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Gas Reclaim in Saturation Diving

Environmental factors: What do we know - what do we not know?

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REPORT

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Gas reclaim in saturation diving - Environmental factors: What do we know - what do we not know?

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ABSTRACT

This report is a summary from a working-meeting on gas reclaim systems for saturation diving. The meeting, which was part of the OMEGA-programme 1994, was held in Trondheim, Norway, December 1994. The meeting "collected" participants both from users (diving industry), producers and researchers connected to operational saturation diving.

The meeting covered two main areas: a) divers gas reclaim and b) chamber gas reclaim. Regarding diver gas reclaim, also details regarding personal equipment were discussed.

To our knowledge, there are only a limited number of studies performed from such systems in operational use. A number of questions were raised about both design and function of gas reclaim systems. Ingression of seawater was experienced as a common problem area for both the chamber gas reclaim (gas bag) and the divers gas reclaim, and was verified both from producers and users of the systems. The participants were asked to suggest three items, which they think should be of priority for further work. From this priority list, two items: "Filters" and "Gas Contamination" rendered the far most marks. Increased interest was shown also for "Humidity in inspired gas" and "Gas Composition".

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Health	Helse
GROUP 2	Microbiology	Mikrobiologi
SELECTED BY AUTHOR(S)	Diving	Dykking
	Breathing gas	Pustegass
	Contamination	Forurensing

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1 INTRODUCTION

A working meeting - "GAS RECLAIM SYSTEMS FOR SATURATION DIVING" was arranged in Trondheim, Norway, 15th-16th of December 1994. The agenda for the meeting and the participants are presented in enclosure 1. Responsible for the meeting was SINTEF UNIMED/w. C. Ahlén.

Participant list:

Diver:	Askil Moe
Diving Contractors:	Stolt Comex Seaway: Yngve Bergflødt and dive tech's: Odd Tveit and Trond Henriksen Rockwater: dive tech/LSS Tony Webster Stena Offshore - Steve Sheppard
System producers:	Gas Services: James Bruce Ottestad Breathing System : Nils Ottestad
Oil companies:	Statoil: Einar Svendsen, Rigmor Reigstad and Karin Lerflaten Norsk Hydro: Cato Hordnes
Research companies:	NUTEC: Kåre Segadal and Rune Djurhuus SINTEF: Catrine Ahlén

Invited to the meeting but not attending were Norwegian Petroleum Directorate, Saga Petroleum, Dræger, Mara Engineering, Ultrafilter and the health management of the diving contractors.

The meeting was opened by section leader Arvid Påsche, who gave a presentation of SINTEF and SINTEF UNIMED. Thereafter, a presentation of the background and aim of this working meeting, as well as presentation of the participants was done by C Ahlén. The participants were representatives from users (diving companies), producers (Gas services), oil companies and researchers.

The meeting was held in accordance to the agenda (Enclosure 1). Each section of the meeting was summarized throughout the meeting, and these summaries, together with a mini-questionaire regarding suggested fields for future work, was sent to all participants as "Minutes of meeting". The results from the questionaire are presented, and proposals for future work will be based on these informations.

2 BACKGROUND

Microbiology of operational saturation diving systems in use in the North Sea have been systematically investigated within the research programmes FUDT (Programme for R&D in Diving Technology) and OMEGA financed by the Norwegian oil and gas industry (Statoil, Norsk Hydro and Saga Petroleum) and the Norwegian Petroleum Directorate, (NPD). The main focus of these investigations have been the frequent skin infections in divers, and especially the severe ear infections of the outer ear. The main aim of the studies have been to get the necessary knowledge of sources and spreading of the main infection-causing microbe - *Pseudomonas aeruginosa* - and thereby be able to prevent or minimize the infections (1). From this work, improvements and optimalization of procedures and products for cleaning/and disinfection have been possible (2). As a result from using the improved procedures, a number of additional spreading manners of the particular infection microbe have been possible to demonstrate, and thereby possible to eliminate/ minimize. The main part of the hygiene work has been related to saturation living chambers and to personal equipment used during work (i.e oralnasals and neckdams).

Beside water, gas is one of the major areas when discussing saturation diving. When discussing gas for breathing during saturation, its appropriate to divide between gas for use in the living chambers and gas for use in the bell and during work out in the water. While all gas earlier was bought in flasks from gas companies, today most gas used in saturation diving is reclaimed on board the vessel. For divers breathing gas during work, the main part of diving vessels in the North Sea and around the world reclaim this gas. This has been considered necessary both of economical reasons, but also from safety when operations have to be performed in areas far out in the seas.

Different types of biological, microbiological and chemical contaminants will be present in gas which have been used as breathing gas. In addition to the normal exhaust components (e.g. CO_2), also other organic and microbial contaminants will be added from the diver. In additon, components from materials and parts of the flow lines will possibly occur.

What do we know about the quality of gas when reclaimed on board diving vessels? To our knowledge, only a very limited number of studies have been undertaken from operational environments. In the FUDT and OMEGA programmes, a number of studies on organic/chemical contamination have been made by NUTEC (3,4,5,6), and microbiological studies have been made by SINTEF (7,8).

In order to get a better understanding of what we know, and what we don't know, a working meeting involving both users and producers of the systems for gas reclaim, was initiated.
The working meeting on reclaimed divers gas included both breathing gas during work as well as chamber gas. Regarding divers breathing gas, also reclaim details of divers personal equipment were included. This report presents the status of knowledge about divers gas reclaim systems, as used in operational saturation diving.

In the text, comments added from questions are writen in *italics*.

3 SECTIONS & SUBJECTS FOR THE WORKING MEETING

The meeting was parted into to main sections, and a subsection:

Section 1: Reprocessing unit for divers breathing gas - CCBS, and
Section 2: Reprocessing unit for chamber gas
Section 1a: Reclaim details with helmets, bell, umbilical .

The presentations and discussions within each of the sections will be reported separately.

3.1 Reprocessing unit - CCBS - for divers breathing gas

3.1.1 System description

The most frequent used gas reclaim system on diving vessels operating on the North Sea is a system produced by Gas Services. The system, named Gas Mizer, was thoroughly described by J Bruce, representing the producer of the system.

The purpose of the Gas Mizer System is to purify and recompose the breathing gas to a correct diver gas quality. There are more than one hundred Gas Mizer systems installed on diving vessels around the world today. The systems have been developed mainly due to high expence of gas, but also because gas not always is available in all parts of the world where saturation diving is undertaken.

In figure 1, a schematic picture of the gas reclaim system - Gas Mizer - is shown.

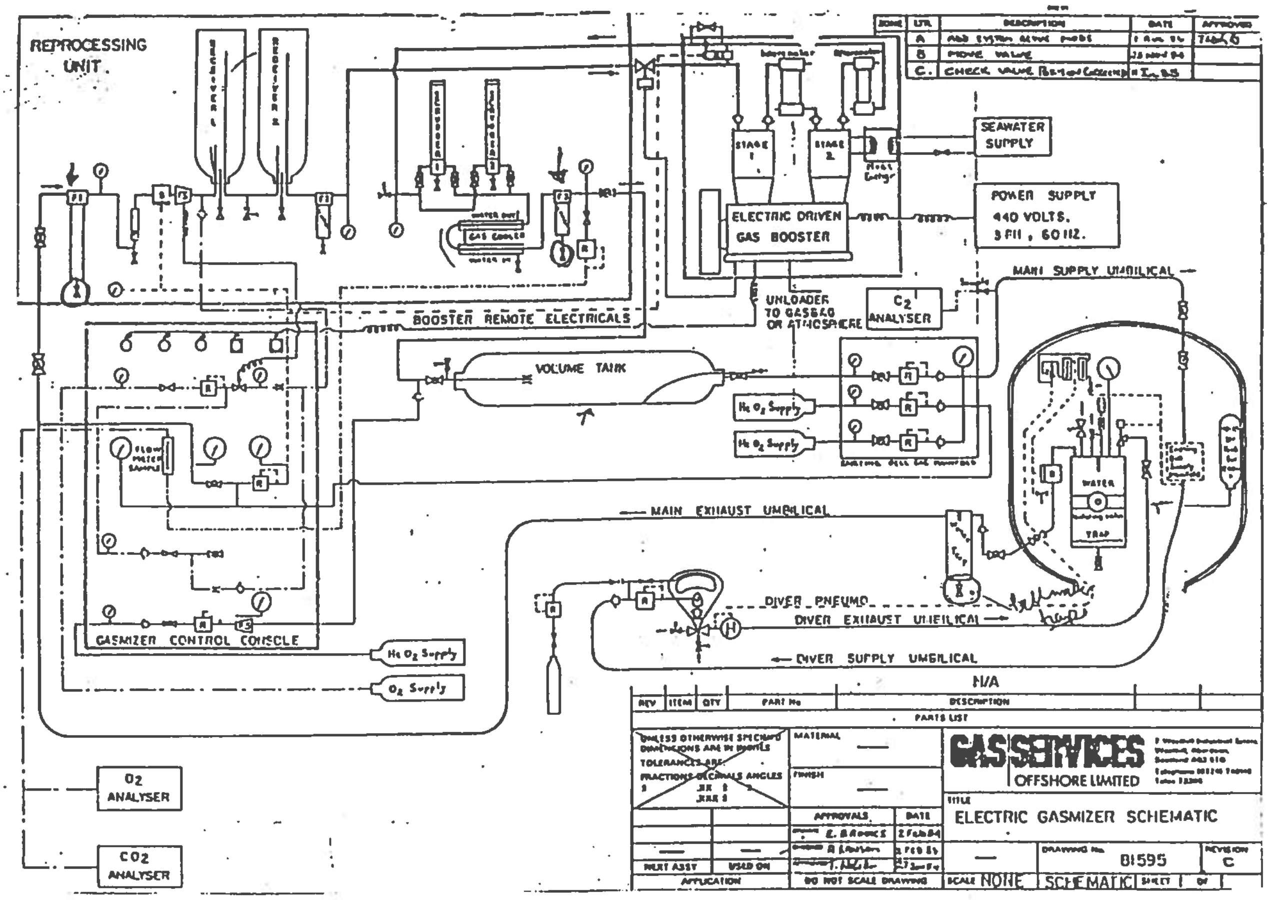

Figure 1 Schematic picture of the gas reclaim system - Gas Mizer

3.1.1.1 Specific information about main details in Gas Mizer

Water traps are installed both for elimination of seawater ingress and of exhaust vapor.

Despite water traps, seawater ingression into the reclaim system occurs. Among possible causes to this, leakage in neckseals, loose fittings, water into helmets and water in umbilicals was discussed.

Filter 1 - a moisture coalescing filter both for liquid and solid particles down to 1 micron.

Receivers in which oxygen is added while there still is low pressure in the system. In the receiver, the gas condensate in bottom, and the gas is let out at the top.

Filter 2 - a moisture coalescing filter both for liquid and solid particles down to 0.01 micron. The main objective of this filter is to eliminate all liquids, which is of main importance to avoid corrosion in the gas compressor. In addition, this filter will eliminate all particles but viruses and gas molecules. *The gas is as dry as is possible to get at low pressures - (still water vapor in the gas).*

Gas booster operates at temperatures between below 100°C to max. 150-200°C. *The time used for the compression is very short, (msec), but the gas often passes during several cycles. The reason for the very tall units of the compressor, this is due to avoiding compressor oil ingress into the gas.*

Scrubber is installed mainly to eliminate CO_2, and contains sodalime/purafil. Water vapor is produced - a scrubber works at its maximum in humid, pressurized warm gas. There is a need to remove the dust. The efficiency is highly related to depth, quality of sodalime, storage as well as on divers breathing frequences. The scrubbers need regular and frequent replacement.

The manufacturer is for the time being not recommending scrubber catalyst for CO.

Cooling is made by use of seawater. *No physical contact between seawater and gas.*

Filter 3 is the final moisture coalescing filter in the actual reclaim system, and is an equal filter to filter 1. From this filter station, often a cupfull of condensate water can be taken out. In additon to water, also scrubber dust will be eliminated at this point. *No other salts or seawater at this point.*

Storage of reclaimed gas is done in a pressurized steel chamber, called the volume tank. In this tank, any remaining moisture is collected. Volume tanks have been shown to possibly contain a lot of water, due to incorrect installation of the depth tubes.

3.1.2 Contaminants in divers gas

3.1.2.1 Chemical and Organic contamination

Chemical and organic analyses of gas from gas systems on board diving vessels have been performed by NUTEC, as a part of the FUDT-programme. Rune Djurhuus gave a presentation of some of the results found from these studies, which included studies of both the divers breathing gas (bell and volume tank) and gas from the living chambers. The studies demonstrated presence of a broad range of organic compounds (e.g. solvents, aromatic/alifatic hydrocarbons, clorofluorcarbons). The main conclusions from these studies were:

a) The diving bell seem to be the most contaminated part of the diving system

b) No correlation was seen between the total amount of contaminants in the atmosphere and the total pressure

c) The total amount of contamination seem to increase with increasing time under pressure

d) None of the investigated contaminants were in the study shown to exceed the threshold limits for continous exposure. Some were though between 25% and 65% of their own limits.

More details about these specific studies can be obtained from NUTEC reports (3), and from EUBS Newsletter (4).

Regarding the possible sources of organic contaminants in divers gas, the gas supply (new gas), the divers themselves and materials were discussed. NUTEC has developed a general procedure for test of chemical off-gassing from materials, including a specific testing procedure for gas hoses at conditions relevant to saturation diving.

Regular monitoring of contaminants in divers breathing gas and standardisation of procedures for sampling and analyses were discussed.

3.1.2.2 Microbiological contamination

Microbial contamination in gas reclaim systems during operational use was investigated in OMEGA-1994. To our knowledge, no systematic studies of microbial contamination in divers breathing gas had been performed, and from some spot investigations of reclaim systems earlier, the gas cleaning efficiency was queried. The field studies included only the reclaim part of the system, i.e. not the gas delivered to the diver. The latter will not only depend on the reclaim system but also on umbilical and helmet details in the gas flow line. The studies focused on viable bacteria, fungi, virus-like particles and mycoplasma, and were made by frequent and regular sampling of water from various parts of the reclaim system; i.e. water traps, filters and volume tanks. The studies were done on several vessels situated on different oil fields in the North Sea. The main conclusions from these studies were:

a) Viable microbes - mainly Gram-negative rods - were found from all parts of the reclaim system sampled.

b) The microbial flora in the reclaim system varied from one field to another, and variations from one bell to another was demonstrated.

c) The Gram-negative rods mainly originated from the seawater outside, which was sampled in parallell.

d) The health aspect from the demonstrated microbes in breathing gas is difficult to evaluate - no threshold limits for microbes have been established.

e) Ingress of seawater - seawater possible to pass through the whole system?

f) As cleaning of the gas is the main purpose of the gas reclaim systems, the results put questions to the function of such systems in operational use.

Efforts to minimize the seawater ingress into the systems seem to be of most importance.

Concerning filters, most of the Gram-negatives have a diameter of about 0.5 micron, and will therefore pass the 1 micron filters F1 and F3. Filter F2 should stop all bacteria and fungi. From earlier studies, this filter had shown nearly always to be dry, although viable microbes were seen further on the line; i.e. at F3. F2 was not actualized as a sampling point in the lfield study in 1994.

In addition to the primary results for evaluating the quality of breathing gas, also additional spreading means of the known hazard for divers ear infections - *Pseudomonas aeruginosa* was demonstrated (internal water trap in bell).

3.1.3 Dive techs experience from gas reclaim systems

By the time for this section, only Rockwater was represented with a dive technician - Tony Webster. Among the problems arizing from handling gas reclaim systems, the following problems were most often experienced:

a) The system is not reclaiming:	- back pressure set too high - umbilical blocked with water - make-up system by-passed - solid soda lime blocking scrubber - prime mover malfunction
b) Collapsed main umbilical:	- too great of a suction - not initially pressurized umbilical
c) Seawater ingress:	- inward relief valves passing - flood valve passing due to gritting - leaking through neck-dams - loose umbilical connection - water trap not being emptied
d) Gas loss:	- leaking neck-dams - leaking overpressure valve - loose fittings or pipework - tracking pneumo open too much

In addition, a number of areas were menthioned, such as too high/too low oxygen levels, collapsed filters and improper position of filters, too high/too low close up pressure, high CO_2 levels etc.

3.2 Section 1a: Reclaim details with helmets, bell and umbilicals

To reclaim the exhaled gas from the diver, a special valve - helinaut - is to be installed on the helmet. This helinaut valve is part of the gas reclaim system from Gas Services, and the equipment was presented by James Bruce. A new type of helinaut valves are produced by this time - named Jewel. While the old types raised problems of seawater ingress, the new valves render a positive helmet thus eliminating seawater ingress. For the time being, the main part of the reclaim systems still have the old type of helinauts in use.

Seawater ingress will still be a possible result upon leakage in neckseals, loose fittings, water into helmets and water in umbilicals (ref. section 1).

The new-developed UBA 90-400 system from Ottestad Breathing Systems was presented by the producer Nils Ottestad. This system have a demand regulator with very low work of breathing and inlet and outlet valves are operated by the same membrane. The system fits well into the gas reclaim systems in use (i.e. Gas Mizer). This system is specially designed to deliver humidified and preheated breathing gas. Humidity in breathing gas has been found to be important for the divers comfort and lungfunction (9).

Divers experience with reclaim details was presented by Askil Moe. He could verify, that a main problem with gas reclaim was the seawater ingress. He also could verify most of the causes to seawater ingress earlier menthioned, but in addition, he put a question on the fact that every now and then no explanation of the seawater ingress could be determined. The real humidity levels of gas was discussed again, and no measurement of humidity of breathing gas during operational diving was known. Discussed were as well the infection hazards from using common breathing equipment.

3.3 Highlights from section 1 and section 1a - Diver gas reclaim

3.3.1 System function

The following areas of the function of the system were highlighted

- Filter function in such systems
- Seawater ingress
- Presence of seawater in various parts of the system

(Presence/function of filter F2 with specific reference to microbiology)

3.3.2 Relevant contaminants

The following areas were highlighted from a contamination point:

- Chemicals (organic compounds, CO)
- Viable microbes (Gram-negatives, seawater flora incl. *P. aeruginosa*)

3.3.3 Sources of contamination

- Divers exhaust
- Seawater
- Material off-gassing (i.e. material off-gassing, biofilm, hot water temperature)
- Bell scrubbering
- Compressor function

3.3.4 Contaminants to be evaluated with respect to clinical importance

- Carbon monoxide (CO)
- Organic compounds
- Microbes

As for all contaminants, as well as for the possible effects of the contaminants, the levels of temperature and humidity will be of importance.

3.4 Section 2: Reprocessing units for chamber gas

3.4.1 System description

Gas reclaim systems for chamber gas are not as frequent in use as are reclaim systems for divers breathing gas. Anyway, there are a lot of systems in operational use, among them "Gaspure", "Helipure"; Kinergetics "Molecular sieve - Pressure Swing Helium reclaimer" and membrane separation systems. As for the Gas Mizer, the main purpose of these systems are to purify and recompose the gas atmosphere in the chamber systems.

The presentation of the chamber gas reclaim systems was done by James Bruce, Gas Services. Although the company previously not worked with chamber reclaim in particular, today the company is the owner also of such systems, and therefore have a good knowledge about them.

In Figure 2, schematic pictures of chamber gas recovery systems are shown.

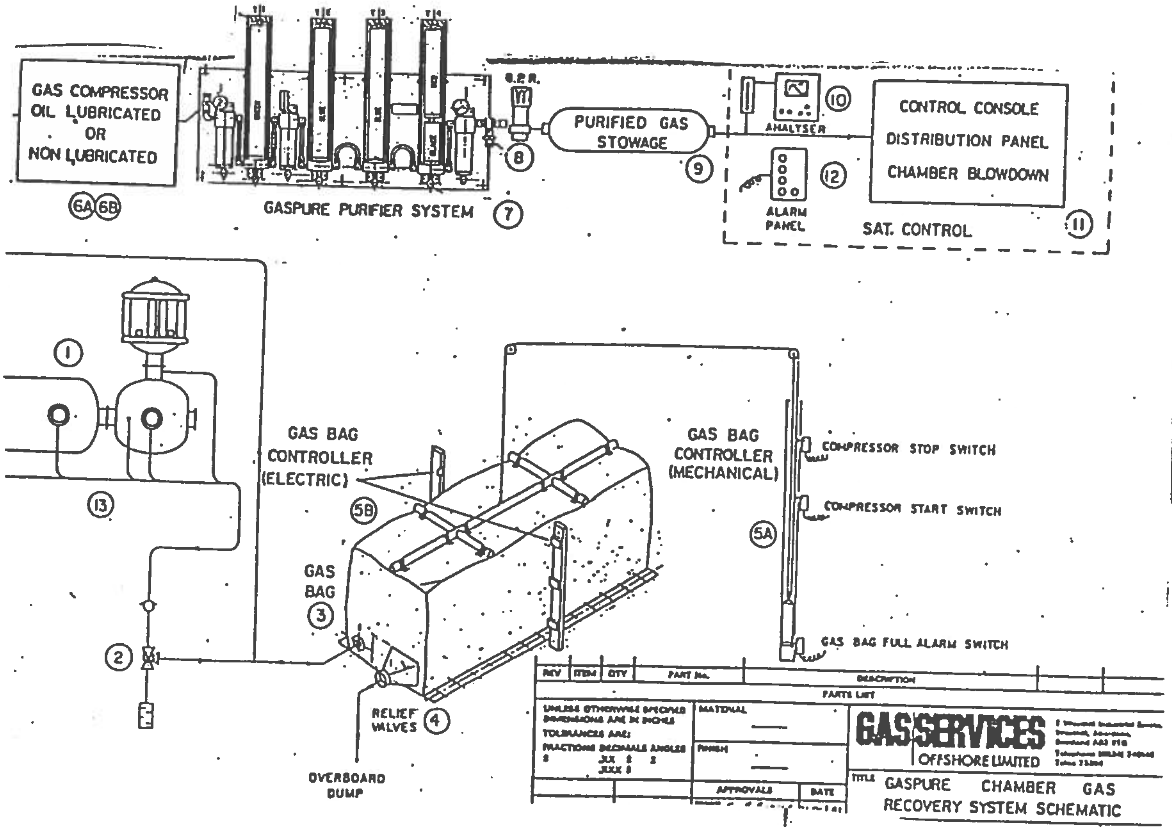

Figure 2 Schematic picture of chamber gas recovery systems - "Gaspure".

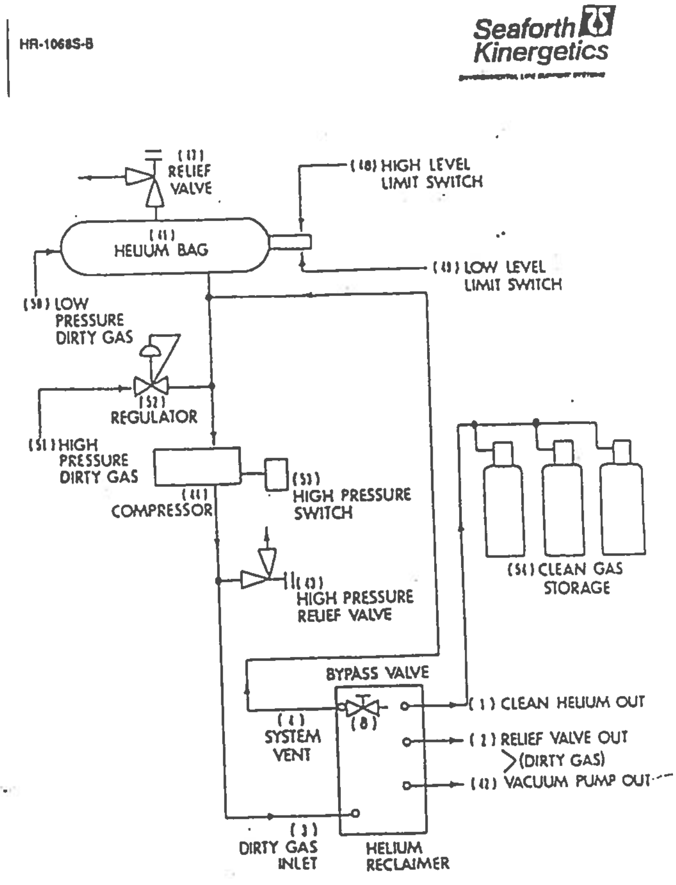

Figure 3 Schematic picture of helium recovery system

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3.4.1.1 Specific information about main details in chamber gas recovery

Gas bag is a big storage bag in which the used chamber gas is stored prior to compression. In additon to chamber gas, also gas from the bell is added. *A main problem in use of gas bags is the seawater ingress. In addition, the wet gas from chambers and oil vapour were other problem areas. Installation of a water trap prior to the gas bag was proposed.*

Compressors in chamber gas recovery systems work at very high pressure and temperatures. This might lead to less problems with certain contaminants (i.e. microbes) compared to the Gas Mizer systems. There are filters installed for oil removal.

Chemical beds are installed in series of four:

- No 1 for removal of carbon dioxide (CO_2).
- No 2&3 have the main function of drying, but also for removal of H2S, mercaptan/methan
- No 4 is parted into two: a) purafil/sofnocat - removal of organic contaminants
  b) platinum based cathalyst - CO

Filters have much in common with the filters earlier described in Gas Mizer:

- Prefilter : Moisture coalescing filter of 1 micron
- Moisture coalescing filter 0.01 micron for water and oil vapor.

Regarding filters, the basic function may be different in the two type of systems; Gas Mizer with low pressure and Gas Pure with high pressure.

When concerning specific recovery of certain gas components, the Helium reclaim system "Pressure Swing Helium Reclaimer" is very efficient. Newer methods for recovery of helium includes the membrane systems. Due to the high sensitivity to water vapor, these systems may not be easy to use in saturation diving. The sensitivity to water vapor renders absorption of water before adsorbtion of nitrogen and oxygen.

In contrast to reclaimed gas from CCBS, which only is re-used as divers breathing gas, gas recovered from chambers may have several areas of usage. The main part is re-used as chamber gas, but some of the gas is used as "top up for reclaim gas", by putting it into the volume tank on divers gas supply (ref. section 1). In addition, this gas may be used for pressurizing the water to showers.

3.4.2 Environmental control - Chemical/physical

3.4.2.1 Oxygen and Nitrogen

The oxygen levels in chamber gas was discussed by Kåre Segadal, NUTEC. The possible health effects connected to oxygen were long term effects on lungs and CNS. The partial pressure of oxygen will generally be increased during all types of diving as compared to normal levels. The levels will vary depending on activity. In saturation diving, the partial pressure of oxygen can reach 70 kPa. He proposed better control of the true oxygen levels in saturation; especially during decompression, when reduced PO_2 during night stops could be an advantage, and suggested catalytic control of oxygen. Different procedures for decomression were discussed as well.

Nitrogen is not specifically removed from chamber gas upon recovery. The true nitrogen levels are not controlled (ref.section 1). Any nitrogen could be of disadvantage during saturation decompression.

3.4.2.2 Organo-chemical contaminants and Toxicology

Studies within this field were referred in Pnt. 3.1.2.1. where both chamber gas and divers breathing gas were included. The chamber gas was from these studies shown to be less contaminated compared to gas from the bell, but more contaminated compared to gas from volume tank.

Acceptable concentration levels are difficult to stipulate for saturation systems. Carbon monoxide (CO) was close to and sometimes above the 1 atmosphere threshold limit.

At present, NUTEC is developing systems for hyperbaric testing of toxicological reactions, caused by organic compounds on living cells.

For the future, suggestions for toxicological control of materials to be used in saturation systems were made. In addition, a standard method for regular monitoring offshore of chamber atmosphere with respect to known hazards have been developed.

3.4.2.3 Microbiology

Saturation systems are habitats for enormous amounts of microbes of many different types. The main part of the microbes are Gram-negative rods, which proliferate in humid climates, but die immediately upon drying. A potensial source to this flora is seawater.

Microbial contamination in the gas atmosphere in living chambers have been investigated throughout saturation periodes (FUDT 1993). The studies showed an increase in numbers of viable Gram-negative rods in the atmosphere in TUP's upon bell trunking, infrequently also inhabiting

Pseudomonas aeruginosa. A clear connection between contaminated fresh water and amounts of Gram-negatives in the atmosphere was as well demonstrated.
A number of spot investigations have been made from the LSS-units for living chambers over the years. These investigations have, without exception, showed viable microbes, also Gram-negative rods including *P. aeruginosa.*

Regarding the gas recovery systems for chambers, no systematic studies on microbiology have been done to our knowledge. Spot investigations from the inside of the gas bags have shown pure cultures of *Pseudomonas aeruginosa.* Survival of the Gram-negatives from the high-temperature - and high-pressure compressors in these systems is hardly probable. *P. aeruginosa* and other Gram-negatives are therefore less likely to accumulate in chamber gas reclaim compared to reclaim of divers breathing gas (Gas Mizer). But, also here, filter systems will play a central role in elimination; both of viable, but also of dead microbes, which antigenically can cause as much trouble as the viable microbe.

3.4.3 Dive technicians experience from chamber gas recovery

The following problem areas were experienced by the dive technicians:

- Seawater in gas bag
- Oil in gas bag
- Unloaded pipe to gas bag
- Gas bag overfilling
- Gas analyses failure
- Filters not changed or filters fitted in incorrect sequence
- High CO-levels

3.5 Highlights from section 2: Chamber gas recovery

3.5.1 System function

Gas bag - Main problems were seawater and oil ingress into the bag. Possible methods for elimination to be evaluated.

Filters - Different function of filters in high-pressure and low-pressure systems?
- Are the filters in use optimal and relevant regarding filter pore sizes?

3.5.2 Environmental control

The following areas were highlighted for environmental control:

Nitrogen/Oxygen	-	Establish procedures for reducing pPO_2, N_2, CO and others
	-	Regular gas analyses (especially CO, N_2)
Organic/chemical	-	Selection and testing of materials - off gassing
	-	LSS-units
	-	regular gas analyses
Microbiology	-	Microbes in gas flow - determination of viable microbes in gas when supplied into chambers
	-	LSS-units
In common	-	Establish standards for gas quality; Dust problems?

4 FURTHER WORK - ITEMS TO LOOK INTO

A list of relevant items, brought forward from the meeting/discussions, were prepared. The participants were asked to chose three items, which they thought should be given priority in future work. Answers were obtained from most of the participants, and the results from this mini-questionnaire are shown below:

Preferential (number of)		ITEMS	
7	❐	FILTERS	
-	❐	SCRUBBERS	
3	❐	GAS COMPOSITION	N2, O2, He
7	❐	GAS CONTAMINATION	- organic (e.g. aromatics, solvents) - chemical (e.g. CO) - microbiological (e.g. P. aeruginosa)
2	❐	LSS UNITS	
2	❐	GAS QUALITY MONITORING	
2	❐	RECLAIM - WATER INGRESS IN HELMETS/SYSTEMS	
3	❐	HUMIDITY - INSPIRED GAS	
2	❐	MATERIAL EVALUATION	
-	❐	RECLAIM GAS STORAGE	
-	❐	BELL SCRUBBERING	
2	❐	APPLICATION AREAS FOR RECLAIMED GAS	

"Filters" was the item chosen by most of the participants from the meeting. Also gas contamination was an item chosen more than others. "Gas composition" and "Humidity -Inspired gas" also got some more marks compared to the rest. A common comment was that both gas composition and gas quality monitoring could be included under gas contamination.

Based on this information, proposals for further work will be prepared.

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