STUDIES ON SATURATION DIVING IN POLAND AND PRACTICAL APPLICATION OF THEIR FINDINGS. PART 5. COMMERCIAL SATURATION DIVING BETWEEN 2007 AND 2011

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ABSTRACT

This part of the series of papers presents the use of the diving complex after modernisation, diving operations in 2007 and 2010–2011, training for saturation divers organised outside the Naval Academy, and the first saturation dives carried out exclusively by a team of Polish divers and technical staff.
Keywords: saturation diving, diving system, breathing mixtures, operating parameters, training for saturation divers, Polish team.

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Note: In this article, we do not provide the professional and academic degrees and titles or military ranks of the persons mentioned in the publication, because not only were they irrelevant for achieving the set goal, but they also changed over the described period.

SATURATION DIVING BETWEEN 2007 AND 2011

DIVES IN 2007

Over the period 2007-2011 underwater works in which saturation diving was deployed were carried out from the Petrobaltic platforms. These works were managed and supervised by divers and experts from the Italian company RANA assisted by the technical staff from the Department of Diving Equipment and Technology of Underwater Works of the Polish Naval Academy (Polish abbr. ZSNiTPP AMW), with medical and organisational support provided by the same unit.

Selected parameters of these dives and their courses are included in Tables 2,3,4,5,6,7 while decompression episode is described in Fig. 1.

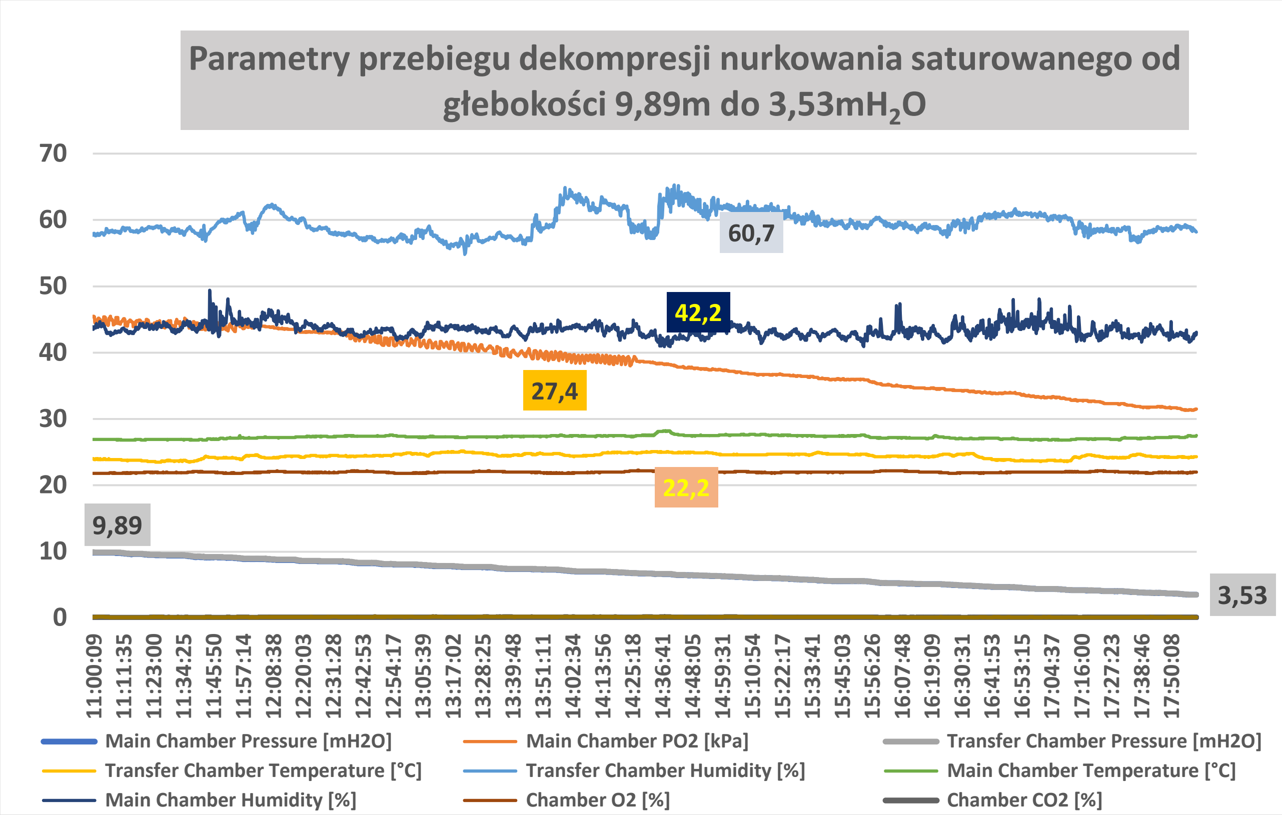

Fig. 1 Example of recording parameters for the selected 8 hours period of the final decompression phase.

The same team that played a crucial role in modernising the diving complex in 2005–2006 took part in the saturation dives organised by the ZSNiTPP Department in 2007. This allowed for the refinement of elements requiring modernisation and the addition of electric heating tapes to the heating points of the installation and elements of the diving system in real winter conditions. The team's technicians gained experience in working with rented cylinder bundles from a gas storage facility with a working pressure of 300 bar. Gas distribution during operation consisted of dividing the cylinder bundles into supply sections in order to maintain the highest possible pressure in them. This eliminated the need for a transfer pump to charge diving cylinders with a working pressure of 200 bar. The main supply of breathing mixtures to the manoeuvring centre consisted in reducing the pressure from 300 bar to 120-150 bar as the supply pressure for medium pressure regulators of 2.5-3 MPa in the manoeuvring centre.

Saturation dives in winter conditions triggered higher consumption of electricity needed to heat the lines and equipment to prevent them from freezing but also to heat spaces for the servicing staff and the team of the stand-by diver. When temperatures dropped below zero, the flow of heating water to the bell was regulated to avoid freezing, especially in the pressure passage and in the cable and hose bundle wound on the diving bell winch drum. The strong cooling effect of the wind caused the external elements to freeze, especially the ropes and elements of the lowering and lifting device. Therefore, a steam pipe was connected to the platform and containers with hot water were kept there.

DEEP-SEA DIVES

From the end of 2007 to 2010, there was a break in saturation diving, which did not mean that the diving complex was not in use. Af-2 secured underwater works in the depth range of 50–85 m using heli-oxygen mixtures. During this time, 181 dives were performed with a working depth stay time of up to 1 hour. Diving in the depth range of 75–85 m means decompression needs to be relatively long. This work was also an opportunity to validate the decompression tables contained in the Regulation of the Minister of Health of 17 September 2007 on 'health conditions for performing underwater work.' Diving technology had to be developed for these tables, as the Af-2 system was not adapted for their use.

To this end, the bell installation was rebuilt to accommodate two divers, and the diving team was trained to have two divers in the water at the same time (bell without an operator). In order to complete a single dive, it was necessary to start the bell lift drive several times (to perform decompression; stops every 3 metres), repeatedly dose oxygen to correct the atmosphere in the bell, and heat the bell at varying ambient pressures. Deep dives required intensive use of the Af-2 system. The use of an open bell caused it to flood, which increased humidity and intensified corrosion. The dives were carried out from the Bazalt ship, where the system was subjected to strong vibrations caused by the operation of the propellers. However, the Af-2 complex proved to be resistant to these effects and operated without failure throughout the entire period, which was the result of both modernisation and systematic annual classification inspections imposed by PRS regulations [1].

Another positive effect was knowledge gained about the specificity of the Af-2 complex and skills in system operation acquired by the manager and divers who were to work as saturation divers in the future.

SATURATION DIVING BETWEEN 2010 AND 2011

After an almost three-year break from saturation diving and an annual classification inspection, the installation of the Af-2 system on the Petrobaltic platform began. We conducted the dives with a team of Italian managers and divers we knew well. Unfortunately, the weather was not on our side. As a result, the dives took place in so-called 'weather windows', where conditions were at the upper limit of acceptable sea conditions. The Italian team spent the mandatory 24 hours in the chamber after diving (the so-called bubble time) practically on the move, with the chamber on board the ship that was taking them to port. On land, they were secured by the chamber of the Department of Underwater Works Technology (Polish abbr. ZTPP), and the divers waited in a hotel until 24 hours had passed since leaving the chamber, after which they would be allowed to fly. This was possible thanks to the technology used, because in the case of saturation diving with trimix, this time is 48 hours.

Saturation dives in 2011 are remembered for two situations which unfortunately affected safety of the diving team.

The diving team of the RANA company was put together ad hoc like many other such teams, i.e., underwater work managers and minimum two divers from RANA were joined by external hires. As a result, the Italian team was made up of Italians and nationals of other six countries. LSS technicians originated from the Netherlands and New Zealand, while operators came from Spain, Poland, Switzerland, and Scotland. Divers who worked in the chamber did not speak English fluently enough to communicate effectively with the rest of the team. In general, the command of English left much to be desired and was a source of trouble in the first days of the diving exercise. Misunderstanding during the working test of the life support systems resulted in the reverse circulation flow, a mistake that was detected only several hours later. As a consequence, dust levels in the chamber increased and it became difficult to determine the parameters. We explained the situation to the life support technicians, who were unable to communicate with the divers. It was only after the Italian manager intervened in his native language that the system was set up correctly. This incident made the Polish team more sensitive and led to the implementation of mutual checks of operations with the bell and chamber, as well as the takeover of certain tasks, such as handling the transfer of divers under pressure.

The other difficult situation was caused by a hurricane in the Baltic Sea, which lasted three days, during which the maximum wind speed reached over 50 m/s according to the anemometer on the platform. Its howling practically made communication impossible, and the waves crashing against the legs of the platform caused water to get on deck (located over 20 m above the surface). The platform folded its cranes and stowed the deck equipment and people were officially banned from staying on the deck. Of course, it was not possible to interrupt the operation of the diving complex, so safety ropes were stretched so that the crew could reach their positions. In such difficult conditions, the system worked flawlessly and the lives of the divers in the chamber were not endangered at any moment. The people on the platform were very stressed by the situation, unlike the diving team, whose main concern was to ensure the system continued to operate safely.

STATISTICS OF SELECTED SATURATION DIVE

Table 1 includes data for saturation diving and its average operating parameters.

Tab. 1

Diving time	24 days– 560 hrs
No. of bell immersions	13
Total diving bell immersion time	73h 55 min
Time worked by divers	56h 37’
Average consumption of mixtures per 1 hr of diver’s work	17.6-m^3
Average daily consumption of CO_2 sorbent for the total diving operations	12.2 kg
Average daily consumption of CO_2 sorbent in the chamber	7.8 kg
Sorbent absorption capacity, use rate	70 -80dm^3/kg 45-55%
Consumption of mixtures for chamber operations	7.3m^3/day
Oxygen consumption by 4 divers without decompression	ca. 98 dm^3/nr

Standard planning assumes oxygen demand of 0.5 dm^3/min to 0.6 dm^3/min per diver in the chamber. With four divers, this should amount to 120-144 dm^3/hour. The discrepancy with practical data results from the fact that when sluicing and performing chamber and bell maintenance operations (sanitary installation maintenance, TUP operation, etc.), we supply oxygen in mixtures in which its content is higher than in the chamber atmosphere at the saturation plateau.

The longest dive during this operation lasted 5 hours and 22 minutes, even though the standard recommended time is up to 4 hours. The extension was necessary in order for the diver to complete the task. For the same reason, the time of bell immersion was extended to 10 hours and 20 minutes instead of the standard 8 hours. Such situations were rather rare in our practice. The decision to extend the time is made by the so-called divemaster, i.e., the manager of underwater works responsible for the entire dive. He is in charge of the dive managers who supervise 12-hour watches. Italian teams do not include a physician, which is in line with the generally accepted organisation of diving work worldwide. The extension of the standard time divers can stay at working depth is based on an assessment of the divers' well-being, their level of fatigue and the complexity of the work. There are cases where a diver performs a short task underwater and then waits in the bell for the next task to begin, or remains in the water or on the bell's ballast waiting for the next task.

In order to prevent hypothermia, the diver's body is heated with water. If the diver is staying in the water without exerting any effort, more heat, i.e., warm water, must be supplied. Warm water is pumped through a single hose to the bell, where it is distributed between heating the diver and heating the bell. If the work is carried out at the limit values of heat supply, taking into account the permissible comfort temperature of the heating water of 35-38°C, during the diver's stay in the water, incorrect distribution may result in a heat deficit either for the diver or in the bell. The bell operator's suit is not heated by water; the operator is heated by the warmth of the bell's atmosphere. The dilemma of whether to put the diver into the bell, where it will be necessary to ‘release’ him from his equipment, or to place him in the depths to rest before the next task, depends on the manager's decision. In the case of Af-2, where the bell is designed for two divers in a working diver-operator configuration, the return of the working diver to the bell involves swapping the positions of the working diver and the operator, as the functions of the divers in the bell are interchangeable when submerged. During work, a diver needs less heat when engaging themselves in intensive work underwater. In fact, there are even cases where a working diver unzips his suit to let cool water in because he cannot interrupt the flow of warm heating water and feels the need to cool down. During practical training on land, divers are not prepared for this important action. Heating the diver's body with water for several hours results in skin maceration, making it very susceptible to infection.

During meetings with foreign diving managers who worked without a physician during diving, they shared their experience regarding monitoring the diver's well-being both underwater and on the plateau. This applies to such an important issue as monitoring the diver's exertion. For example, in the case of very heavy work (working with an ejector, twisting structures, etc.), the diver's work is reduced to 1.5-2 hours [1]. Limiting the time spent on heavy work, in addition to ensuring the diver's occupational health and safety, also has additional benefits, such as saving expensive breathing mixtures and ensuring the accuracy of the task. The diver's physical fatigue is a factor that must be avoided. A tired diver is susceptible to infections and illnesses, and is less effective when performing tasks. Ensuring that divers recover their strength after returning to the saturation plateau chamber involves not only sleep and nutrition hygiene, but also ensuring rest, which in the case of a small chamber of the Af-2 complex (volume 7.5 m^3, 4 people, average height 180 cm, weight 90 kg) is difficult and requires strict discipline and mental stamina from the divers.

Materials, especially gases and sorbents, are always calculated and stored in excess, as the normative data and planned working time of divers are assumed to be 28 days of saturation diving and 4 hours of working time in water for a given task, plus an inviolable reserve. Excess materials and gases increase logistical difficulties and are very costly. From the point of view of safety, the reserves specified in the literature are exceeded by more than 100% in relation to practical data, especially in the case of very expensive breathing gases. The data selected and presented in the tables has been chosen based on the lowest consumption of basic materials and breathing gases among many saturation dives. Several factors contributed to this result, including the anthropological data of the Italian diving team, which corresponded to the standard of the 1960s (height 160-170 cm, weight 60-75 kg). The second factor was work in the water corresponding to medium and low effort, which radically affects the consumption of breathing gases and sorbents.

Tab. 2

Consumption of heliox mixtures during the compression to saturation plateau 65 m.*

Starting breathing mixtures	Type of breathing mixture	End pressure in hyperbaric chamber	Amount of breathing mixture
Compression mixture for depth not exceeding 6.5m	Hx 20% (air)	65 kPa	9.38 m^3
Compression mixture for the depth between 6 and 65m	Hx 2%	650 kPa	81.62 m^3
TOTAL	Hx 20% - 9.38m^3	Hx 2% - 81.62 m^3	

Tab. 3

Exemplary consumption of breathing agents over the total stay at saturation plateau for 24 days.

No.	Service operation	Average daily consumption	Gas consumption at saturation plateau	Type of gas
1	Sluicing	2.56 m^3	61.44 m^3	Hx8%
2	Hygiene procedures	2.6 m^3	62.4 m^3	Hx 8%
3	Filling the shaft	36 times during saturation	147.42 m^3	Hx8%
4	Filling the bell	3 times during saturation	70.2 m^3	Hx8%
5	LSS	5.85 m^3	140.4 m^3	Hx 8%
6	Oxygen delivery	2.88 m^3	69.12 m^3	O_2
	TOTAL	Hx 8% - 481,86 m^3	O_2 – 69.12 m^3	

Values for individual saturation dives differ. The consumption of breathing agent and sorbents largely depends on the human factor, diver's experience and the system dictated by formal and training documentation. Summary tables below present data from saturation dives carried out by the Italian-Polish team on the Polish continental shelf.

DISTINCTIVE FEATURES OF SATURATION DIVES

The adoption of a saturation plateau depth of 65 m H_2O results in having oxygen content in the chamber atmosphere above 6%, which implies the first degree of fire hazard in the chamber.

Divers cannot work with bare hands, as this would cause skin infections. Due to the conditions prevailing in the chamber (high ambient temperature, relatively high humidity, restrictions on the use of hand cream), the treatment of skin diseases in the chamber is problematic. A skin infection would eliminate a diver from work, and, if no improvement in their health status occurs for a longer period of time, it could lead to the termination of diving.

There was a case of a diver fainting in the bell while preparing to go to work. We can only speculate about the causes:

- The Italians claimed that the high temperature was to blame. Are local temperature differences possible when two divers are in the bell? Doubtful...
- It is possible that compression of the carotid artery by equipment components was responsible [2];
- Eating too much or lack of control over the amount and timing of meals, as well as the diver working immediately after a meal could also have been to blame.

When examining the possibilities for treating pressure sickness in Af-2 complex, it was found that the chamber's supply systems needed to be redesigned. It should be possible to switch between three mixtures (Heliox 35%, Heliox, air or Heliox 20%, and Heliox 8% working) to the masks. The switching should be quick. In this case, we only had two lines, and changing the mixture required switching the hose between the gas mixture storage tanks, which only then allowed for therapeutic recompression and decompression.

Tab. 4

Time data for selected saturation dive carried out between 05.10.2007 and 27.10.2007; divers' working depth 65 82 m.

Dive number, date	Divers' initials	Start time [hour;min]	End time [hour;min]	Bell immersion time [hour;min]	Divers' working time [hour;min]	Total divers' working time [hour;min]	Amount of Heliox 8% mixture [m³]
1 -.05 10.07	1 An .2. Bon.	1500-	1648-	2.08'	1.48'	1.48'	24.5
2.-05-06. 10.07	1 Leo ,2.Bart E.	1-2256, 2-0325	1-0310, 2-0550	6. 57'	1-4.19 2.-2 25'	6.39'	
3.-06. 10.07	1 An,2-2. Bon	1-1819	1-2156	4.10'	3 37	3.37'	150
4.-14-15 .10.07	1 Leo, 2.Bart.	1-2035, 2-0045	1-2300, 2-0205	7.30	1-2.35',2.20'	3.45'	40.0
5.-16 .10.07	1 An .2. Bon.	1-0750, 2-1133	1-1105,2-1655	10.20'	1.-3.15'23-5.22'	8.37'	128
6- .17.10.07	1 Leo ,2.Bart E.	1-1455-	1-1751-	3.45'	2.56'	2.56'	61
7.-19.10.07	1 An .2. Bon.	1-2320-	1-2340-	1.24'	20'	20'	50
8.-21.10.07	1 Leo ,2.Bart E.	2-0615	2-0740	2.19'	1.25'	1.25'	
9-21.10.07	1 An .2. Bon.	2-1754	2-2038	3.36'	2.44'	2.44"	57.5
10-22.10.07	1 Leo ,2.Bart E.	1-0750, 21205	1-1130,2-1515	8.51	1-3.40',2-3.10	6.50	
11-22-23.10.07	1 An .2. Bon.	1-1659,2-2215	1-2049,2-0125	9.39	1-,4.00,2-3.15	7.15	
12-23.10.07	1 Leo ,2.Bart E.	1-0720,2-1130	1-1035,2-15040	9.27	1-3.15',24.10'	7.25'	182.5
1323.10.07	1 An .2. Bon.	1-1722-	1-2005-	3.49	2.43	2.43	253

Tab. 5

Consumption of gases and basic sorbents for saturation diving between 05.10.2007 and 27.10.2007; divers' working depths 65 78 m, plateau 65m.

No.	Date	Mixture 8%[m^3]	Mixture 2%[m^3]	Oxygen [m^3]	CO_2 sorbent [kg]	Activated carbon [kg]
1	04.10.07	0	81	0	0	0
2	05.10.07	24.5	-	1,5	36	0.3
3	06.10.07	150		1.5	4.5	0.3
4	07.10.07	3		0.5	-	0
5	08.10.07	22		1.5	31.5	0.4
6	09.10.07	3.5		1.5	-	0.3
7	10.10.07	0.5		6.5	4	0.3
8	11.10.07	25	6.5	3	18	0.3
9	12.10.07	3		3	31.5	0.3
10	13.10.07	9.5		3.5	-	0
11	14.10.07	22.5		2.5	-	0
12	15.10.07	19.5		3	22.5	0.3
13	16.10.07	128		-	31.5	0.3
14	17.10.07	61		3	9	0.3
15	18.10.07	11	8.5	1.5	-	0.3
16	19.10.07	50	8.5	5	22.5	0.3
17	20.10.07	6.5		3	27	0.3
18	21.10.07	57.5	5.5	-	9	0.3
19	22.10.07	182.5		4	0	0
20	23.10.07	253	8	2	0	0
21	24.10.07	20	10	4	0	0.3
22	25.10.07	20		5	22.5	0.3
23	26.10.07	2		6	22.5	0.3
24	27.10.07			5		0.3
TOTAL		1074.5	128	71.5	292	4.2

Tab. 6.

List of saturation dives performed by the Italian-Polish team between 2007 and 2011.

No.	Year	Divers' working depth	Duration	Divers' working time	No. of bell immersions	Base	Diving team	Underwater works
		[m]	[hour]	[hour]				
1	2007	74-78	404	59;52	9	Petrobaltic platform	Italian-Polish team	Installation of underwater structures
2	2007	74-78	560	71;59	13	Petrobaltic platform	Italian-Polish team	Installation of underwater structures
3	2007	74-78	301	35;48	5	Petrobaltic platform	Italian-Polish team	Installation of underwater structures
4	2010	76-78	677	106;25	28	Petrobaltic platform	Italian-Polish team	Installation of underwater structures
5	2011	76-78	351	53;13	9	Petrobaltic platform	Italian-Polish team	Installation of underwater structures
	TOTAL		2293	327;05	68			

SATURATION DIVES PERFORMED BY THE POLISH TEAM

POLISH TEAM PREPARATION FOR SATURATION DIVING

The Polish side, with the support of LOTOS Petrobaltic managers, was getting ready to carry out saturation dives based on domestic capabilities. The Polish Naval Academy Underwater Technology Department (Polish abbr. ZTPP AMW) did not undertake to take over all matters related to conducting saturation diving even though the Polish companies, LOTOS Petrobaltic, and divers who had gained experience in deep diving using the Af-2 diving system insisted on that. However, the Department did undertake to manage and supervise the dives. A team of 8-10 divers was required to carry out the task. Although ZTPP AMW was the only institution in the country at that time with the necessary technical and substantive resources, it did not undertake to train the team. However, it could not refuse to provide support and participate, as it was bound by a long-term cooperation agreement with LOTOS Petrobaltic in the field of underwater technologies, and also because it was the only team in the country capable of conducting these dives.

According to the authors, the reasons for the Academy's limited participation were the lack of will on the part of the University's decision-makers at the time, caused by warnings about hazards involved in diving work, and human pettiness. Another, equally important argument was the overly formal and slow administration, which was not interested in additional research work that did not fit into the formal structures. The main argument was that the Academy could not participate in commercial ventures, but only in specially established consortia, for which there was a lack of will not only within the Academy.

An additional, very significant problem was the absence of the Department of Maritime and Tropical Medicine of the Military Medical Academy, medical institution which supported the ZTPP AMW from the very beginning of its activities. In 2003, the Military Medical Academy was dissolved, depriving experimental diving and saturation diving carried out in Poland of professional medical support.

In view of the Academy's refusal, the private company AquaWorks, driven by the enthusiasm of divers, launched saturation diving training in 2011 at the then Institute of Maritime and Tropical Medicine in Gdynia-Redłowo. The part devoted to saturation exposures conducted in the LSH-200 chamber complex was delivered by the substantive and technical staff trained by ZTPP. The training complied with the requirements of the Underwater Works Act, but was conducted in land conditions simulating those in a water chamber. The engineering side was prepared by Mr. Ryszard Pisula, a talented designer who worked at ZSNITPP until 1986. Thanks to this training, eight Polish deep-sea divers obtained saturation diving qualifications.

The major component of training in real-life conditions was completed when preparing to the first saturation diving in October 2011 already under the management of the ZTPP AMW team.

Bearing in mind that a Polish team of as yet unknown composition is participating in the project, Polish saturation diving technology was developed at ZTPP on order of the drilling director, taking into account the conditions in our country and the specific nature of the Af-2 system design. This technology was developed by a team working since 1995 in all areas of saturation diving. The documents have been approved by the relevant institutions, including the Mining Authority, as in mining nomenclature offshore drilling platforms are referred to as mines. Basic documents have been developed:

1. Saturation Diving Technology in Af-2 Diving Complex Part 1 “Saturation Diving: Preparation”
2. Saturation Diving Technology in Af-2 Diving Complex. Part 2 ”Saturation Diving: Implementation”
3. Saturation Diving Technology in Af-2 Diving Complex Part 3 ”Typical and Emergency Situations in Saturation Diving”
4. Annex 1 to Part 1 of Saturation Diving Technology in Af-2 Diving Complex ”Diving First Aid Kit”
5. Annex 2 to Part 1 of Saturation Diving Technology in Af-2 Diving Complex “Saturation Diving Hygiene Principles for Divers”
6. Annex 1 to Part 3 of Saturation Diving Technology in Af-2 Diving Complex “Medical Evacuation Procedure”
7. Annex 1 to Part 1 of Saturation Diving Technology in Af- 2 Diving Complex “Divers’ Evacuation Procedure Under Pressure”

These documents describe activities performed under emergency conditions for all positions involved in the organisation of saturation diving and comprise over 350 pages. They do not include the so-called detailed technical service procedures, of which there are several dozen.

FIRST COMMERCIAL SATURATION DIVES OF THE POLISH TEAM

The first saturation diving took place in the toughest conditions.

The work of divers depends on sea conditions. A major difficulty is the lack of shelter in stormy weather, especially in the Baltic Sea in autumn and winter. The Af-2 system was mounted on deck 2.2 metres above the water surface. In bad weather (sea state above 4-6), water flows across the deck. When sailing to a shelter in the harbour, the location of the chamber at the stern exposes the divers inside to vibrations from the propellers and may cause them to suffer from seasickness. The same factors affect the diving system operating personnel.

Fig. 1. Waves seen from the stern of ATHS Bazalt ship during an ”escape” from stormy weather, view from the right/left side of the chamber and diving bell of the Af-2 complex.

The ATHS Bazalt ship offers sub-standard social conditions for the entire diving team. Despite this, the Bazalt was a welcoming place, especially due to the commitment and friendly attitude of the crew. During many years of cooperation involving months of deep-sea underwater work from the deck of this ship, the diving team became close with the crew. The Polish Naval Academy team has been working on the Bazalt since 1997. These circumstances ensured a positive climate for the first dive. What was unique was that the three underwater work managers working on watches who undertook to carry out the saturation diving had no previous experience in managing such diving in real-life conditions and were performing their work for the first time. Of the team of 4 divers as many as 3 had no previous experience in saturation diving. While all divers and one manager were very much familiar with the Af-2 diving system (they actively participated in underwater deep-sea works), the supporting physician and two other managers had to undergo a fast-track training during the first saturation diving exercised in difficult conditions. The IMCA training documents provide for 2400 hrs of practical experience as an assistant manager. All managers involved in the undertaking were experienced in working on land as they took part in saturated expositions at the ZTPP and in training for divers but none of them could meet the requirement by even 25%.

ZTPP specialists, who were doing all the jobs except those intended for divers, undertook to introduce the AquaWorks team and divers to the secrets of saturation diving. They also conducted so-called on-the-job training before diving. As they also provided technical, shipowner and overall supervision of the project, they intervened in difficult situations and emergencies. In the chamber, G. Mączka, who was the team leader and had been practising saturation diving since 1995, trained the divers and introduced them to the secrets of saturation diving. The overall supervision and decision-making process was carried out by the co-author of this article, who had many years of experience in managing operational and research saturation diving and acted as the so-called ‘on-call manager’.

The safety of the ship and underwater operations was in the hands of master mariner Leszek Szymborski, whose expertise was invaluable during difficult dives from the deck of the Bazalt. Another very important issue was ensuring basic security of operations from the shore provided by the LOTOS Petrobaltic and ZTPP bases. Shore-based security was managed by Mr M. Rewers, Head of the Marine Operations Office, and a member of his team, M. Czerwiński, who also acted as coordinators during the diving operations. Coordinators took care of the advancement of underwater work, eliminated obstacles in the cooperation between the diving team, platform and the ship, as well as interfered in case of personality clashes between the participants of underwater works. On behalf of ZZTPP the exercise was secured by the entire team headed by the co-author of this publication.

Some examples of log entries, which summarise the first week of saturation diving performed by a Polish team only:

1. *The dive commenced at 17:30 on 22 October 2011. Compression lasted approximately 4.5 hours. Compression began in sea state 3-4, wind force 4-5°B and a temperature of 10°C. The saturation plateau at which the four divers are staying is 70 metres (there were problems with compression, but they did not pose a threat to the divers' lives or health).*
2. *To date, five bell dives have been performed, with divers working for over 32 hours. The divers' work at a depth of 75-84 m included:*

- *excavating access to welds using an ejector (this required considerable physical and mental effort from the divers)*
- *cleaning welds for NDT testing*
- *performing NDT tests on footing base welds,*
- *connecting ropes to pipe lines – siphon pipes.*

In three cases, the bell's immersion time was shortened due to deteriorating weather conditions threatening the divers' safety. In addition, most of the dives took place at night. Considering the above, the intensity of underwater work was high.

Divers are in good shape. Three divers working directly ‘on the ground’ with the ejector have minor rashes on their hands, which does not disqualify them from further *work. In future, divers should be advised to wear gloves that insulate them from contact with the ground. Working with an ejector is very hard work, and the gloves cause fatigue in the hands when gripping the ejectors.*

During underwater work, any disturbances that could pose a threat to the platform must be eliminated. These include:

- *a pipe with water pouring onto the deck in the area of the manoeuvring centre, which caused the dive to be interrupted/shortened,*
- *the smell of faeces on the ship's deck,*
- *the system and deck being covered with dust (bentonite) from the platform – currently, the complex must be washed in the port.*

3. *Material provision and technical support for underwater work*

Tab. 7

Daily consumption and basic stock on board of the ship on 30.10.2011 r.

No.	ITEM	Unit.	CONSUMPTION	IN STOCK
1	Heliox 2% O_2	[m³]	134	916
2	Heliox 8% O_2	[m³]	786	2103
3	Heliox 10% O_2	[m³]	0	226
4	Heliox 15% O_2	[m³]	11	202
5	Heliox 20% O_2	[m³]	45	159
6	Heliox 35% O_2	[m³]	0	225
7	Heliox 50% O_2	[m³]	0	225
8	Oxygen	[m³]	47	431
9	CO_2 sorbent	[kg]	213	827
10	Activated carbon	[kg]	4	37
11	Air	[m³]	130	230

Working heliox 8% O_2 in stock is sufficient for 8-10 bell dives lasting 8 hrs. Other gases in stock will allow for 20 days of saturation diving including decompression. Stock of other materials suffices for a 28-day cycle of saturation diving.

Tab. 8

Basic gases in stock at the base on 30.10.2011

No.	ITEM	Unit	IN STOCK
1	Heliox 2% O_2	[m³]	1,110
2	Heliox 8% O_2	[m³]	6,954
3	Heliox 10% O_2	[m³]	222
4	Heliox 15% O_2	[m³]	90
5	Heliox 20% O_2	[m³]	179
6	Heliox 35% O_2	[m³]	225
7	Heliox 50% O_2	[m³]	225
8	Oxygen	[m³]	127
9	CO_2	[kg]	620
10	Activated carbon	[kg]	5

Stock sufficient to carry out 2 more saturation dives.

ISSUES RELATING TO UNDERWATER WORKS

1. *The presence of a team of divers on a rolling vessel, especially divers in the chamber, reduces their ability to perform underwater tasks. They are exposed to seasickness and vibrations because the chamber is installed at the stern and under the ship's propellers (high wave amplitude, vibrations from the propellers causing discomfort and hindering operation). This requires the designation of shelters from adverse conditions. Excessive exposure to heavy swells may prevent divers from performing their tasks and expose them to health risks (dehydration).*

Personnel servicing the divers are also subject to the same factors.

Escaping a storm is a prerequisite for the effectiveness of divers and support personnel, i.e., their availability for work.

2. *Vibrations of the hull cause gas installations to leak and electrical equipment to malfunction. This is particularly noticeable when sailing in stormy conditions.*

3. *The reduced social standard of the diving crew in autumn conditions causes frequent infections and the possibility of their spread.*

Having the above in mind, in stormy conditions the ship must remain in the harbour

PROBLEMS TO BE SOLVED AT THE BASE

1. *The need to work in winter conditions requires additional preparation of the system for operation on the ship. A detailed list of works will be provided.*
   These works will include:
- *insulation of power lines,*
- *insulation of system components (containers, chambers, etc.)*
- *wind and water protection,*
  It is also necessary to improve social conditions.

2. *Works to be carried out in port:*
- *cleaning the system,*
- *sealing minor leaks in gas systems,*
- *replacement of the bell hatch valve,*
- *replacement of bell measuring sensors,*
- *metrological servicing of important measuring instruments (verification),*
- *modernisation of CO_2 sorbent containers,*
- *replacement of the electric power cable for the divers' water heater,*
- *replacement of corroded system pressure gauges,*
- *repair of two CO_2 measuring instruments,*
- *replacement of the bell computer.*

A detailed list of works to be performed on the system after the current saturation dive and the orders will be provided at the base.

NURSAT Project Manager at the Polish Naval Academy

S. Skrzyński

As can be seen from the above report, working on a ship involved specific problems that were addressed on an ongoing basis. Reliable communication between stations on the ship-platform-diving system, real-time weather monitoring and 'escaping from the workplace before a storm' are factors that contribute to safe and effective work. Stopping work at the right moment to take shelter from a storm sometimes required 'determination', as the base always 'pressed' to continue work for as long as possible, due to the additional costs generated during a stopover in port. The situation was similar when pressure was exerted to return to work as quickly as possible, even with the suggestion that the sea crossing should take place in relatively poor conditions so that upon arrival, the weather conditions would be suitable for diving. This habit of dispatchers was a remnant of deep dives, which lasted several or more hours. They forgot that in saturation dives, divers remain in the chamber without interruption.

Diving was performed by divers from AquaWorks owned by S. Szczęsny:

Saturation divers: G. Mączka, P. Żyła, Z. Jabłoński, and H. Palacz.

Stand-by divers (also reserve divers) on the surface: Z. Jabłoński, R. Makarów, A. Biegalski, and J. Kur.

Work managers: J. Maculewicz, J. Pomian and J. Wojdowski .

Life support system technicians on 12-hour watches: R. Kuffel, J. Kulik, M. Kaszorek, B. Trybulec, P. Nawrocki, K. Opaliński M. Zawieja, W. Pytlak, M. Adamski, and A. Ziemski.

Mechanic S. Wiśniewski and electrician-electronic technician J. Pawlak were 24hrs on duty, obliged to be present at the time of bell immersion.

Z. Sićko was a physician on the team.

S. Skrzyński, the head of the Polish Naval Academy team, was the manager of underwater works who supervised saturation dives and took care of divers' safety.

THE COURSE OF DIVING

All processes involved in preparing for a saturation dive must be carried out in a thoughtful and planned manner and must be properly checked by the relevant personnel. Excessive zeal in approaching the tasks prolonged the start of compression. The preparatory excitement immediately before the start and the extended working procedure of checking the diving system increased the tension.

Compression was carried out efficiently. After reaching the plateau, an error was detected when the partial oxygen pressure exceeded approximately 25 kPa. By increasing the pressure in the chamber with the first starting mixture, the operators exceeded the assumed depth by 6.5 m, which resulted in exceeding the partial oxygen pressure when supplying the second heliox mixture with 2% oxygen content. After exceeding this pressure, an alarm was triggered, which was deliberately turned off as it was decided not to interrupt the compression. At the 70 m saturation plateau, after attempts to homogenise the atmosphere, the resulting partial oxygen pressure was over 70 kPa. At no point was there any danger to the divers, who were unaware of the situation. Unfortunately, according to the technology used in this dive, we only had a helium-oxygen mixture with 2% oxygen content to correct the atmospheric composition. Until 2001, pure helium was used as the compression gas, which would have allowed for a quick reduction of the partial pressure of oxygen (see fig. 3). The decision to discontinue the use of pure helium during saturation diving resulted from the implementation of IMCA recommendations. The entire process was recorded, which allowed it to be reproduced for operational control and training purposes. The course of the partial pressure reduction is shown below in Fig. 3.

All participants in the project feared failure, especially since the underwater work was difficult due to minimal visibility and the possibility of divers becoming stuck in the ground. The diver's work involved strenuous effort in controlling the ejector inlet, which required digging out the footings (the bases of the platform columns holding the drilling platform pontoon more than 20 metres above the water surface) at depths of more than 80-86 metres.

Selected data for these saturation dives of the Polish team are given in Tables 7, 8, 9, 10,11

The courses of parameters for selected episodes of diving are shown on charts in fig. 2,3,4.

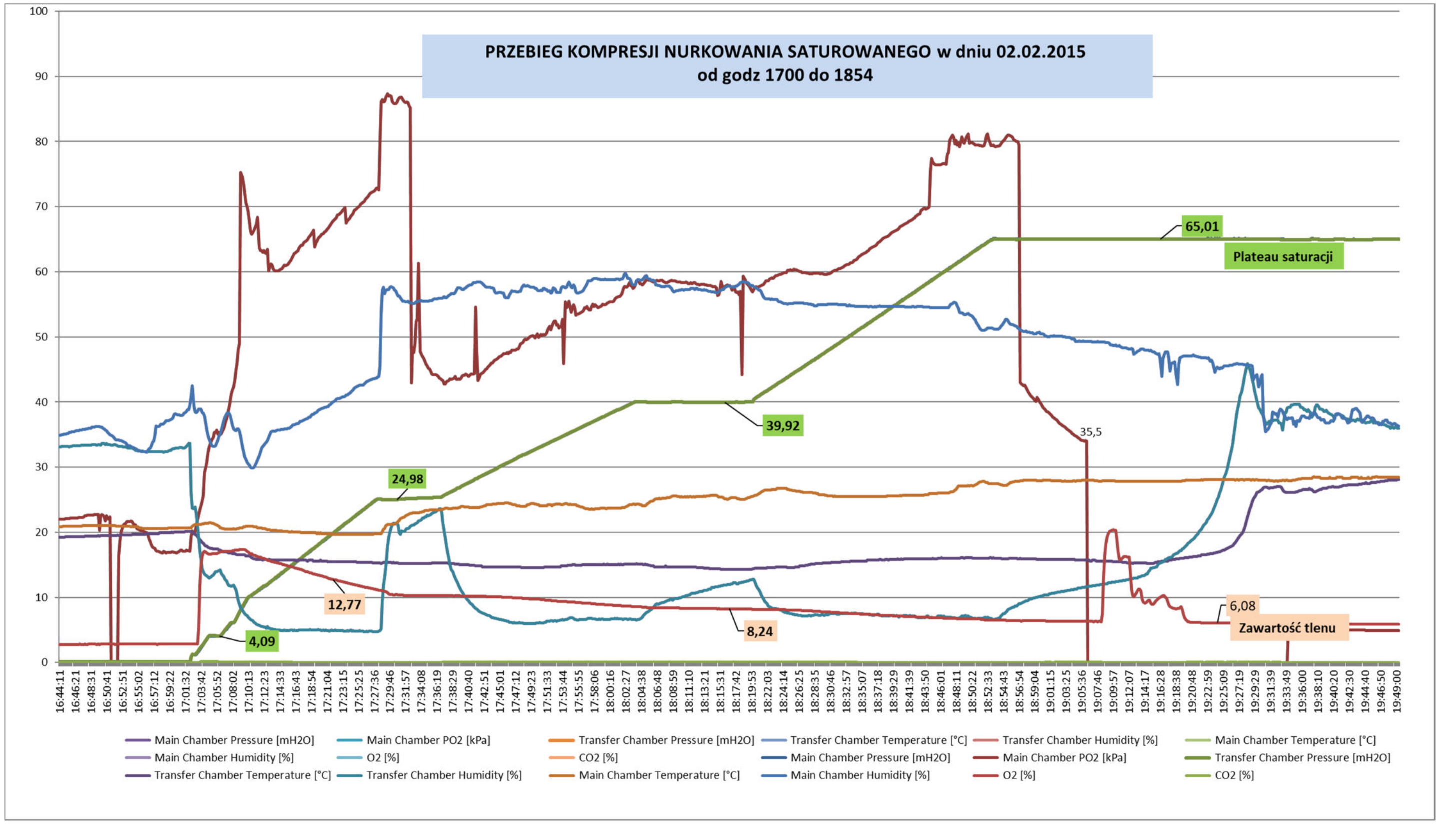

Fig. 2 The course of compression during a saturation dive (example; dive on 02.02.2015 between 17:00 and 18:54)During compression, stops are made to check the operation of the systems, s. tabilise the atmosphere and check for leaks. The figure shows stops at depths of 4 m, 24.9 m, and 39.9 m. The slope of the pressure increase curve indicates the compression rate, which in our case is from 1 m/min to 0.65 m/min. During compression, the oxygen content in the chamber atmosphere decreases.

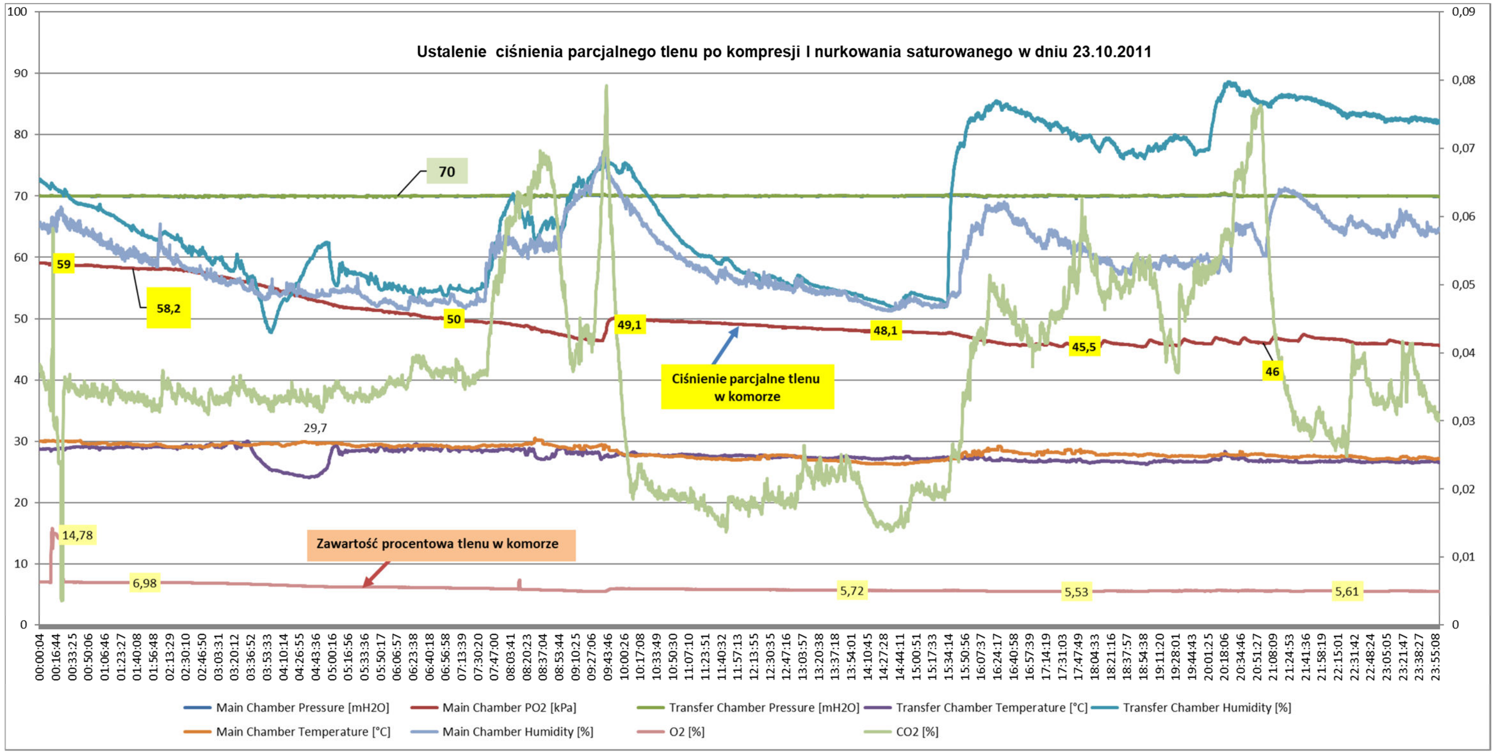

Fig. 3 Atmosphere parameters 6.5 hrs after the start of the compression following the exceeding of oxygen partial pressure.
Explanation: During the compression, due to an error in the supply of starting mixtures, the assumed permissible partial oxygen pressure of 45 kPa was exceeded, reaching over 70 kPa. From the moment the saturation plateau was reached, the process of lowering this pressure began by using a 'flush' with the starting mixture used in compression (i.e., heliox with 2% oxygen content). This operation lasted 10 hours. The divers did not notice it. The operation had to be repeated because, after reaching 46 kPa, the manager ordered oxygen to be administered and the partial pressure of oxygen rose again to about 50 kPa. The operations to reduce the partial pressure of oxygen were repeated.

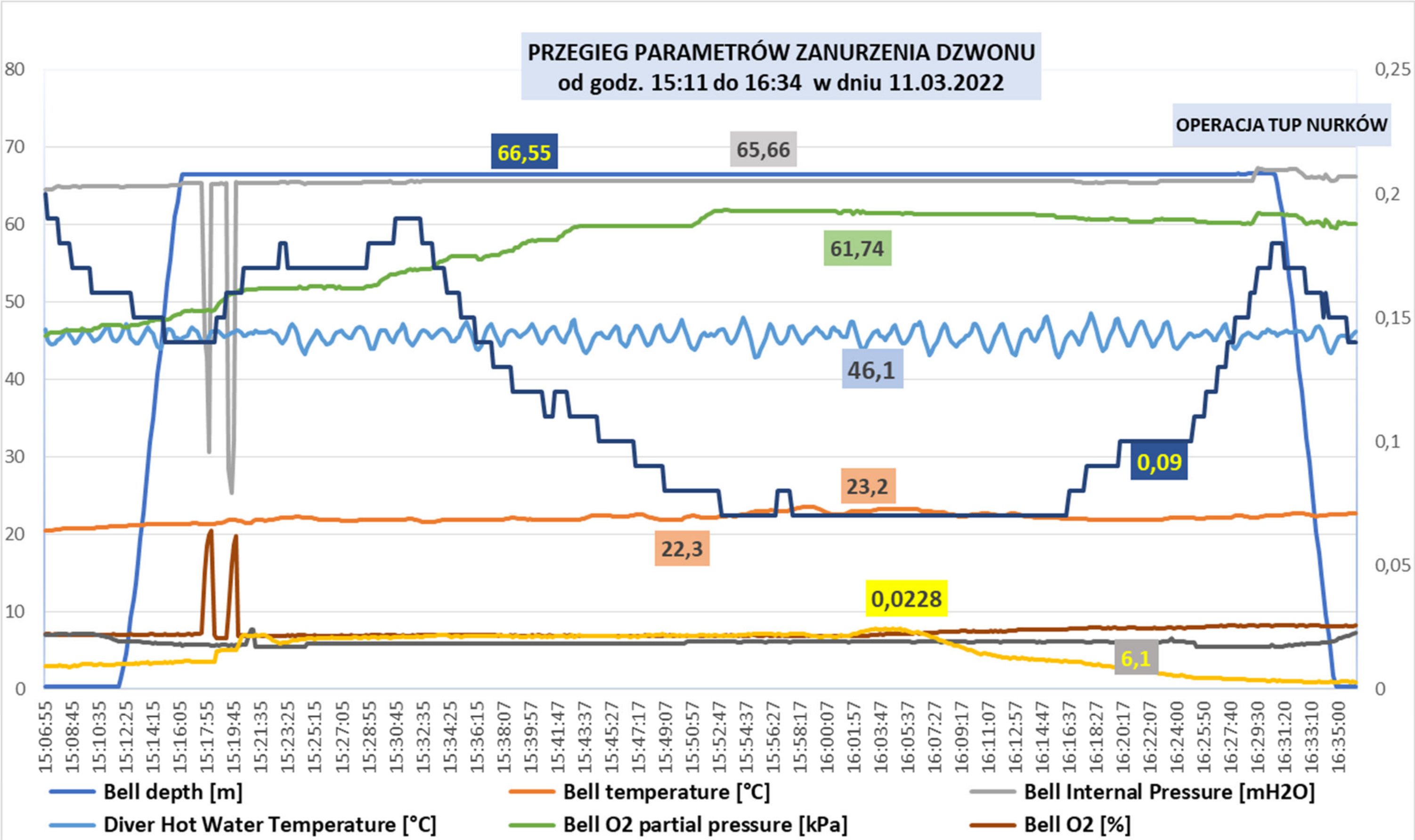

Fig. 4.Changes in bell atmosphere parameters during the immersion.
Comments to the chart: CO_2 content and its partial pressure are measured in two ways. The line shows the content, while the "stepwise" chart of the partial pressure come from the measurement made at the manoeuvring centre and temporary intake from the pneumo line.

Tab. 9

Duration of a stage in direct preparations of a mobile diving complex Af-2.
Based on data from the last six years: installation time on the platform was 35 days and on the Bazalt ship 28 days..

Installation year	Start date End date	Installed on	Transport time Af-2 [days]	Time needed to prepare and fix the footing [days]	Installation time for Af-2 complex	PRS tests	No. of days
2007	27.03. 25.05.	Petrobaltic platform	4	8	18	4	**58**
2008*	02.08 02.09	ATHS Bazalt ship	3	10	15	2	**31**
2009*	10.07 22.08	Petrobaltic platform	3	9	22	2	**37**
2010	01.10, 07. 11.	Petrobaltic platform	5	10	17	1	**35**
2011	09.05 15. 06	ATHS Bazalt ship	2	12	14	1	**30**
2012	13.08 15. 09	ATHS Bazalt ship	2	10	15	1	**28**
2019 2020**	28.12 2019 28.02.2020	LOTOS GIANT platform	7	10	21	2	**40**

**The system prepared for deep-sea diving – a smaller scope of works.*
*** On the GIANT platform the installation was interrupted for holidays and there was a break for over a month after the installation was completed and approved until saturation diving started.*

Tab.10

Operational data for X saturations on the Polish Lotos GIANT Platform; start on 18.04.2020 at 16:00hrs end on 28.04.2020 at 20:00hrs.
Saturation plateau 65m for p_{O2}= 0.46ata and p_{CO2}= 0.005ata divers working at the depth 70-78m

Day of diving	Date	Dive no.	Divers' working time	Hx 2% consumption	Hx 8% consumption	Consumption of Hx 10%/ or Hx15%	Consumption of Hx 20%	Oxygen	CO_2 sorbent	Activated carbon	Consumption of Hx 35%	Comments
		-	[hr/ min]	[m³]	[m³]	[m³]	[m³]	[m³]	[kg]	[kg]		
0	Leak test			0	97	101	32	2.8	6			Bounce diving
1	18.04.	Compression		103	27		20	0.5	0	0.1		
2	19.04.	No.1 (no.41)	3:12	4.5	46	0	0	3	21	0.1		Camera failure
3	20.04.	No. 2 No. 3	4:02 6:00	15	111	0	0	2.8	12	0.1		
4	21.04.	No. 4 No. 5	7:00 6:17	0	165	0	0	1.1	27	0.1		
5	22.04.	No. 6 No. 7	7:10 7:50	7.3	134	0	0	2.6	27	0.1		
6	23.04.	No. 8- No. 9	7:08 1:25	0	97	0	0	2.8	12	0.1		
7	24.04.	No. 10-	2:35	7.3	15	0		1.7	15	0.1		
8	25.04.	-	-	7.4	15	0	9	4.2	15	0.1		Decompression at 15:00
9	26.04.	-	-		0	0	11	5.1	15	0.1		Decompression
10	27.04.	-	-		0	0	2	4.2	15	0.1		Decompression
11	28.04	-	-		0	0	2	4.2	15	0.1		Decompression at 20:00
TOTAL			52hrs 39min	144.5	707	101	76	35	180	1.1		

1. Divers' working time 52hrs 39min.
2. Average consumption per hour of diving: 13,4 m³ ±2 of the working mixture.
3. Mass of CO_2 sorbent per day: 18±1kg.
4. Duration: 10 days and 6 hrs (246 hours).
5. Decompression: 3 days 5 hrs (77 hours).

Tab. 11

Summary data for saturation dives performed by the Polish team between 2011 and 2022.

No.	Year	Working depth	Duration	Divers' working time	No. of bell immersions	Base	Underwater works
1	2011	76-82	327	35;23	8	AHTS Bazalt	Installation of underwater structures
2	2012	76-82	619	82;25	21	AHTS Bazalt	Installation of underwater structures
3	2013	78-84	278	23;00	4	AHTS Bazalt	Installation of underwater structures
4	2013	78-85	579	49;47	11	AHTS Bazalt	NDT with digging up footings
5	2014	78-82	519	93;46	19	AHTS Bazalt	NDT with digging up footings
6	2015	78-85	417	56;15	10	AHTS Bazalt	NDT with digging up footings
7	2015	78-85	275	35;50	6	AHTS Bazalt	NDT with digging up footings
8	2020	76-81	331	65;20	11	LOTOS GIANT platform	Replacement of a submersible pump
9	2020	76-81	502	90;42	16	LOTOS GIANT platform	Replacement of a submersible pump
10	2020	76-81	246	53;39	10	LOTOS GIANT platform	Replacement of a submersible pump
11	2021	76-78	528	89;55	16	LOTOS GIANT platform	Replacement of a submersible pump
12	2022	74-76	527	105;18	20	LOTOS GIANT platform	Replacement of a submersible pump
	TOTAL		5148	781:20:00	152		

1. The average efficiency of divers' work, calculated as the ratio of divers' working time to the duration of the dive was 15.1%
2. The longest break between the dives was five years and was also caused by the pandemic. In 2019 the installation of the complex on the GIANT platform was interrupted due to the Polish Naval Academy team falling ill.

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