Nigerian Research Journal of Engineering and Environmental Sciences 9(2) 2024 pp. 594-603
p ISSN: 2635-3342; e ISSN: 2635-3350

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Review Article

A Review of Major Accidents in the Oil and Gas Industry and their Impact

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http://doi.org/10.5281/zenodo.14565692

ARTICLE INFORMATION

Article history:
Received 11 Sep. 2024
Revised 07 Oct. 2024
Accepted 26 Oct. 2024
Available online 30 Dec. 2024

Keywords:
Major
Accidents
Oil and gas
Industry
Impact

ABSTRACT

Accidents in the oil and gas industry are still prevalent despite efforts by operators and regulators to improve safety. This paper reviews accidents in the oil and gas industry and their human, environmental and economic impact. Peer-reviewed articles in journals, accident assessment reports and conference proceedings on accidents in oil and gas facilities and their impact were reviewed extensively. The findings revealed that poor safety management, mechanical failures due to unsafe design and corrosion, human error, failed operating procedures, negligence, natural events, inexperience and lack of adequate technical skills were mainly responsible for the accidents in the oil and gas facilities investigated. Also, accidents in oil and gas facilities have extensive catastrophic effects on the ecosystem and economy of the affected region/country. Good process safety management, adherence to safety rules and regulations, efficient and reliable equipment and well trained technical staff will greatly reduce the frequency of accidents in the oil and gas industry.

1. INTRODUCTION

Industries rely heavily on oil and gas for their power generation; therefore, there is need for exploitation, processing and storage to ensure global availability (Schmidt et al., 2016). The discovery of oil and natural gas in several parts of the world brought about industrial growth and also eased local and international transportation (Hassan, 2013). Refined petroleum products are essential for the survival of transportation industries and are also important sources of energy for homes and businesses (Al–Moubaraki and Obot, 2021). Fertilizers, plastics, medications, ammonia etc are by products of petroleum (Al–Moubaraki and Obot, 2021).

Due to the importance of oil and gas as the main sources of energy, petroleum refining installations and petrochemical plants have been built to produce refined petroleum products. Petroleum refining is a high risk operation due to the high levels of operating temperatures and pressures (Abbasi et al., 2020). These operating conditions make refineries susceptible to mechanical failures and corrosion, which can result in catastrophic accidents that may have adverse effects on man, environment and the economy (Ndubuisi et al., 2023; Okpala, 2024). Also, transporting petroleum products from the production centers to consumption locations entails risks, mainly oil spill which can cause extensive damage to ecosystems and loss to human society. From 1985 to 2001, petrochemical industries recorded the highest number of accidents in the European Union (Ramos et al., 2017).

According to Nivolianitou et al. (2006), 40 % of the accidents were due to human factors and 44 % due to equipment. Random events and natural phenomena could also be responsible for major accidents in the oil and gas industry (Nivolianitou et al., 2006). Therefore, it is necessary to have a proper understanding of the cause(s) of or factors responsible for accidents in oil and gas facilities and their impact on the affected area(s). This will go a long way in averting or reducing accidents in oil and gas facilities

The aim of the review is to provide a detailed account of the cause(s) of or factors responsible for major accidents in the oil and gas industry and their human, environmental and economic impact.

2. METHODOLOGY

Peer-reviewed articles in journals, accident assessment reports and conference proceedings on accidents in the oil and gas industry were the materials used for the review. The materials were extensively reviewed and information on the nature of the accident, causes of or factors responsible for the accident and the impact of the accident on man, environment and economy were obtained.

3. ACCIDENTS IN THE OIL AND GAS INDUSTRY AND THEIR IMPACT

Accidents are caused by unsafe acts and conditions, and could thus be prevented through engineering, education, enforcement and encouragement (Briggs, 2002 as cited in Nkwocha et al., 2018). The causes of or factors responsible for some of the devastating accidents in the oil and gas industry and their human, environmental and economic impact are briefly reviewed in the subsections below.

3.1. Exxon Valdez Accident

The 987 feet tanker (Exxon Valdez) en route from Alaska to California struck a Bligh reef in Prince William Sound, Alaska spilling its content into the ocean on March 24th, 1989 (Skinner and Reilly, 1989). The Exxon Valdez oil spill was one of the largest oil spills in the history of United States of America (Iman et al., 2019). Approximately forty two thousand cubic metres of crude oil was released into the ocean, polluting at least one thousand nine hundred and ninety kilometers of natural littoral ecosystem (Peterson et al., 200).

Several factors could be attributed to the Exxon Valdez accident. According to Halley (2013), ExxonMobil shipping company was unable to provide sufficiently rested and capable crew for the tanker. The tanker's Raytheon Collision Avoidance System (RAYCAS) radar was disabled and not in operation for more than a year before the accident (Halley, 2013). Also, inspection by the US coast guard on the vessel was not performed before takeoff; and effective pilot and escort services were lacking according to Halley (2013).

The immediate effect/impact of the Exxon Valdez oil spill on marine animals in the Gulf of Alaska were the death of: 250 000 seabirds; 3000 sea otters; 300 seals; 250 bald eagles and 22 killer whales (Histroy.com Editors, 2018). In addition, the spill caused long - term changes in the ecosystem and that manifested in several sea animals as deformation, interrupted reproduction and a high probability of becoming preys (Peterson et al., 2003). The spill also affected the livelihood of local fishermen because of the depletion of pink salmon and pacific herring populations (Rousi et al., 2012). The spill also impacted the finances of ExxonMobil in terms of payment of compensations and fines. According to Knudsen (2009), ExxonMobil paid 900 million dollars for restoration efforts; 287 million dollars compensatory damages; 507.5 million dollars punitive damage and 15.8 million dollars for injury to Herring in 1989 and 7 million dollars in 1993. A decrease in the number of vacation/pleasure visitors due to the spill was also observed in the affected area according to a report by McDowell Group (1990). Impact Assessment Inc (1990) reported increased occurrence of psychiatric disorders of depression, general anxiety disorder and post- traumatic stress disorder in the inhabitants of the affected area(s).

3.2. Deepwater Horizon Accident

Deepwater Horizon (drilling platform) was leased to British Petroleum (BP) by Transocean (Makocha et al., 2019) and it is a semi – submersible drilling rig built in South Korea (Averill et al., 2022). The platform was built at the cost of 365 million dollars and was designed to operate in water as deep as 8000 feet and to drill to a depth of 30 000 feet (Makocha et al., 2019). On 20th April 2010, the platform (Deepwater Horizon) exploded and was engulfed by fire after a blowout which led to the sinking of the platform (Makocha et al., 2019; Averill et al., 2022). The explosion led to the death of eleven workers and injury to seventeen (British Petroleum, 2010); and caused the largest marine oil spill in the Gulf of Mexico, USA (McGuire et al., 2022).

The main reasons for the explosion and subsequent sinking of Deepwater Horizon (drilling platform) according to Averill et al. (2022) were:

- Cement Bond Log test which is meant to test the integrity of the cement was not conducted mainly to save cost.
- Pressure tests were conducted despite the fact that the Cement Bond Log test was not done previously. The positive pressure test was successful; however, the negative pressure test indicated pressure anomalies.
- A well kick followed which led to hydrocarbons and mud escaping from the well bore, causing a blowout.
- Eventually the gas migrated to an ignition source and resulted in two explosions and a class two conflagration fire engulfed the platform.

The emergency systems within the blowout preventer were activated in an attempt to shear the drill pipe and seal the well (Makocha et al., 2019). But all attempts were not successful.

The Deepwater Horizon oil spill caused extensive damage to marine and shoreline habitats, affecting both commercial and recreational fishing industries (Lin et al., 2016; Turner et al., 2016). The oil spill contaminated more than 1100 miles of coastline, 1200 square miles of the deep ocean floor and 68 000 square miles of surface water; about one million coastal and offshore seabirds died and more than 1000 sea turtles were found dead and thousands were exposed to oil according to the Natural Resource Defence Council (2015). Coastal vegetation was damaged and erosion rates increased in the affected areas due to the spill (Lin et al., 2016; Turner et al., 2016). According to Court et al. (2020), the total economic impact for ten years of foregone commercial fishing revenues and recreational fishing expenditures due to the spill were: a loss of over 25 000 jobs, $ 1.2 billion in total value added or gross regional product, $ 2.3 billion in industry output, $ 700 million in labour income, $ 160 million in state and local tax revenues and $ 160 million in federal tax revenues. Commercial and civil penalties were imposed on British Petroleum (Farber, 2014) as a result of the spill. These penalties are measured in billions of dollars (Farber, 2014), consequently the finances of the company were seriously impacted. British Petroleum paid $ 5.5 billion as civil settlements; $ 8.8 billion in natural resources damages and $ 4 billion in fines and penalties as a result of the spill according to Tatum and Strand (2017). Chemicals from the oil and dispersant were reported to have affected people living within the region the spill occurred and workers involved in cleanup. A 2012 survey of the health implications of the spill on cleanup workers reported eye, nose and throat irritation; respiratory problems; nausea and vomiting; skin irritation; short- term memory loss, liver and kidney damage etc (Makocha et al., 2019). Also, parents of children living within 10 miles from the coasts of the affected states (Lousiana and Florida) reported cases of bleeding ears in children and early start of menstruation among girls (Anderson et al., 2011).

3.3. British Petroleum (BP) Texas Refinery Accident

According to the U.S Chemical Safety and Hazard Investigation Board (2017), the BP refinery in Texas City, Texas, 30 miles southeast of Houston is the third largest refinery in the United States of America and can produce about 10 million gallons of gasoline per day (about 2.5 percent of the gasoline sold in the United States) for markets primarily in the Southeast, Midwest and along the East Coast. The refinery has 30 process units spread over 1,200-acre site, employs about 1,800 permanent BP staff and approximately 800 contract workers supporting turnaround work (Broadribb, 2006). The refinery was owned and operated by Amoco prior to the merger of British Petroleum and Amoco in 1999 and largely uses Amoco safety management systems pre-dating the merger (Broadribb, 2006).

Based on the report of the U.S. Chemical Safety and Hazard Investigation Board (2007), on the morning of March 23rd, 2005, the raffinate splitter tower in the refinery's isomerism (ISOM) unit was restarted after a maintenance operation. During the startup, operations personnel pumped flammable liquid hydrocarbon into the tower for over three hours without any liquid being removed, which was contrary to startup procedure instructions. Critical alarms and control instrumentation provided false indications that failed to alert the operators of the level of liquid hydrocarbon in the tower. Consequently, the 170 feet (52 m) tall tower was overfilled and liquid hydrocarbon flowed into the overhead pipe at the top of the tower. The overhead pipe ran down the side of the tower to pressure relief valves located 148 feet (45 m) below. Since the pipe was filled with liquid, the pressure at the bottom rose rapidly from about 21 pounds per square inch (psi) to about 64 psi. The three pressure relief valves opened for six minutes, discharging a large quantity of flammable liquid to a blowdown drum with a vent stack open to the atmosphere. The blowdown drum and stack overfilled with flammable liquid, led to a geyser-like release out of the 113-foot (34 m) tall stack. This blowdown system was an antiquated and unsafe design; it was originally installed in the 1950s and had never been connected to a flare system to safely contain liquids and combust flammable vapors released from the process. The released volatile liquid evaporated as it fell to the ground and formed a flammable vapour cloud. The most likely source of ignition for the vapour cloud was backfire from an idling diesel pickup truck located about 25 feet (7.6 m) from the blowdown drum. The disaster resulted in fatalities, injuries and financial losses.

In the explosion, three occupants in the Quality Assurance/Quality Control (QA/QC) trailer perished and 12 out of 20 workers inside the trailer were killed. A total of 180 workers at the refinery were injured as a result of the explosion and fire. The most severe blast damage occurred within the ISOM unit, from the trailer area to the catalyst warehouse and the surrounding parking areas. The satellite control room was severely damaged, and the catalyst warehouse was destroyed. Most of the approximately 70 vehicles in the vicinity of the isomerism unit were damaged. More than 40 trailers were damaged and 13 were destroyed as a result of the explosion. The fatalities, injuries, facilities and equipment damage presented in this paper are based on the report of the U. S. Chemical Safety and Hazard Investigation Board of 2007.

3.4. Bonga Oil Field Accident

The Bonga field is an oil field in Nigeria, located in licensed block OPL 212 off the Nigerian coast and later renamed OML 118 in February 2000. The Bonga oil field lies in water 1 000 meters deep covering an area of 60 km^2. It has the capacity to produce more than 200 000 barrels of oil and 150 million standard cubic feet of gas per day (Ejatlas, 2023). The commercial production of oil and gas at Bonga field started in November 2005, 120 kilometers off the coast of the Niger Delta (Ejatlas, 2023). The oil field is exploited via a floating, production, storage and offloading (FPSO) vessel. After the completion of the topside installation in 2004, the FPSO sailed to Nigeria and was installed at Bonga field by means of four groups of three mooring legs to begin operations. The vessel is connected to 16 subsea oil production and water injection wells and the connections use inconel clad Steel catenary risers. The Bonga FPSO has a storage capacity of 324,233 cubic meters (two million barrels of crude oil). The FPSO also had a gas export facility of 150 million standard cubic feet per day. It can also carry 10,970 cubic meters of diesel oil as well as 138,131 cubic meters of water ballast.

According to Penningtons Manches Cooper (2023), the Bonga oil spill was caused by a rupture in a flexible flow line connecting the Bonga oil field FPSO vessel to a single point mooring buoy. The rupture of the flexible flow line was attributed to corrosion (Obike et al., 2020). The leak occurred overnight during a cargo operation when crude oil was being transferred from the Bonga FPSO through the single point mooring buoy onto a waiting oil tanker, MV Northia. The leak was stopped after about six hours. Consequently, 40 000 barrels of crude oil leaked into the ocean.

The Bonga oil spillage affected more than 168,000 individuals from 350 communities in the Niger-Delta region of Nigeria (Eziukwu, 2015). The rich mangrove forest (encompassing 185 km of the Nigerian coastline), which provides 60% of fish breeding ground (Standing, 2008) was seriously affected by the spill. Also, the means of livelihood of approximately 28 000 fishermen were also affected by the spill (Eziukwu, 2015). Due to the loss of revenue and means of livelihood, some fishermen and farmers resulted to illegal activities (piracy, hostage taking and oil bunkering) as alternative means of survival (Onuoha, 2012).

3.5. Ghislenghien Natural Gas Pipeline Accident

The Ghislenghien disaster was an explosion of a natural gas pipeline which occurred on 30th July, 2004. According to the French Ministry for Sustainable Development (2009), the structure involved in the accident was an underground gas pipeline buried 1.10 m below the ground surface. The pipeline connected the port city of Zeebrugge (North Sea) with France. Two gas pipes were operating at a distance of 7 m apart at the accident site. One had a diameter of 90 cm and was built in 1982, while the other was 1 m in diameter and installed in 1991. The steel tubes were 13 mm thick.

According to Sulaima et al. (2014), at about 8:15 am, fire-fighters were notified of a gas leak in a zone of the Belgian city of Ghislenghien, approximately 50 km from Brussels. The leak on the 100-cm diameter gas pipeline was evidenced by a loud hissing, tremor and sudden creation of a cavity in the ground. At 8:30 am, fire-fighters requested the assistance of the gas utility crew and set up a safety perimeter. The leak increased in intensity, forming a whitish spray shooting some fifteen meters high. At about 9.00 am, an explosion occurred. The gas cloud ignited and produced a large "fireball" that later transformed into a long flare of approximately 150m-200m high. Investigators found out that the gas explosion was caused by a leaking pipe (Sulaima et al., 2014). Investigators attributed the leak to a potential mechanical aggression that weakened the pipe wall; 3 to 4 mm of material remained at the level of the scratch, thereby creating a zone of lower pressure resistance (French Ministry for Sustainable Development, 2009).

The consequences of the explosion according to the French Ministry for Sustainable Development (2009) were: the death of 24 people; destruction of a 4,000-m² cardboard mill, a filling station, a large number of roofs and cars; and many agricultural fields.

3.6. Sendai Refinery and Petrochemical Complex Accident

The Tohoku earthquake occurred on 11th March 2011 in North Eastern Japan followed by a tsunami caused several accidents in the pacific coast of Japan (Saeki and Kiyono, 2015). Different types of accidents such as infrastructural damage, explosion of stored compounds and equipment failure occurred in the industrial sites within the area (Ricci et al., 2022). Several industries were affected by the earthquake and tsunami (Bird and Grossman, 2011). One of such industries is the Sendai refinery and petrochemical complex. The refinery and petrochemical complex built in 1971, occupies an area of 1.5 km^2 in the port city of Sendai and has a refining capacity of 145 000 barrels per day (French Ministry of Ecology, Sustainable Development and Energy, 2013).

According to the French Ministry of Ecology, Sustainable Development and Energy (2013), an earthquake (Mw 9.0) (Zama et al., 2012) which occurred off the pacific coast of Tohoku at 2.46 pm led to emergency shutdown of facilities power outages and burning of uncooled liquefied petroleum gas stockpiles. Shortly, tsunami arrived in a series of waves that affected a lot of facilities within the petrochemical complex.

The tsunami and ground motions damaged oil storage tanks, pipelines and other hazardous materials facilities within the refinery and petrochemical complex (Zama et al., 2012; Krausmann and Cruz, 2013). Many pipelines were broken, and oil leaked from the damaged pipes to the surroundings causing extensive pollution problems (Krausmann and Cruz, 2013). According to the report released by the Fire and Disaster Management Agency (2011), 1807 and 1404 hazardous materials facilities were destroyed by the tsunami and ground motion respectively. In addition, there were fire outbreaks in 42 facilities and oil leakages occurred in 122 facilities. Based on the report of the French Ministry of Ecology, Sustainable Development and Energy (2013), the earthquake damaged the catalytic cracking reactor and supports/foundations of the heat exchangers. Also, the ministry reported that seaside erosion; damage of tanker loading stations; damage of pipe racks; destruction of electric motors; electrical substations; control rooms and submersion of control rooms and equipment. Several oil refineries in Japan stopped operations immediately after the earthquake and tsunami (Nishimura, 2015). Consequently, oil shipments from oil terminals in the pacific region were greatly affected (Petroleum Association of Japan, 2012 as cited in Saeki and Kiyono, 2015).

3.7. Tianjiayi Chemical Plant Explosion

The Tianjiayi chemical plant is located in the Chenjiagang chemical industrial park, Xianshui County, Yancheng, Jiangsu, China (Zhang et al., 2023). The chemical plant established in April 2007 is situated in the south of the industrial park and produces chemicals such as fertilizer and pesticides (Zang et al., 2019; Marsh Jlt Specialty, 2020). The explosion at the chemical plant occurred on 21st March, 2019. Based on the report of the China Earthquake Network Centre (CENCE), the magnitude of the explosion was approximately 2.2; the focal point was 0 km; occurred at 14.48 local time and with an epicenter of 34.334 ^{o}N 119.776 ^{o}E (Song et al., 2022).

According to the report of the investigations, the chemical plant was responsible for the explosion because it neglected the laws/rules governing environmental protection and safety in dealing with chemical wastes (Zhang et al., 2019). The spontaneous ignition of chemical wastes illegally stored for long period of time was the root cause of the explosion (Zhang et al., 2019).

The explosion was catastrophic with extensive destructive effects. The explosion resulted in 78 deaths, 76 serious injuries and a total of 640 people hospitalized (Zhang et al., 2019; Zhang et al., 2023). The direct economic loss as a result of the explosion was approximately 1.986 billion yuan (Zhang et al., 2023).

3.8 Skikda Liquefied Natural Gas Plant Explosion

The liquefied natural gas plant is located in the industrial zone of Skikda in the Gulf of Stora, Algeria (Bouras et al., 2024). The petrochemical plant is owned by Sonatrach (state owned oil company) and had six liquefied natural gas producing units called trains (Ouddai et al., 2012). Trains 10, 20, 30 and 40 are located parallel to one another east of the LNG storage area and the remaining trains 5P and 6P are cited on the west side of the storage tanks (Potent and Partners, 2004). The Hassi R' Mel gas field supplies the LNG plant with natural gas via pipelines (Potent & Partners, 2004). Trains 10, 20, 30 and 40 each have a design capacity of about 1.1 Bcm/y (0.85 MMt/y); while trains 5P and 6P are larger with a design capacity of some 1.64 Bcm/y (1.25 MMt/y) each (Potent &Partners, 2004). According to the National Association of State Fire Marshals (2005), at 6.40 pm a control room operator observed that the pressure within the boiler was rising rapidly. The operator tried to correct the anomaly by decreasing fuel flow to the boiler. However, the boiler's pressure relief valve was activated before that could happen. Another operator close to an adjacent LNG unit noticed a vapour cloud forming near the boiler. The leaking gas was drawn into the boiler via its air inlet fan. Consequently, the gas combined with the right quantity of air in the boiler's firebox and exploded.

According to the official investigation report, the explosion was caused by the failure of one of the cold boxes in unit 40; which leaked liquefied natural gas or refrigerant to the atmosphere and a vapour cloud was formed over unit 40 (Ouddai et al., 2012). The vapour cloud was ignited and that led to explosion and fireball.

According to the National Association of State Fire Marshals (2005), the explosion resulted in the death of 27 people and 74 injuries. Three liquefaction units and buildings were destroyed (Ouddai et al., 2012). The capacity of the plant reduced after the accident and financial losses to the tune of 900 million United States dollars were incurred by the company (Ouddai et al., 2012).

3.9. AZF Fertilizer Plant Explosion

The AFZ fertilizer plant located South of Toulouse, France belongs to Grande Paroisse Company which is a branch of Total Fina Elf Chemical Group (French Ministry of Sustainable Development, 2013). The plant is involved in the production of nitrogeneous fertilizer, industrial nitrates and chlorine-containing compounds (Dechy and Mouilleau, 2004). At 10:17 am, a severe explosion (detonation) occurred in warehouse No. 221 at the AZF fertilizer plant in Toulouse with catastrophic effects (Dechy et al., 2019). According to the French Ministry of Sustainable development (2013), about 400 tonnes of downgraded, off – specification ammonium nitrate was stored in Warehouse No. 221. Some of the stored products were used for the production of fertilizer and others were dedicated for the production of explosives. Based on the concentration of ammonium nitrate present in the stored materials the potential risk of explosion was high.

From other workshops, rejected materials were brought to an inlet area by subcontractors and pushed into the building via transport equipment. Complex fertilizers were produced from the stored materials by recycling. Materials from the packing and production workshops were brought into the building on the morning of the explosion (Dechy et al., 2019). The last batch of material was transferred into the building less than 30 minutes prior to the explosion (Dechy et al., 2019). The explosion was felt several kilometers away and dust fallout from the installations and a crater was observed outside the plant (French Ministry of Sustainable Development, 2013).

The direct cause of the accident/explosion is not known. It is believed that the management of the company failed in its safety management of ammonium nitrate based waste products (Dechy et al., 2019). Waste materials containing chlorinated compounds were mistakenly mixed with ammonium nitrate based waste materials (Dechy and Mouilleau, 2004). Consequently, there was a reaction between the waste materials which produced an unstable substance that is highly sensitive and capable of exploding (French Ministry of Sustainable Development, 20130.

According to Dechy et al. (2019), there were 30 fatalities which comprises of workers in the plant and nearby residents; about 10 000 people were injured, and 14 000 people suffered post traumatic acute stress. Based on the French Ministry of Sustainable Development (2013), a river was polluted due to the release of nitrogen- containing substances from the plant. Also, 27 000 houses; 17 schools; 26 high schools and universities were damaged as a result of the explosion (Dechy and Mouilleau, 2004). One thousand (1000) companies were damaged which resulted in job and financial losses (Lang et al., 2007).

4. CONCLUSION

Poor safety management, mechanical failures due to unsafe design and corrosion, human error, failed operating procedures; negligence, faulty equipment, natural events, inexperience and lack of technical skills were mainly responsible for the accidents in the oil and gas facilities. Accidents in the oil and gas industry have extensive destructive effects on the ecosystem and economy of affected area(s). Therefore, concerted efforts should be made by operators and regulators of the industry to reduce accidents.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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