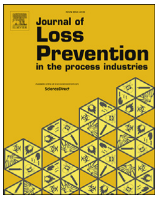
ARTICLE IN PRESS

Journal of Loss Prevention in the Process Industries xxx (2017) 1–11

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

journal homepage: www.elsevier.com/locate/jlp



An autonomous underwater robot for tracking and monitoring of subsea plumes after oil spills and gas leaks from seafloor

Naomi Kato [a,*], Mahdi Choyekh [a], Ryan Dewantara [a], Hidetaka Senga [a], Hajime Chiba [b], Eiichi Kobayashi [c], Muneo Yoshie [d], Toshinari Tanaka [e], Timothy Short [f]

[a] *Department of Naval Architecture and Ocean Engineering, Osaka University, 2-1, Yamadaoka, Suita, Osaka 565-0879, Japan*
[b] *Department of Maritime Technology, National Institute of Technology, Toyama College, 1-2 Ebie-neriya, Imizu, Toyama, 933-0293, Japan*
[c] *Graduate School of Maritime Sciences, Kobe University, 5-1-1, Fukae-minamimachi, Higashinada-ku, Kobe, 658-0022, Japan*
[d] *Management Strategy Office, National Institute of Maritime, Port and Aviation Technology, 6-38-1, Shinsen, Mitaka, 181-0004, Japan*
[e] *Frontier Technology and Engineering Division, Port and Airport Research Institute, National Institution, 3-1-1, Nagase, Yokosuka, 239-0826, Japan*
[f] *Space and Marine Technology Program, SRI International, 450 8th Avenue SE, St. Petersburg, FL 33701, USA*

ARTICLE INFO

Article history:
Received 15 June 2016
Received in revised form
9 October 2016
Accepted 7 March 2017
Available online xxx

Keywords:
Autonomous underwater robot
Monitoring
Water column profiles
Dissolved substances
Water currents

ABSTRACT

To response to the lessons from The Deepwater Horizon oil spill accident off Louisiana in the Gulf of Mexico in 2010, an autonomous underwater robot was proposed and tested for early detection and monitoring system as one technological measure around offshore oil and gas production systems. The mission of the robot is to monitor not only detailed structure of oil and gas plumes in the water columns, but also time-varying structure of transportation of oil droplets in 3-D space. It was found that the proposed system using an autonomous underwater robot is capable of in situ measurement for dissolved substances as well as oceanographic data and water current profiles in water columns which are indispensable to early detection and monitoring of oil spills and gas leaks from offshore oil and gas production platforms. The robot can provide oceanographic simulation with the real-time data to precisely grasp the 3-D structure of oil and gas plumes as a data assimilation scheme between an autonomous underwater robot and oceanographic simulation.

1. Introduction

There have been many major sea oil spills in recent years releasing large amounts of oil, and causing fatalities and huge economic losses. In addition, oil spills damage not only the ocean environment but also regional economies. Once spilled oil washes ashore, it is difficult to recover it effectively. This results in a high residual amount of spilled oil and long-term damage to the environment as well as to marine and human life.

As an example, the Ixtoc-I (Atwood, 1980) platform located in the southwestern Gulf of Mexico (GOM), and owned by Mexico's government's oil company Pemex, released an estimated 3.3 million m^3 of oil for nearly 10 months staring on June 3, 1979.

In another example, the Piper Alpha, a North Sea oil production platform operated by Occidental Petroleum (Caledonia) Ltd., began production in 1976. In July 1988, the platform suffered an explosion, and the resulting oil and gas fires killed 167 men and completely destroyed the platform (Mcginty, 2008). At the time of the disaster, the platform was responsible for approximately 10% of North Sea oil and gas production and it was the worst offshore oil disaster in terms of lives lost and industry impact. On April 20, 2010, the Deepwater Horizon (DWH) oil rig exploded killing 17 people, and resulting in one of the worst oil spill disasters in the history of the United States. The oil spill from the seabed continued for 87 days until it was capped on July 15, 2010. The US Government estimated the total discharge at 0.57 million kL (National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, 2011). This oil spill accident is considered the largest in the history of the petroleum industry. Finally, a recent gas leak accident occurred on March 25, 2012, at the wellhead platform on the Elgin gas field, which is in the UK's North Sea approximately 240 km east of Aberdeen and is operated by the French energy group Total. The gas leak resulted in the shutdown of production and the evacuation of personnel. The leak continued for over 7 weeks, and it was stopped after well intervention work on May 16, 2012 (Wilson et al., 2013).

After the DWH oil spill accident, the National Commission on

---

* Corresponding author.
E-mail address: naomikato05@gmail.com (N. Kato).

http://dx.doi.org/10.1016/j.jlp.2017.03.006
0950-4230/

Please cite this article in press as: Kato, N., et al., An autonomous underwater robot for tracking and monitoring of subsea plumes after oil spills and gas leaks from seafloor, Journal of Loss Prevention in the Process Industries (2017), http://dx.doi.org/10.1016/j.jlp.2017.03.006

the Deepwater Horizon Oil Spill and Offshore Drilling (2011) was created as an independent and non-partisan entity by the US President to determine the causes of the disaster and to improve the country's ability to detect and respond to spills and to recommend reforms to make offshore energy production safer. Among those recommendations, the commission pointed out the need to systematically collect critical scientific data, fill research gaps, and provide comprehensive, ecosystem-based scientific reviews of Outer Continental Shelf areas that are currently or will likely be open for oil and gas leasing. Furthermore, it called for increased research and development to improve oil spill detection in deep waters, and oil spill response, and area where there is still much to be done.

Following the DWH oil spill, several researchers have investigated oil and gas plumes in vertical water columns concerning the physical, chemical and biological aspects near the site of the DWH oil well from which large quantities of oil and gaseous hydrocarbons such as methane were released into the deep ocean. Ryerson et al. (2012) measured initial hydrocarbon compositions along different transport routes to the deep subsurface plumes, the surface slick, and the atmosphere during the DWH oil spill. They reported that the primarily soluble mixture detected in subsurface plumes made up about 35% of the leaking mass and that the insoluble, non-volatile mixture detected in the surface slick made up about 10% of the leaking mass. Reddy et al. (2012) collected and analyzed the endmember sample of gas and oil that flowed from DWH. Using the federally estimated net liquid oil release of 0.48 million kL, they estimated that the total C1–C5 hydrocarbons (methane, ethane, propane, butane, pentane) released to the water column was 1.7×10^{11} g. Their results showed that most of the C1–C3 hydrocarbons and a significant fraction of water-soluble aromatic compounds were retained in the deep water column, whereas the relatively insoluble petroleum components were predominantly transported to the sea surface or deposited on the seafloor. Joye et al. (2011) reported layers of dissolved hydrocarbon gases at between 1000- and 1300-m depth, where concentrations exceeded background levels. They suggested that microbial consumption of these gases could lead to large-scale and long-term exhaustion of oxygen in the hydrocarbon-enriched waters. White et al. (2012) found that coral colonies at one site 11 km southwest of the Macondo well showed widespread signs of stress and strong evidence that flocculent material associated with corals contained oil from the Macondo well.

On the other hand, with respect to transportation of oil droplets in 3-D space, there was the possibility that some portion of the hydrocarbons issuing from the DWH wellhead would remain in subsurface water to be carried by the prevailing ocean circulation. Noth et al. (2011) used an analytical multi-phase plume model combined with time-varying flow and hydrographic fields generated by a 3D hydrodynamic model as input to a Lagrangian transport model to simulate the transport of oil droplets dispersed at depth from the DWH oil spill. They reported that the plume model predicted a stratification-dominated near field, where small oil droplets were trapped by density stratification. Their simulated droplet trajectories showed that droplets with diameters between 10 and 50 μm formed a distinct subsurface plume, which was transported horizontally and remained on the subsurface for more than 1 month. In contrast, droplets with a diameter greater than 90 μm rose rapidly to the surface.

Unfortunately, all of these studies have been much after the disaster. We can learn that early detection and monitoring systems should be established inside and around offshore oil and gas production systems during production and in the case of accidents. We can also learn that not only the detailed structure of the oil and gas plumes in the water columns, but also the time-varying structure of transportation of oil droplets in 3-D space should be monitored from the physical, chemical and biological aspects after large scale oil spill accidents to adequately respond to spilled oil and gas.

However, few existing compact systems can conduct a complete water survey for early detection and monitoring that can measure oceanographic data as well as underwater currents and dissolved gases simultaneously around an offshore oil and gas production system. Based on the collected information, oil and gas drifting simulations must be performed to predict where spilled oil will wash ashore and to adequately deploy oil recovery machines before this occurs.

The early detection and monitoring of not only the detailed structure of oil and gas plumes in the water columns, but also time-varying structure of transportation of oil droplets in 3-D space around an offshore oil and gas production system can also be done during hurricanes and other storms. These conjoint natural hazard triggered technological accidents are known as Natechs. Cruz and Krausmann (2009) documented hundreds of oil and gas spills from offshore production systems during Hurricanes Katrina and Rita in the Gulf of Mexico..Given the difficulty to detect and respond to spills, oil spills related to the two storms were being reported event one year after the hurricanes.

2. Technological measures for preventing the spread of oil spills and gas leaks

To prevent oil spills and gas leaks from spreading and causing further damage to the environment over time, early detection and monitoring systems should be deployed around the offshore oil and gas production system. If an accidental oil spill occurs, the exact location of the drifting oil and the meteorological and oceanographic data should be collected in real time so that oil recovery operations can be coordinated smoothly. Based on the collected information, oil and gas drifting simulations must be performed to predict where the spilled oil will wash ashore and to adequately deploy oil recovery machines before this occurs.

Leak detection technologies mainly consist of internal systems monitoring the internal state of equipment, external systems monitoring the external state of equipment, and periodic leak monitoring systems. For example, internal systems can detect leaks indicated by changes in flow imbalance. An underwater station installing sensors such as an optical camera, biosensor, and fluorescent sensor is one such external system solution for long-term monitoring in a fixed position. Remotely operated vehicles and autonomous underwater vehicles are used in periodic leak monitoring systems. Substance dissolution measurements can be made using an underwater station for a long period at a fixed position, or unmanned underwater vehicles can install the corresponding sensors periodically over a wide area. An underwater station or an unmanned underwater vehicle is usually utilized to monitor a particular substance, such as oxygen, methane, or carbon dioxide. This method can provide continuous information regarding the dissolution of substances, but only for a particular and limited variety of substances. On the other hand, an underwater mass spectrometer (UMS) can detect the dissolution of multiple substances simultaneously (Short et al., 2006).

In addition, the measurement of underwater currents is important for detecting and tracking dissolved gases and for predicting the evolution of the leaked gas in simulation models. Few existing compact systems are able to conduct a complete survey that can measure salinity, temperature, and depth as well as underwater currents and dissolved gases simultaneously that considerably affect three significant processes: formation and decomposition of gas hydrate and dissolution of gas (Zheng and Yapa, 2002, 2003). In the Deep Spill experiments in Norway, for

Please cite this article in press as: Kato, N., et al., An autonomous underwater robot for tracking and monitoring of subsea plumes after oil spills and gas leaks from seafloor, Journal of Loss Prevention in the Process Industries (2017), http://dx.doi.org/10.1016/j.jlp.2017.03.006