PROBLEMS IN SELECTING A DECOMPRESSION TABLE FOR SATURATION DIVING FOR COMMERCIAL PURPOSES IN POLAND. PART III C
TECHNICAL AND ORGANISATIONAL ISSUES OF THE IMPLEMENTATION OF SATURATION DIVING IN POLAND FROM THE 1990S ONWARD. PART 3

Stanisław Skrzyński

Department of Underwater Works Technology, Polish Naval Academy

ABSTRACT

This article is another in a series of articles on the research and implementation of saturation diving technology in Poland. It discusses the specificities related to the implementation of this technology against the background of economic and historical conditions in our country. In Poland, the issue of saturation diving for the needs of the emerging offshore mining industry has been for over a dozen years dealt with by the Department of Diving Equipment and Technology of Underwater Works (Polish abbr. ZSNiTPP). In parallel, deep diving technologies were developed, in the first stage, as a basic diving technology and, since 1994, as complementary to ensure the full backup for saturation diving. Since 1995, saturation diving has become an everyday occurrence in the Polish economic zone of the Baltic Sea. This article shows the difficult path that the implementation of saturation diving took during a period of economic instability when the scale of the domestic offshore industry's facilities was small compared to global companies. Selected animators and participants in the implementation are recalled for two periods: one marked with the cooperation with the Italian underwater services company RANA and the other one, a period of implementation of long-term underwater works based on domestic capabilities. The article also considers the technical and organisational conditions for the implementation of saturation diving for the Polish mining industry. In 1990, the Oil and Gas Exploration and Production Company Petrobaltic (today LOTOS) played one of the key roles in the implementation of saturation diving in our country. The implementation of saturation diving in Poland was linked to the only operational diving system of Italian production, the Af-2, which enabled scientific research related to the application of new technical solutions and testing under operational conditions, as well as contributed to the development of scientific, engineering, and medical staff for the Polish offshore industry. The company played one of the main roles in the implementation of saturation diving in our country The 1995 became a landmark year in the history of saturation diving in Poland, as well as in the Baltic Sea. Through this technology, the process of installing the first two underwater exploitation heads on production wells B3-7 and B3-10 was initiated. The saturation diving was possible thanks to the leasing of the Af-2 diving system by Petrobaltic and its subsequent purchase by the Naval Academy in 1998.This system, after a series of upgrades, is still in service today.
Keywords: saturation diving technology, decompression tables, saturation diving parameters, long-term underwater work, diving system, emergencies, technical and organisational backup for diving, medical issues of operational saturation diving, mobile diving system, saturation diving base, breathing mixtures.

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INTRODUCTION

FIRST COMMERCIAL OPERATIONAL SATURATION DIVES IN POLAND

Underwater work continued in 1994 in accordance with the deposit development project. The Navy's salvage ships LECH and PIAST, working with the PETROBALTIC platform, the newly acquired BALTIC BETA platform, as well as the multi-purpose vessels 'Petrobaltic' GRANIT and BAZALT, taking advantage of the extremely favourable weather conditions, carried out a number of works. These works included, inter alia:

- installation of an oil transfer line (2,000 m long pipeline manufactured by Co- flexip) from production wells B3 - 5/6 to the main collector,
- installation of two flexible lines (350 m long each) connecting the main collector with the BALTIC BETA platform, which is the production centre,
- installation of a control line for the main collector shut-off valve.

In total, in 1994 the diving vessels of the Naval Sea Rescue Service of remained at the disposal of 'Petrobaltic' for 67 days, and the costs of their involvement exceeded PLN 11 billion at that time [12]. The divers taking part in the work performed deep dives for about 40 hrs. It should be emphasised that with the use of saturation diving, the diving costs would have been many times lower due to the shorter time needed to execute this work.

PREPARATION FOR SATURATION DIVES

Towards the end of 1994, after an analysis of the availability of dive systems for hire at a time compatible with the work on the construction of the underwater infrastructure, preparations for saturation dives were started. The proposal to use a fixed dive system installed on a service vessel was rejected after the first bids were received, due to the price and available timescales (one English bid was for £180,000 per day of work excluding the so-called 'consumables,' i.e., the cost of materials and dive team). A saturated diving system was sought that could be installed on jack-up rigs, which was pioneering at the time, at least in the North Sea. The only company to take up the subject was the Italian RANA. The diving systems it owned did not fit on the platforms, so RANA promised to reconfigure the system. For Petrobaltic purposes, the Italians reactivated the Af-2 mobile diving system in a relatively short period of time from the components in their possession. Also the formal matters decisive for the approval for operation and enabling the insurance of divers and technology were successfully dealt with. In Poland there were neither official documents nor regulations that would govern the construction of a diving system for saturation diving, although there were ideas and designs on which the Polish side followed

The diving system was brought to Poland by road transport, which implied partial dismantling of its heaviest components. The shipment list consisted of 33 pieces of self-contained equipment, plus 222 other items, e.g.: materials, specialist equipment and spare parts. Once fully assembled, the system was transported to the Petrobaltic Beta platform. Assembly was carried out by the Italian team in cooperation with the team from the Diving Equipment and Technology of Underwater Works (ZSNiTPP). Surfaces for setting up the system had to be prepared by removing several pieces of equipment from the deck.

The system took up every available space even in the spaces of the platform leg guides. As there were difficulties in obtaining helium containment and it was still unstable despite attempts to do so, helium deliveries were made in transport cylinders. In order to become independent of helium supplies, it was decided to purchase a duar with 500kg of liquid helium and gasify it on site using typical diving techniques. Once the liquid helium was gasified, it had to be compressed to a minimum of 150 bar and pumped into tanks additionally borrowed from the Navy. A GERA diving compressor made in GDR, which had a filter at the output to catch any oil contamination, was used as the pumping machine. In the next dive, this method of obtaining helium was abandoned due to the difficulty and its low efficiency. The installation on the platform allowed the Polish-Italian team, which mostly consisted of 'freelancers' recruited through recruitment advertising campaign, to get to know the system. RANA's full-time employees were the underwater work managers (a superintendent and two supervisors, two dive systems technicians, and two life support technicians).The other two assistant life support technicians and four dive-certified deck staff worked on a contract basis.

When contracting the Italian diving personnel from RANA, the 'Petrobaltic' Board of Directors included the Polish team by increasing the surface support staff by 10 people, in order to train Polish personnel in both diving and dive safety.

The mobility of the diving system required solving numerous problems, both technical and organisational, that were 'invisible' or absent in a fixed diving system. Many of them were resolved, starting from problems and analyses related to organisation, meeting the requirements of selected technical regulations, the scope of operational tests, matching the system configuration to the site and the working check of the dive system and its readiness for operation, to the selection of consumables and gases and logistical security for underwater work.

For the first time, the Polish team had to plan the work and operate away from the base. This resulted in overstocking of consumables and spare parts, tool picking and 'over-zealous maintenance'. Distrust of the Italians was high, which we felt already during the first saturation dive. This was due to the different approach to the work and the language barrier. In the Italian team, the manager proposed solutions to technical and organisational problems. The rest of the Italian team showed no initiative in this regard, not to say that they were completely indifferent. The Polish team, on the other hand, showed great initiative and enthusiasm, proposing numerous options for solving the problem. This required analysis and approval by the Italian team, which irritated and surprised them at the same time. The state of distrust lasted until the first failures, which the Polish team quickly fixed (e.g., repairing the communication in the bell and the working diver's helmet, frequently detecting and fixing leaks in gas, water and hydraulic installations, or repairing the underwater TV camera, which was the basis for controlling the divers' work (Italian divers did not have helmet cameras)).

SATURATION DIVING IN 1995

The year 1995 marked a breakthrough in the history of commercial diving both in Poland and in the Baltic Sea. In June of that year, after the system had been installed on board the Baltic Beta platform, the process of installing the first two underwater operating heads on production boreholes B3-7 and B3-10 began. Despite the existence of a saturation diving programme developed in 1980-1995 by ZSNiTPP Department of the Naval Academy and the Department of Maritime and Tropical Medicine of the Military Medical Academy (KMMiT WAM), operational saturation diving had never been performed in Poland before. The technical condition of the Af-2 system required numerous improvements. Thanks to the technical assistance of the Department's equipment input and the use of Naval Rescue Service assistance (especially for securing typical emergency situations, including the evacuation of divers under pressure), a full saturation diving security configuration was technically and organisationally achieved.

The first saturation dive took place from 12.06. to 06.07.1995 on the 'Battic Beta' platform with a saturation plateau of 70 m. The divers worked at depths of up to 80 m. Four Italian divers worked on the installation of the underwater operating heads and the connection of the transmission lines underwater. This dive allowed the Polish team to familiarise themselves with the operation and organisation of the diving team and the organisation of work on the drilling platform. It was also an important factor in the integration of the Polish and Italian teams.

After completion of the work on the BETA platform, the Af-2 diving system was dismantled and placed on the Petrobaltic platform. Taking into account the organisational situation at RANA and the intention of the Petrobaltic Board to have a team in the country to carry out saturation diving in real offshore conditions, it was agreed that the next saturation dives would be carried out by a mixed Polish-Italian team. This solution faced a lot of opposition, both from the Polish and Italian sides. The Naval Academy was concerned about the possible adverse effects of saturation diving and the lack of administrative preparedness to carry out these dives (e.g., one of these concerns was; how to pay the high fees to the saturation divers, unheard of in everyday practice).The Italian side, on the other hand, was concerned that the Poles would (in principle, rightly) become their competitors in the market. Both sides were only persuaded by the fact that armed forces divers are not allowed to work commercially and that these dives are carried out on a research project basis due to the lack of domestic legal arrangements. This solution had two 'godfathers', Director Jerzy Bokinec and a high-class diving superintendent, a specialist with extensive experience of underwater work Vittorio de Boni from the company 'RANA'.

After the installation of the Af-2 system on the 'Petrobaltic' platform, the second dive took place from 02.08. to 01.09.1995 from a saturation plateau of 73 m. Four divers participated in this dive, two Italian and two Polish. On the Polish side, the saturation divers were Ryszard Kłos from the Department of Diving Equipment and Technology for Underwater Work (ZSNiTPP) of the Naval Academy and Grzegorz Mączka from ORP 'Lech'. The safety diver was Jarosław Peron from OSNiP of the Polish Army. The Polish team was led by cmdr Stanisław Skrzyński, head of the ZSNiTPP of the Naval Academy, and the entire underwater work was supervised by superintendent Vittorio de Boni. A team of doctors headed by Dr Romuald Olszanski of ZMP KMMiT, Military Medical Academy was responsible for the selection and training of divers and conducting medical examinations.

The duration of the saturation dive was 29 days and 16 h. During this time there were 18 bell dives with an average dive time of 5h 15min and a total time of 67 hours (decompression time of 56h 23min plus two breaks of 6h each).The divers' working time totalled 93 hours, of which the longest task of 1 diver outside the bell lasted about 7 h. From discussions with Italian divers, it was clear that they happened to perform saturation dives lasting more than 40 days.

The co-operation between the divers from both teams was exemplary, although the Polish diving pair had to be held back in their work as they wanted to prove themselves by completing the underwater task as quickly as possible. As an example, it was the Italian pair who could not remove the steel plate at the base of the well. The Polish pair wanted to do it by force, asking for an extension of the 4-hour normal working time in the water. And this did not work. The operation was only accomplished by underwater thermal cutting. This task was carried out alternately by Polish and Italian divers, which required two more immersions of the bell (the maximum normative immersion time for the bell, i.e. the divers' work in the depths, was set at 8 hours).

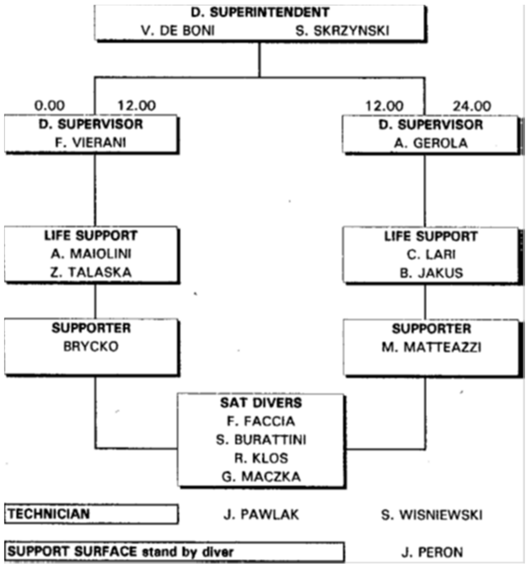

Fig. 1 Organisation of night and day watches during the 2nd saturation dive in 1995. The dive team works on 12-hour watches, night watches from 12.00 to 24.00 and day watches between 24.00 and 12.00.

Polish divers quickly mastered skills such as dive preparation, bell handling and post-dive hygiene. They already had practical experience with the bell for deep dives in the days when water-heated suits were not used. The bell in saturation dives requires divers to handle the heating, change breathing equipment and go out to work in the water and cooperate with each other. The bell of the Af-2 system is designed for two divers in a diver - bell operator arrangement. The bell operator is assigned a number of tasks such as belay diver duties, adjusting the hot water supply to the bell and the working diver, assisting in dressing the working diver, maintaining communications, controlling the bell atmosphere or belaying the working diver. The bell equipment must provide a minimum of 24 hours autonomy, and the ability to assist an injured diver, which implies that the bell is very cramped. This makes it difficult to move around in it and the diver must be careful not to unintentionally move the valve levers or damage the measuring device. In addition, divers 'going to work' for eight hours took sandwiches and at least one litre of water to the bell to drink.

The second saturation dive showed that it was possible to work in a mixed Italian-Polish team and perform the planned tasks safely. The Polish team was dominated by the Department's personnel (underwater work manager, diver and 5 technical staff), who carried out research programmes and built diving systems equipment. Thanks to the participation of the Naval Academy and the Polish Navy team, the diving sceptics, those 'who knew best' and decision makers in civilian circles as well as in the Naval Academy were proved that the undertaken course of action was correct and beneficial to the Polish scientific and economic potential.

DIVING TECHNOLOGY APPLIED BY RANA

By way of explanation, it should be stressed that the Polish team adopted the procedures in force at RANA. However, after some doubts were raised and clarified, the Italian side was persuaded to also accept some proposed national solutions. One such example of a concession was the participation of a doctor during the dive, which the Italian side agreed to, as Italian procedures do not provide for direct medical cover at the dive site. The principle of a higher level of medical security in diving for military and scientific purposes, i.e., by a diving doctor at the diving site, has been maintained in the Polish Navy until now.

On the other hand, for legal reasons and on the basis of experience, Italian saturation diving parameters and their measurement methods were adopted. A significant problem was the differences in measurement accuracy. Compared to the Polish technology, the Italian company's dive measurement accuracies were a class lower. For example, the temperature and humidity in the chamber were measured with general purpose instruments; a room thermometer and a hygrometer (sic!). The measurements were not reflected in the shunting control panel and were recorded from the chamber for record keeping. The maintenance of the partial pressure of oxygen as predicted by the diving technology in the ranges 265 to 425 mb (0.270 to 0.474ata) with an average value of 330mb (0.337ata) was not secured by the portable oxygen measuring instruments used by Serwomex. The same was true of the carbon dioxide measurement, which was measured with indicator tubes with a range of 100 to 3,000 ppm or 0.1 to 1 % vol.

Oxygen and carbon dioxide were not measured continuously, but every 30 min using so-called 'inner tubes' (a thick rubber balloon with a tube to inflate). After the 'inner tube' had been flushed three times (filling and releasing samples of atmosphere from the chamber or from the bell), it was connected to an oxygen meter, or in the case of an indicator tube, the volume under test was measured with a pump. These measurements were very subjective and their accuracy depended on the precision of the measurements taken. In our national system at the time, such measurements were only an option for emergency measurements.

During the second dive, in which the Polish team participated, we connected the instruments for continuous measurement to the chamber, without abandoning the method of measurement used by the Italians. The Italian team was sceptical of the new method, partly because it required maintenance (calibration and synchronisation of the PC software, which was being used for the first time at the time) which put an additional burden on the staff. Therefore, measurements were taken piecemeal so as not to interfere with the diving process.

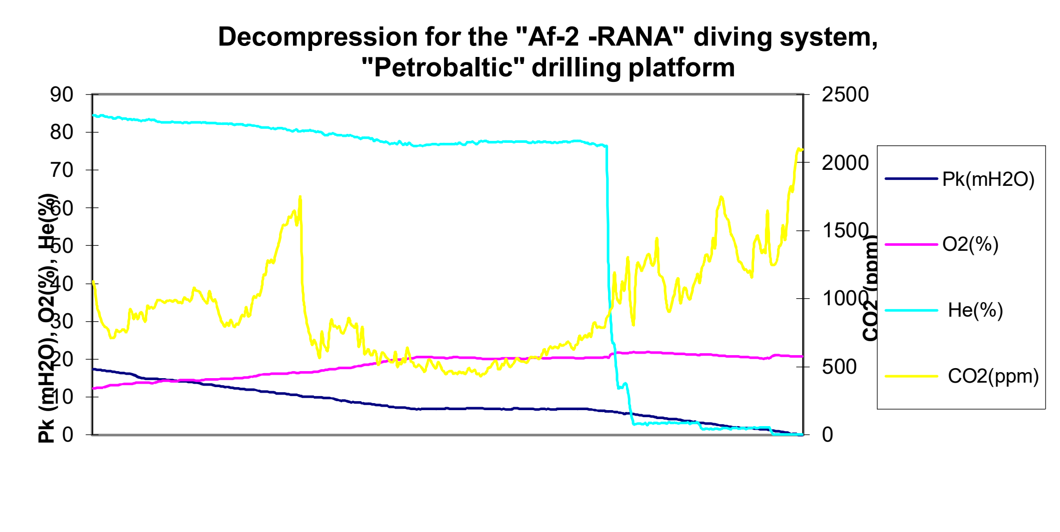

Fig. 2 The final stage of decompression with an apparent exchange of helium for air at 6.5m.

The following gases and breathing mixtures were used in the execution of the saturation dive:

- Diving air - used during compression operations to a depth of 6.5m and in decompression from 6.5m to zero depth,
- Helium (minimum purity 99.995) - used for compression from 6.5 until saturation plateau is reached and to maintain saturation plateau pressure,
- Medical oxygen - used to maintain a constant partial pressure of oxygen in the atmosphere of the chamber and during decompression, and from a depth of 15.5m to 0m to compensate for the loss of oxygen content due to consumption by the divers.
- Heliox with 10% oxygen - used to fill the atmosphere of the diving bell and as a working mixture for divers working in the depths. Heliox 10% oxygen was used in dives, although 15-12% was stipulated for the actual depth range in the RANA regulations, and 10% content was stipulated for depths of 85- 100m.

The consumption of air in the first and last stages of a saturation dive puzzled Polish experts on the subject, as it was not described in the professional literature available at the time.

The following parameters, given in Table 1, were adopted for the dive. In the safety regulations, RANA originally used [mbar] as a measurement unit, which did not refer to the measuring accuracy of the instruments used, so these values are given in [ata].

Tab. 1

Allowable partial pressure for the primary respiratory gases in the RANA system.

Allowable partial pressure for the primary respiratory gases in the atmosphere		
Hyperbaric chamber	[mbar]	[ata]
pN2	1330	1.36
p02 minimum	265	0.27
p02 maximum	465	0.47
pCO2 maximum	2.6	0.25
Diving bell	[mbar]	[ata]
pN2	1330	1.36
p02 minimum	465	0.27
p02 maximum	600	0.61
pCO2 maximum	5.2	0.05

Continuous monitoring of the partial pressures of oxygen and carbon dioxide was not carried out during the dive in a way required by most of the recognised classification regulations of the North Sea countries. In particular, they required signalling of exceedances of the partial pressures of these gases, which were mandatory, for example, for the GWK -200 and LSH -200 b systems built in Poland in the 1980s and early 1990s. The manoeuvring control panel of the Af-2 system only met the conditions for oxygen and carbon dioxide measurements of the DNV Rules for Classification Diving Systems. [13]. The single rather than continuous measurement method used required special attention from the operators. The oxygen analyser offered the possibility of meeting the indication accuracy of ± 0.015 bar of oxygen molecular pressure. The tube indicator, which had a minimum theoretical indication of 0.01 % [vol], did not provide an indication accuracy of ± 0.001 bar of molecular pressure, but the measurement range was within the permissible 0.025 % vol for the absolute pressure prevailing in the chamber [14].

Compression to saturation plateau should not proceed faster than 20m H_2O/hour, with interruptions. These were due to: the need to switch from air to helium at a depth of 6.5m to reach the saturation plateau, stabilisation breaks lasting a few minutes to check the homogeneity of the atmosphere and assess the tightness of the chamber and associated equipment (generally at depths of 20 and 40m).

The course of changes in decompression pressure was modelled after the following method applied by the US Navy, which has remain practically unchanged until today:

- Depressurisation stage from 06:00 until 24:00 – 18 hrs.
- Break in depressurisation stage from 24:00 until 06:00 - 6 hrs.

Rate of pressure reduction:

- From 180m to 60m 33.3min/m or 1.8m /h
- From 60m to 30m 40.0 min/m or 1.5m /h
- From 30m to 15m 50.0 min/m or 1.2m /h
- From 15m to 0m 66.6 min/m or 0.9m /h.

The important problem of evacuating divers under pressure was solved by the 'bell to bell' method, the only one feasible at the time. This operation was a major risk, due to the fact that the bell equipment from the rescue ship did not have atmospheric heating. In addition, the operation was time-consuming, depending on the external conditions on the platform and the weather.

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dr inż. Stanisław Skrzyński
Katedra Technologii Prac Podwodnych
Akademii Marynarki Wojennej
s.skrzynski@amw.gdynia.pl