Saturation diver fatality due to hydrogen sulphide while working on a subsea pipe line

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Abstract

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In the offshore oil industry, Multipurpose Support Vessels with extensive diving capability are used for inspection, maintenance and repair of subsea pipelines. The diving industry has developed systemic safety checks and strict regulatory control after a number of fatal accidents in early years. However, accidents do continue to occur and, when involving divers in the water, are often fatal. Hydrogen sulphide (H_2S), called 'sour gas' in an oil field, is produced by the action of anaerobic bacteria on sulphate containing organic matter. A highly toxic gas, it remains a constant danger for offshore oil industry workers who must remain vigilant. Crude oil and gas produced in these oilfields is called 'sour crude' and pipelines carry this crude with varying content of dissolved H_2S to shore for processing. Divers are routinely called to attend to leaking pipelines and come in contact with this crude. Their hot water suits and umbilical lines are often covered with crude containing dissolved H_2S. There is always a possibility that these may enter and contaminate the bell environment. Such a case leading to fatality is reported here.

Introduction

Saturation divers play a major role in the development and production of an offshore oil field. During the construction and developmental phase of an oil field, they dive extensively from construction and pipe-lay barges often working against time. Once production has commenced, pipelines laid at the bottom of the sea and platforms need constant inspection, maintenance and repair. A number of diving vessels are often deployed in the oil field for this reason. The shallowest 20 metres' seawater (msw) of the platform legs is generally attended to by a surface supplied air diving team. If the depth of the oil field is 100 msw, structures deeper than 20 msw would typically be attended by teams of saturation divers; two in each team at different storage depths called split levels. Upward and downward excursion from these depths is limited to 10–20 msw but the entire length of the platform underwater including cross members can be attended to by the saturation diving teams stored at the appropriate depths. One or two teams are stored at each depth depending on the quantum of work.

Case report

The incident happened on board a Multipurpose Support Vessel (MSV) operating in an offshore oil field. The vessel was a purpose-built MSV with accommodation for 12 divers in saturation and a single three-man bell of 4.5 m^3 volume. The diving system was certified to 300 msw and was well maintained. Although it was a three-man bell, a two-man bell run was the norm followed by the client and the contractor. The MSV was on a long charter for carrying out inspection, maintenance and repair duties for the client oil company. On the eventful day, her crew was informed by the charterers about an oil leak in one of the main 36-inch diameter subsea lines carrying sour crude. The vessel was directed to proceed to the site and carry out pipeline repair on an emergency basis.

The MSV had carried out similar operations on 'sour crude' pipelines and a standard operating procedure (SOP) was in place. Salient features included the following. First, the diver shall wear a disposable coverall over the hot water suit which is to be discarded before entering the bell. Second, the diver helmet and umbilical shall be cleaned properly before it is brought inside the bell. Third, both divers shall be on built in breathing system (BIBS) masks when the bell is launched, and the bell man shall be on BIBS throughout. Standard oro-nasal BIBS were fitted in the bell. Fourth, the bell is to be flushed continuously preventing ingress of toxic gas inside the bell.

The MSV left for the indicated location and on arrival, observed a large oil film and gas bubbles on the sea surface.

The pipeline was at 74 msw depth. The MSV was positioned and bell diving started. The bell was at 65 m depth a short distance away from the pipeline, not directly above it. On reaching the seabed, the diver reported oil and gas gushing out from the pipe line with great force and as a result was unable to approach the leak location for closer inspection. This was immediately reported to the oil company and a request was made to reduce the pressure of product flow in the pipeline.

Once the product flow was reasonably reduced, the diver approached the leaking pipeline to locate the rupture. The diver reported that a big trench had formed in the seabed, gouged by the force of the gushing oil. The probable position of the leak was at the bottom of the pipe. The size of the rupture could not be ascertained. The diver was unable to get closer to the leak position as the seabed all around the trench was fully covered with oil sludge.

On complete stoppage of gas and oil flow and consequent cessation of the leak, the diver approached the location and did a close survey of the leak area and the pipeline. After getting preliminary details, he was asked to return to the bell. The bell man was informed of this.

The bell man assisted the diver to enter the bell and removed his helmet. He also had to remove his BIBS for a short time to assist the diver. They exchanged pleasantries. The diver started cleaning his umbilical after sitting down in bell. He had not put on the BIBS and had not secured his safety harness to an 'eye' in the bell. Shortly after, the bell man stopped reacting to the diving supervisor's instructions, collapsed and laid down on the diver's seat.

Within a few seconds of this, the unfortunate incident occurred; the diver, who was sitting in the bell, fell down all of a sudden. Part of the umbilical was still outside the bell awaiting cleaning and the bell bottom door was not closed. Not having secured the safety harness, he fell into the water and was carried away by the current. The bell man was on BIBS and was still unconscious.

As the bottom door of the bell was open, the bell could not be lifted out of the water. The bell was being flushed continuously.

An emergency situation was declared, and a medical officer (the author) was informed by the MSV owner's representative that his presence on board was required urgently. A helicopter sortie was arranged immediately.

Another MSV working in adjoining field, about 40–50 nautical miles away, was requested to proceed to the area for help as quickly as possible. After reaching the helibase, the author established communication with the diving superintendent of the affected MSV and was appraised of the situation. He suggested to the diver superintendents of both the MSVs that a bell-to-bell rescue was the best option available and that they should start preparing a dive plan accordingly. It was then decided that the medical officer should proceed to the rescue MSV and not the affected MSV. The rescue vessel was still underway when the helicopter landed with the medical officer on board. A job specific safety checklist based on risk analysis was prepared jointly with the diving superintendent. The masters of both vessels had worked out a protocol of operation as regards dynamic positioning reference systems and thruster, hull interaction, wind, current and other considerations.

When the rescue MSV arrived at the dive site a rescue diver and bell man were identified and briefed by dive superintendent. All equipment for the rescue diver and unconscious diver was checked and rechecked. Bell diving was carried out from the rescue MSV and the rescue diver reached the unconscious bell man. He was disrobed and new gear was donned on him. He was wet-transferred to the rescue vessel bell. After the rescue, the rescue diver and bellman were instructed to disrobe completely in the bell and not bring any personal gear into the saturation system trunking and transfer under pressure areas of the rescue MSV to avoid the contamination of the living chambers.

In the meantime, the medical officer accompanied by one diver, with resuscitation drugs and equipment were pressurised to 65 msw on heliox into the rescue MSV's saturation living chambers.

The patient, when received was unconscious. His pulse was 60 per min, regular, slow volume. Blood pressure was 106/64 mmHg. Respiration was shallow. His oral cavity was cleared using a foot operated suction machine and a Guedel airway inserted. An intravenous line was secured and 5% glucose infusion was started. The BIBS supply was connected to an Ambu bag and the diver was ventilated using treatment mix (265 kPa PO_2). After approximately 15 min the patient regained consciousness but was disoriented. After 20 min, the BIBS supply was disconnected and the patient was ventilated using chamber gas containing 50 kPa PO_2 for five minutes. During a second ventilation period with treatment mixture, his condition improved. He would obey verbal commands but was not talking. He was disoriented, finding himself with divers who were not there in the chamber earlier and was surprised to see the medical officer treating him inside the living chamber of another MSV. He was eventually able to take deep breaths and ventilation support using the Ambu bag was discontinued. He was switched over to BIBS and an additional four cycles of 20 min breathing treatment mix was completed with five minute breaks. A total of six cycles of treatment mix was given.

Furosemide 20 mg was injected slowly over a minute through the intravenous line to treat potential pulmonary oedema, and repeated eight hourly. Nitrite solution was not available. The 5% glucose was followed by 500 ml Ringers lactate. No additional intravenous fluids were administered as the diver had recovered consciousness and oral feeds could be started. Breath sounds were normal. There was no clinical evidence of pulmonary oedema. His BP was 110/68 mm and he had passed urine. Adequate oral fluid intake was ensured. He had no recollection of past events other than the diver locking out of the bell. After a 24-hour hold, standard saturation decompression was started which was uneventful. He remained alert but quiet.

Once he was evacuated ashore, he underwent a thorough medical evaluation. A magnetic resonance imaging brain scan, a high resolution computed tomography scan of the lungs and a complete blood work up was carried out. He was evaluated by a neurologist and a psychiatrist. He was declared fit to dive after a month and resumed his work offshore.

The day after the rescue, the body of the diseased diver floated a few meters away from the vessel and was recovered.

Discussion

The presence of hydrogen sulphide (H_2S) in the bell was the root cause of the accident resulting in the fatality. The permissible exposure limit of H_2S is 15 parts per million (ppm) for 15 min at normal temperature and pressure (NTP). At 10 ppm it has a 'rotten egg' smell but at concentrations above 200 ppm, the olfactory nerve becomes paralysed immediately. At concentrations above 500 ppm often the sense of equilibrium is lost and the affected person can become unconscious. Beyond 1000 ppm death is almost instantaneous.[1]

H_2S is transferred easily across the alveoli into blood where it affects cytochrome oxidase causing cellular anoxia and oxygen transport by haemoglobin is affected. The effect is same as oxygen deprivation or asphyxiation but rather more quickly. It is a strong pulmonary irritant causing pulmonary oedema.

Treatment of H_2S poisoning is complicated as its mechanism of toxicity is similar to that of cyanide. H_2S poisoning is commonly treated in the emergency room with intravenous sodium nitrite along with supportive therapy. Hyperbaric oxygen has been used as supportive therapy although it is not available routinely.[2] Given this case occurred in a diving system with the patient under increased ambient pressure, resuscitation was carried out using hyperbaric oxygen.

The deceased diver had reported that a trench had formed along the pipeline where the rupture had occurred and was filled with oil sludge. While working he had dislodged the sludge which resulted in release of dissolved H_2S. Although the diving bell was not directly above the leak, there is a possibility that some H_2S entered the diving bell. Electronic continuous gas monitoring system was not fitted in the diving bell nor was a handheld detection unit carried in the bell. The diving supervisor would not have had any indication of H_2S in bell.

Another possibility is that although the diver had discarded his coverall per standard practice, a considerable amount of oil was on his diving suit. His umbilical was also covered with oil sludge. Rising from seabed to the bell, the pressure decreased by almost 100 kPa (one bar), reducing solubility of H_2S in oil and excess gas was released from solution and entered the bell. The bell man was affected first. As soon as the diver removed his helmet and started breathing bell heliox mixture, he was affected, became unconscious and slipped out of the bell. He probably had no time to hook his harness to an 'eye' in the bell.

The bell man was breathing a heliox mixture containing 70 kPa PO_2 and on BIBS. This is probably the reason he survived a high H_2S content in bell brought in by the diver with his umbilical and diving suit. Aside from the short period of exposure with BIBS off when both exchanged pleasantries he did not continue to breathe from the contaminated bell environment. The diver on the other hand, was sitting and as soon as he removed his helmet, was exposed to high H_2S content at high pressure (750 kPa) and lost consciousness.

During treatment, the patient was given 35% HeO_2 mixture, called 'treatment mix'. At 65 msw he was breathing approximately 265 kPa PO_2. Six cycles of 20 min interspaced with five minute 'chamber mix' (50 kPa PO_2) was sufficient to neutralize the effects of hydrogen sulphide. Intravenous furosemide ensured pulmonary oedema was treated although not detected clinically. There was also no indication for inserting an endotracheal tube.

Ideally, a remotely operated vehicle (ROV) could have carried out a pipeline survey at zero risk. When this accident happened, ROVs were not routinely available. Today, work ROVs are present on MSVs and carry out pipeline surveys, marine growth removal, etc. Divers continue to work on pipelines but a similar accident has not recurred. The International Marine Contractor's Association (IMCA), an industry trade association representing offshore, marine and underwater engineering companies, has also revised its guidelines on diving in contaminated waters subsequently.[3]

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