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Hazardous materials analysis and disposal procedures during ship recycling

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ABSTRACT

Dismantling end-of-life ships in an environmentally sound and safe manner is of great concern as well as being a major challenge nowadays. When dismantling the vessel, on-board hazardous materials such as asbestos, polychlorinated biphenyls (PCBs), glass fibre, solid foam and waste oil can incur severe negative implications on the environment and human health. The characteristics and harm of on-board hazardous materials are profiled in this paper. Current removal and disposal methods of hazardous materials are analysed. Further practical measures and suggestions to deal with the hazardous materials in the ship breaking yards are proposed. Two case studies about green disposal of the main hazardous materials during shipbreaking are presented. Both of the two companies are following Hong Kong Convention and verified by DNV-GL classification, which makes the recycling procedures of hazardous materials are quite similar to each other. In essence, more attention should be paid to the disposal of hazardous materials as integral to safe and environmentally sound practices when breaking the ships.

1. Introduction

Ships are typically disposed of after a life span of 22–30 years (Mikelis, 2008; Deshpande et al., 2012). Ship recycling, as referring to breaking up a ship and recycling its constituent materials, is generally considered the best choice for sustainable development. The global ship recycling industry has moved to developing countries such as India, Bangladesh, Turkey, Pakistan and China (Mikelis, 2008; Deshpande et al., 2012; Ormond, 2012; Hiremath et al., 2015; Rahman and Mayer, 2015). Ship recycling industry is becoming an important part of the economy for Asian developing countries, with strong internal demand for the recovered steel, but suffers from various constraints such as lack of labour and environmental standards (Puthucherril, 2010; Glisson and Sink, 2006; Chang et al., 2010; Yujuico, 2014). End-of-life ships sent to the breaking yards for recycling are often encumbered with hazardous materials and chemicals such as asbestos, polychlorinated biphenyls (PCBs), glass fibre and solid foam, which can have severe negative implications on the environment and human health (Sonak et al., 2008; Neşer et al., 2008; Harris and Kahwa, 2003). Recycling end-of-life vessels in an environmentally friendly manner is a major challenge faced by ship owners, ship breaking yards as well as government agencies worldwide.

Safety precautions in ship breaking yards in developing countries are notoriously scarce, accident rates are high and deaths frequent, whether by falling from height, explosions, toxic fumes, snapping cables or other causes. Investigation of occupational noise exposure in a ship recycling yard showed that ship recycling workers are at risk of experiencing occupational noise and there is a lack of appropriate hearing protection being used in ship recycling yards (Kurt et al., 2017). To this must be added the long-term harmful effects of exposure to hazardous materials, such as asbestos, which are contained in the structure of many old ships. Standardship recycling methods must follow strict regulations, and therefore, can only release negligible amounts of hazardous substances into the environment. As a norm, ship breaking yards in developing countries operate little or only rudimentary facilities in dealing with on-board hazardous wastes, as commensurate with the generally poor infrastructure for waste management (Ormond, 2012). Neşer et al. (2012) investigated the concentrations of heavy metals and organic carbon in sediment of the Aliaga Bay in Turkey caused by ship recycling when evaluating an environmental risk assessment from metals contamination in 2009–2010, and the results showed that the sediments contaminated with heavy metals were considered as heavily polluted per the sediment quality guidelines. Zakaria et al. (2012) identified the underlying problems of ship

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recycling industry and therein analysed the nature of the problems aimed towards overcoming the obstacles in Bangladesh, suggesting that well-designed plan focusing on technological, safety and environmental issues must be ensured to avoid human causalities of ship-recycling industry in Bangladesh. The social and environmental impacts of the ship recycling in Bangladesh were presented by Hossain (2015), by considering the positive economical contributions and negative effects like lack of occupational health and safety standard. Choi et al. (2016) pointed out that standard ship recycling methods must follow strict regulations, and therefore, can only release negligible amounts of hazardous substances into the environment. Du et al. (2017) carried out field survey and found that Chinese large-scale ship recycling yards have been applying advanced practices as much as possible to protect environment and safety of workers. Du et al. (2017) analysed the challenges of ship recycling industry in China by evaluating the dismantled steel market and price, tax policy and investment cost of ship recycling yards, major laws and regulations related to ship recycling industry, and also proposed solutions and strategies for Chinese ship recycling companies in order to strengthen international competitiveness of the ship recycling industry. Garmer et al. (2015) developed a three-step risk assessment method that offered a systematic pedagogic approach for the "analysis team" comprising production managers, safety officers, safety supervisors and the designated expert monitor to reduce risks and enhance safety at ship recycling yards, and the method appeared to give consistent results in a variety of validated scenarios.

In practice, many problems on safety and environment are still not adequately resolved. The focuses of the present study are to analyse on-board hazardous materials, and discuss the removal and disposal methods of these hazardous materials during ship recycling. The green disposal methods of typical hazardous materials in Chinese large-scale ship recycling yards are presented. Opportunities and challenges of green ship recycling are also studied. The findings shall provide useful pointers towards the management of occupational risk as well as environmental protection in ship recycling process, and thereby promote the sustainable development of ship recycling industry at large.

2. Methodology

An in-depth review of the literature was first conducted to identify the hazardous materials during ship recycling. The literature review focuses on the hazardous materials and their disposal methods during ship recycling. The hazardous materials on-board ships are handled in compliance with the Hong Kong Convention for the safe and environmentally sound recycling of ships. On-site observation and survey were carried out to study the disposal methods for the hazardous materials. The survey was conducted in several ship recycling companies of different sizes, such as Changjiang Ship-Breaking Yard (with an area of 370 acres), Zhoushan Changhong International Ship Recycling Co., Ltd (with an area of 1500 acres and about 2,000 m coastline), Tianma Ship Recycling Yard (with an area of 101 acres and 1,000 m coastline), Jiangmen Zhongxin Shipbreaking & Steel Co., Ltd, and so on. Firstly, face-to-face interview and survey were carried out with the managers or the people familiar with the procedures in those ship recycling companies. Thereafter, the ship recycling dock, ship recycling process, yard layout, information about the equipment and facilities in ship recycling yards were obtained. We obtained those materials which could be harmful to health and safety of workers from the release of toxic gases into the air during breaking. Therein, a series of hazardous materials such as asbestos, PCBs, glass fibre, solid foam, waste oil and so on were identified and analysed based on the review of the literature and on-site observation. The scope of the study follows the scheme as represented in Fig. 1.

3. On-board hazardous materials and their recycling methods

An ocean-going vessel, like a miniature city, generates all kinds of contaminants such as liquid, metal, gaseous, chemical and solid pollutants (Du, 2012; Du et al., 2012). Hence, ship recycling activities are perilous in terms of environment, human health and biodiversity. The application and harm of key typical hazardous materials are summarised in Table 1 (Galley, 2014; IMO, 2015).

During shipping recycling, on-board hazardous materials which can be harmful to humans, animals and the environment are distributed widely in varying amounts and are generally difficult to deal with. Knowing how to remove and dispose of hazardous materials is imperative for considerations of occupational health and environment. Removal and disposal of end-of-life vessels in an environmentally sound and safe manner is a major challenge today. The emphasis of this study is a "bottom up approach" in solving practical and operational issues on how to handle hazardous materials generated during the recycling process of ships and how to further improve the focus on health, safety and environment at recycling facilities, so as to provide rational and practical basis for designing and constructing cost-effective and safe ship recycling facilities.

3.1. Asbestos

Asbestos is a set of six naturally occurring silicate minerals (Alleman and Mossman, 1997), all of which have in common their eponymous asbestiform habit, long (roughly 1:20 aspect ratio), thin fibrous crystals, with each visible fibre composed of millions of microscopic "fibrils" that can be released by abrasion and other processes (Gee and Greenberg, 2001). Asbestos was used in old ships as thermal system insulation and surfacing material (Devouard and Baronnet, 1995). It usually exists in the propeller shafting, diesel engine, turbine engine/steam turbine, boiler, exhaust gas economiser, incinerator, auxiliary machinery, heat exchanger/heaters, valve, pipe, dust, tank, electric equipment, ceiling, floor and wall in accommodation area, galleys and messes, fire insulation, inert gas system, air conditioning system, and miscellaneous.

When asbestos-containing materials are damaged or disturbed by demolition activities, microscopic fibres become airborne and can be inhaled into the lungs where they can cause significant health problems (Selikoff and Lee, 1978; Frank, 1993; Yano et al., 2001; Franke and Paustenbach, 2011; Strohmeier et al., 2010; Le et al., 2011). Currently, approximately half of the deaths from occupational cancer are estimated to be caused by asbestos (WHO, 2016). So, effective detection method and concentration allowance will provide references for ship-breaking facility to make scrapping plan and apply handling technology. Current detection methods and specifications of asbestos (Li and Tong, 2015) are given in Table 2. The proper procedure of dealing with asbestos in green ship recycling yards is shown in Fig. 2.

The procedures to handle asbestos-contained material (ACM) are as follows. Enclosed space is to be created to prevent asbestos dust spreading in the air. Workers should wear personal protection equipment. Water is sprayed onto asbestos-contained material (ACM) so that the components are dismantled in pieces without breaking upon full wetting. Compact special vacuum cleaner is used to absorb the ACM dust that is dropped onto the floor. The ACM is packed into the plastic bags of designated thickness and temporally stocked in the special lockup room with WARNING marks. Finally, the ACM is sent to a qualified company for final burial.

3.2. PCBs

Polychlorinated biphenyls (PCBs) is a mixture of synthetic organic chemicals bearing the same basic chemical structure, similar physical properties and chemical properties as belonging to a broad family of man-made organic chemicals known as chlorinated hydrocarbons. It was first used as early as 1929, and was banned in 1979 according to U.S. Environmental Protection Agency (USEPA), given its toxicity. PCBs come in different forms from thin light liquid to yellow or black waxy