleviate the physiological effects of deep diving – including:

• High pressure nervous syndrome (HPNS)
• Respiratory comfort / work of breathing
• Diver cognitive & physical capabilities
• Sleep patterns & appetite
a brief history of hydreliox diving

Deep diving trials using Heliox concluded that there were real depth limits to this technique.

Comex Sagittaire – 1974
(610MSW - 50 hours bottom time)
a brief history of hydrelloix diving

Gas density effects, thermal balance, insomnia, communications issues, psychological issues and HPNS

National Hyperbaric Centre
Aurora ’93 trials 1993 (450 / 470MSW for 33 days)
a brief history of hydreliox diving

Trials with nitrogen as an ‘additive’ to the breathing mix to alleviate the ‘anxiety’ at 150m

Comex Janus IV - Phase B (1977 - 501MSW in water)
a brief history of hydreliox diving

Comex demonstrated Ultra-deep diving both in chamber and in the water using HeN$_2$O$_2$ but significant challenges were present.

In 1981 Duke University (USA) conducted trials using HeN$_2$O$_2$ to 686MSW in the chamber where divers experienced difficulty and suffered trembling and memory lapses.
a brief history of hydreliox diving

HYDRA experimental chamber dives led to open water dives to 534MSW from Orelia in 1988 (HYDRA 8)
a brief history of hydreliox diving

Orelia was not designed for Hydreliox – so had to be adapted to support operations using hydrogen:

- Chamber room purged with nitrogen
- Tenders used closed circuit re-breathers
- Bell umbilical stored on deck
- $\text{H}_2$ gas storage & gas handling on deck
a brief history of hydreliox diving

HYDRA 10 – deepest chamber dive to 701MSW - 1992

Théo Mavrostomos
World record holder
a brief history of hydreliox diving

HYDRA 10 – dive profile (42 days)

- Normal blowdown to 200m on HeO$_2$
- Continue blowdown to 400m adding only H$_2$
- Return to HeO$_2$ for 400m to 700m
- Linear bleed to 420m
- Remove H$_2$ to reduce depth to 280m
- Normal deco to surface
a brief history of hydreliox diving

Comex developed new equipment and techniques:

- Hydrogen removal unit (‘de-hydrogenator’)
- Laboratory instrumentation and monitoring
- Closed-circuit rebreather for diver’s bail-out
- Mass-spectrometer & GC based gas analysis
- Advanced medical / clinical monitoring of divers
a brief history of hydreliox diving

Hydra 12 investigated ‘Helium IN – Hydrogen OUT’

• Chamber & Bell atmosphere was conventional HeO₂
• Divers’ lock-out gas was Hydreliox – to avoid hydrogen in the chambers
• Issues experienced with vestibular bends due to high gas-gradients during transition IN – OUT – IN even at 210m

• Technique proved successful apart from gas gradient issues
• Similar diver performance to previous Hydreliox trials
Benefits to the diver – Hydreliox vs Heliox

HYDRA results showed significant benefits of Hydreliox:

• Improved cognitive abilities of divers
• Ventilatory comfort (less breathing effort & stress)
• Physical comfort (absence of joint & muscular pain)
• Absence of significant clinical & para-clinical disorders, including HPNS, anxiety & narcosis
• Improved sleep patterns & appetite
Benefits to the diver – Hydreliox vs Heliox

Other important considerations identified:

- Careful selection & training of divers is required (physical & psychological)
- Importance of comfort, ergonomics and environment in chambers
- Optimised compression & decompression profiles developed
- Maximum ppH₂ = 20 bars
- HPNS & narcosis monitoring of divers required
- Importance of decompression monitoring
- General medical clinical and para-clinical monitoring (before, during and after hyperbaric exposure)
- Hydrogen not flammable below 4% O₂
Obstacles to commercialisation of Hydreliox

Why has Hydreliox not been commercialised?

• Flammability / explosive nature of hydrogen
  – If hydrogen was not flammable, it would be the diving gas of choice and Comex would have further developed Hydreliox rather than He in H out.

• Much of the commercial saturation diving carried out today is shallower than 180MSW

• Deeper diving operations are feasible on Heliox to 350m+ with increasing difficulty and reduced diver capability with depth

• Commercial drivers have not existed to develop the technology

• ROV and remote intervention techniques have improved
Hydrogen acceptance & use in current times

Hydrogen is becoming more readily accepted due to:

• Its use as a green fuel for cars

Hydrogen stored at 350 bars
Hydrogen acceptance & use in current times

Hydrogen is becoming more readily accepted due to:

• Its use as a green fuel for buses

H₂ Stored at 700 bars
Hydrogen acceptance & use in current times

Hydrogen is becoming more readily accepted due to:

- Consumer safety through system design

350 bar $\text{H}_2$ refuelling
Hydrogen acceptance & use in current times

Hydrogen vehicles (FCEV) will increase

Scandinavian H₂ refuelling station
Hydrogen acceptance & use in current times

Fuel Cell technology has advanced significantly

Automotive fuel-cell stack
Hydrogen acceptance & use in current times

Hydrogen production from electrolysers

Alkali liquid electrolyser

PEM electrolyser
Hydrogen acceptance & use in current times

Hydrogen compressors

3-stage diaphragm compressor
(950 bar output)

Ionic liquid compressor
Hydrogen acceptance & use in current times

Hydrogen in marine environments

• Norway leading the way with Hydrogen fuelled vessels
• September 2017 – Viking Cruises announce first H₂ powered cruise ship
• Significant experience within DNV-GL and LR Norway for H₂ systems
• Erna Solberg is promoting hydrogen research for maritime & automotive uses
Technology enhancements in commercial diving

Fully automated diving systems (since 2009):

• Deep Arctic (Divex HMCS)
• Seven Atlantic (Divex HMCS)
• Seven Falcon (Drager)
• Deep Explorer (JFD HMCS)
• Seven Kestrel (Drass ISAT)

Safety PLC systems comply with IEC61508

The Bergen International Diving Seminar 2017
Technology enhancements in commercial diving

PLC / SCADA control of chamber parameters
Gas-free control rooms

Chamber control room
Dive control room
Technology enhancements in commercial diving

Remotely controlled / automated gas distribution & control to chambers & SDCs
Technology enhancements in commercial diving

Improved chamber ergonomics & diver comfort

- Private sleeping compartments
- Mood lighting
- In-chamber entertainment systems
- Improved diver voice communications
- Private telephone calls from divers to shore
- Internet & email access
Technology enhancements in commercial diving

Improved diver monitoring & instrumentation

- IMCA & NORSOK diver exposure monitoring
- High accuracy environmental sensors
- Medical monitoring
Technology enhancements in commercial diving

Recent developments in diver bail-out systems
Justification for using Hydreliox?

The Ethical view...

Why do we need to dive deeper than 180MSW?

• In some regions this is uncommon (UKCS, Norway)
• In other areas diving is regularly carried out to 300MSW
• There are situations where unplanned deeper intervention would be beneficial

Is diving >180MSW safe enough with impaired diver capabilities and increased stress using current methods?

• Is there a justification based on more cognitively capable divers being able to operate more safely in normal and emergency situations?
Justification for using Hydreliox?

The Medical view...

Assuming we are to dive deeper than 180MSW...

- Research has shown improvements to diver comfort
- More cognitively capable divers will be able to deal with emergency situations better
- Absence of or reduced HPNS and anxiety
- Improved sleep patterns and appetite are beneficial

Hydreliox diving is suitable for depths as shallow as 200m with the above advantages
Justification for using Hydreliox?

The Commercial view...

Could we use MUO to develop deeper fields more effectively?

• Current field development deeper than ~200m is normally diverless
• If this could be extended safely the economic benefits of diver-based construction compared to diverless are significant (imagine the cost comparison for BP Quad 204)

Fields could have diver installed permanent works with remote intervention for maintenance.

Unplanned interventions could be carried out where remote technology can’t be used.
Justification for using Hydreliox?

The Environmental view...

There are diver intervention activities that could avoid environmentally risky diverless interventions.

Consider a production tree in 450m with a failed valve actuator:

• Diverless options are to override the actuator (reducing safety) temporarily then to swap out the tree using a rig – with all the environmental risks.

• Diver intervention options would include actuator replacement on the existing tree (not an operation that could be performed by ROV).
Safety & risk concerns and mitigation

Any of the previous possible justifications can only be considered if the use of Hydreliox is proven to be safe:

• Hydrogen is flammable and explosive when mixed with oxygen at $O_2$ concentrations >4%
• In-chamber $O_2$ concentrations are less than the 4% LFL
• Greatest risk exists outside the chamber complex where $O_2$ concentration is ~21%
• Hydrogen escapes will dissipate quickly upwards – and this can reduce the risk of accumulation (provided that no high spaces can trap the rising gas)
• Hydrogen requires less ignition energy than most other flammable gases
Safety & risk concerns and mitigation

A diving system and vessel that uses Hydreliox would need to be designed and Classed for hydrogen use:

• All hydrogen production, preparation and storage on open ventilated decks
• Chamber rooms would be zoned accordingly with minimum electrical equipment
• Chamber room and pipework designed to promote rapid ventilation and vertical conduit of any leakage
• Automated safety systems & shutdown systems
• Advanced gas leak and flame detection
Safety & risk concerns and mitigation

• Hydrogen storage onboard would be minimised, and hydrogen could be produced onboard to meet operational requirements to avoid HP gas transfer from shore.

A single 20’ containerised electrolyser could produce all the H₂ needed for a 24-man system in less than 48 hours from a 350kW supply.

Typical production rate of 60Nm³/hr with 2,300m³ required (plus top-up).
Safety & risk concerns and mitigation

• Zoned vessels and installations are commonplace and a well understood engineering process.

Electrical equipment for use in Zone 1 & Zone 2. ATEX, IECEx
Thoughts for the Future...

• Is there an agenda to consider deep diving using Hydreliox?
• How does our Industry perceive the current Heliox deep diving risks and methods? Is it safe? Are methods acceptable?
• Do the advances in hydrogen technology give opportunities that were previously impractical?
• Could we design and build a DSV and diving system that could support Hydreliox as a routine activity?
• If we could demonstrate that a safe Hydreliox system could be built, why would we not consider this for the future of deep diving?
Hyperbaric Normalisation

Is Heliox

The future of deep diving?

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