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CASE REPORT

Deaths due to hydrogen sulphide on a jack up rig at Bombay High: an avoidable accident

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ABSTRACT

An enclosed space is an area with poor or no natural ventilation which is not designed for continuous occupancy, where access is limited and which may contain a dangerous atmosphere. Enclosed space atmospheres can be hazardous due to one or a combination of the conditions which includes oxygen deficiency; presence of toxic and/or flammable gases. When it is intended that personnel should enter or work in an enclosed space, care should be taken to create and maintain safe working conditions.

The case report describes an incident on board an oil rig where the rig workers were exposed to noxious gases resulting in multiple fatalities. Work involved gas sampling/monitoring at various locations inside the "spud tanks" of the rig and certifying it free of noxious gases for marine surveyor's inspection.

Contributory factors that have been frequently identified following enclosed space accident investigations are non-compliance with procedures, inappropriate equipment, poor supervision, complacency and over familiarity leading to short cuts being taken, detection and monitoring equipment not used or not working properly and improper action in an emergency. Preventive measures to avoid such accidents and create a safe working area are discussed.

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Keywords: hydrogen sulphide, jack up rig, enclosed space entry, permit to work, breathing apparatus, hyperbaric oxygen

INTRODUCTION

In every accident, there is a causative factor which is often preventable. Failure to adhere to safe working practices invariably end in an accident. Untrained worker or inadequate/inappropriate gear is often the root cause attributable in accident investigation.

Hydrogen sulphide (H_2S) is an extremely hazardous gas that occurs naturally in crude oil and natural gas. The gas is formed by the decomposition of organic matter containing sulphates by anaerobic bacteria. For the same reason, it is also found in sewers, paper and pulp mills etc. It is referred to as "sour gas", "sewer gas".

Hydrogen sulphide is a highly toxic, colourless, combustible gas. It has the unmistakable odour of rotten eggs at low concentration. However, the sense of smell is not a reliable warning because exposure to this gas results in paresis of olfactory nerve very quickly. It has a density of 1.5392 g/L and being heavier than air, tends to settle down in low lying areas. It is soluble in water and oil [1]. Presence of H_2S at work place is a serious and hazardous work environment.

Offshore drilling in depths up to a maximum of 120 m of sea water (msw) is carried out by using a "jack up rig". They are fitted with long support legs that can be raised or lowered. Bottom of the legs are fitted with base cones, which are approximately 380 m^3 in volume and penetrate into the soil to give stability to the rig. They are like the feet of a rig and support the weight of the rig (15,000 tons) (Figs. 1, 2).

All marine structures have to undergo periodic inspection cycle every 5 years to ensure its efficiency within design parameters, so also spud cans. They are pulled out of water

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Figure 1. Jack up rig

Figure 2. Spud can removed for maintenance

and undergo external and internal inspection. Unfortunate incident occurred during an inspection of a spud can.

CASE REPORT

The rig was not working, legs were fully retracted and the spud cans were above the water and accessible for man entry. They were dewatered and forced ventilated for 2 days. "Gas free", i.e. no H_2S present, "safe to enter" certificate had to be generated before a marine surveyor could enter the spud can for inspection. A diving team was present on board and the same consisting of three divers and one diving supervisor was nominated to enter the vast inside of a spud can and obtain gas samples using chemical tubes.

Diver had to climb down about 5 m using a vertical ladder into the spud can and then traverse to various corners. He was wearing SCUBA (self-contained underwater breathing apparatus) equipment. His life line was attended by another diver also wearing a breathing apparatus who stood at the bottom of the ladder and visible to the supervisor who was above. There was one "stand by" person fully dressed up with a breathing apparatus to intervene at short notice next to him. Few minutes after starting the operation, supervisor saw the attendant, who was at the bottom of the ladder, suddenly fell down and became unconscious. On seeing that, the supervisor, on an impulse, climbed down the ladder to assist him without a breathing apparatus. Before he could reach the attendant, he too became unconscious and collapsed. Alarm was raised and the rig engineer increased the ventilation rate to drive away "sour gas" from inside. Moment this was done, a large quantity of gas emerged out of the narrow opening on the spud can and the "stand by" person was affected and collapsed on the deck.

Emergency was sounded and the author was requested to proceed offshore by the contractor who had undertaken the job. Special helicopter was arranged for the same and author reached the rig in about 3 hours. But unfortunately all 3 persons who had entered the spud can were dead. "Stand by" person was resuscitated by the rig medic using amyl nitrite inhalation, oxygen resuscitator and intravenous ringer lactate as advised by the author. Helicopter that brought the author to the rig was standing by at a platform nearby and the patient was air evacuated and admitted in an intensive care unit of a hospital in Mumbai (Bombay) for further management.

Diver, his attendant and the diving supervisor died inside the spud tank. Stand by diver was rescued, revived and treated in the intensive care unit of a hospital.

DISCUSSION

CAUSE OF ACCIDENT

Cause of death as determined by coroner was asphyxia. Circumstantial evidence pointed to inhalation of H_2S that was anticipated in the spud can. Spud can is almost 5 m in height and because of its typical internal construction, has numerous nooks and corners which are not well ventilated. In addition, there were puddles of mud sludge which contain dissolved H_2S. First person who went inside the spud can dislodged the collected H_2S in low areas and also the sludge containing dissolved H_2S. Being exposed to this, he became unconscious and collapsed. Access to a spud can is very small and exhaust of continuous ventilation could escape to atmosphere through this single opening only. Attendant who was at the bottom of the ladder was thus affected by the toxic gas evolved and collapsed. Supervisor entered the spud can without a breathing apparatus and was affected by H_2S. "Stand by" person was affected by the gush of gas coming out of the opening due to forced ventilation but being in the open, quantity of gas inhaled was much less and could be revived.

There are various standards laid down for working in H_2S environment. Permissible exposure limit of H_2S is 10 parts per million (ppm) for 8 hour shift, 40 hours a week, called time weighted average. Short term exposure limit of 15 ppm for 15 min. A worker may be exposed to this level for 4 times

Table 1. Hydrogen sulphide effects on body

Concentration [ppm]	Effects
0.13	Obvious and unpleasant odour generally at 0.13 ppm and quiet noticeable at 4.6 ppm
10	Unpleasant odour. Possible eye irritation. Threshold limit value (8-hour time weighted average)
15	Short term exposure limit averaged over 15 minutes
20	Burning sensation in eyes and irritation of the respiratory tract after 1 hour or more exposure
50	Loss of sense of smell after about 15 or more minutes exposure. Exposure over 1 hour may lead to headache, dizziness, and/or staggering. Pulmonary oedema reported following extended exposure to greater than 50 ppm. Serious eye irritation or damage
100	Coughing, eye irritation. Loss of sense of smell after 3 to 15 minutes. Altered respiration. Pain in eye, and drowsiness after 15 to 20 minutes, followed by throat irritation after 1 hour. Prolonged exposure results in a gradual increase in the severity of these symptoms
300	Marked conjunctivitis and respiratory tract irritation
500	Unconsciousness after short exposure, cessation of breathing if not treated quickly. Dizziness, loss of sense of reasoning and balance
700	Unconsciousness quickly. Breathing will stop and death will result
1000	Unconsciousness at once. Permanent brain damage or death may result

in a shift provided there is an exposure free gap of 1 hour between each exposure. Acceptable ceiling concentration of 50 ppm for 15 min provided that rest of the shift period should be spent in H_2S free environment [2].

Immediately dangerous to life and health, an atmospheric concentration of any toxic, corrosive or, asphyxiant substance that poses an immediate threat to life or would cause irreversible or delayed adverse health effects or would interfere with an individual's ability to escape from a dangerous atmosphere. The National Institute for Occupational Safety and Health (NIOSH) considers 100 ppm as the limit. Effects of H_2S on the body are enumerated in Table 1 [3].

ROOT CAUSE ANALYSIS

The fatal accident took place because wrong breathing equipment was being used and untrained persons were carrying out the job. Divers are trained to work underwater using breathing apparatus. They were being used to take gas samples from an enclosed space. Breathing apparatus used underwater, is referred to with an acronym, SCUBA (self-contained underwater breathing apparatus). Compressed air is supplied from a cylinder carried on back and air supplied through a reducer. Face mask used in underwater breathing apparatus is not tight fitting and some water gets inside and equalizes pressure under the mask. If the mask was tight fitting, as the diver descends in water and there is an increase in ambient pressure, the mask will squeeze the face. To avoid this, the face mask should not be tight fitting. In this case, poisonous gas could enter the loose fitting face mask and was inhaled. Breathing apparatus used for enclosed space entry, called SCBA (self-contained breathing apparatus), the face mask is gas tight, preventing entry of toxic gas, fumes etc. from entering the face mask. As this is used on surface in ambient pressure, there is no pressure variation while using. Test for gas tightness is the basic test that needs to be performed by a worker before opening the air cylinder of the breathing apparatus. He can then enter an environment filled with toxic gas in a safe manner. Face masks do not have a proper fit in persons having thick beard and it was a prevailing practice to exclude persons with beard from working in "sour gas" fields. Both face masks look similar but have a fundamental difference between the two.

Crew was not trained for the job and had no idea of the risks involved. Risk analysis of the job was not undertaken and no tool box meeting was held. Contingency plan not prepared. As the gas testing work was out sourced, the safety officer of the rig also did not inspect the team that had arrived on board for the job.

MECHANISM OF ACTION

Hydrogen sulphide when inhaled passes easily across the alveolar-capillary barrier and enters blood stream. It associates with haemoglobin; cytochrome enzyme system is compromised and oxygen transport is affected causing symptoms similar to asphyxia. This causes severe acidosis. H_2S has a strong irritant effect on the mucous membrane especially that of respiratory tract resulting in pulmonary oedema. For the same reason it causes excessive lacrimation and keratoconjunctivitis. It paralyses the olfactory nerve. At concentrations above 1000 ppm, loss of consciousness and death is immediate [4].

TREATMENT OF H_2S POISONING

Removing the victim from the exposure is the most important component of the treatment. Care must be taken that the rescuers are well protected and do not become a victim themselves as is observed often. Victim must be resuscitated with 100% oxygen by mask, ideally by using ambu bag or an automatic oxygen resuscitator. Hyperbaric oxygen therapy, if available should be administered immediately [5]. Hyperbaric oxygen leads to super saturation of serum and other body fluids with oxygen due to increased pressure. At 3 atmospheres absolute pressure (ATA), 6 vol % of oxygen is dissolved in the plasma which is sufficient to meet body's requirement of oxygen at rest [6].

Amyl nitrite capsules which are often found in emergency medical kit are inhaled for 30 s, one every minute, while intravenous access is established to start Ringer lactate.

Sodium nitrite is often used as an antidote because of similarity of mechanism of action of cyanide and H_2S poisoning. Both form a reversible bond with cytochrome enzyme system.

Sodium nitrite (300 mg) is administered intravenously, 10 mL of 3% $NaNO_2$, over 4 min [4, 7]. Drop in systolic pressure has to be monitored. Acidosis should be corrected with sodium bicarbonate administered intravenously along with fluids. Patient should be transferred to an intensive care unit to treat pulmonary oedema and monitoring for the next 24 hours.

POSSIBLE SOLUTIONS

Good planning and training programs for workers are the best ways to prevent exposure, injury, and death. H_2S contingency plan needs to be prepared and followed carefully [3]. This includes the following as bear minimum:

- Actively monitor for H_2S gas, including both personal and area monitoring. H_2S being a heavy gas, gas monitors should be fitted at floor levels at numerous exposed parts of the rig connected to a central monitoring system. Workers should be advised to wear a personal detection monitor preferably over the chest pocket or on the collar, i.e. as close as possible to nose;
- Breathing apparatus: all personnel must be well versed in the use of breathing apparatus;
- Two workers should work together called "buddy" system;
- Oil free, electric compressors must be used to pressurize the cylinders and the air must conform to breathing air standards as specified in BS 15879:2009 [8];
- Emergency response team: trained personnel for extraction, rescue and first aid when required;
- Permit to work system must be incorporated and strictly followed. Safety guideline resolution passed by International Maritime Organization (IMO) for entering enclosed spaces should be followed [9];
- All personnel should be aware of emergency response procedures and corrective actions. Periodical drills should be carried out for the same.

Conflict of interest: None declared

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