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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.

Key words: Ship recycling; hazardous materials; disposal methods; practical measures

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, 2009; Glisson and Sink, 2006; Chang, 2010). 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 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 casualties 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 1,500 acres and about 2,000 metres coastline), Tianma Ship Recycling Yard (with an area of 101 acres and 1,000 metres 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 Figure 1.

Figure 1 Workflow of the study

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).

Table 1 Primary hazardous materials and their properties

Materials	Locations	Hazardous properties
Asbestos	Used as lagging, especially in engine room. Now largely replaced by rock wool.	It may remain in suspension for a long time, and accumulates in lungs causing lung cancer, asbestosis and mesothelioma. Symptoms may not show up until many years after exposure.
Polychlorinated biphenyls (PCBs)	In a wide range of materials, including cable insulation, transformers, capacitors, switches, some paints, pumps, cranes etc.	Carcinogenic, bioaccumulative. Associated with cancer, liver, neurological and immune system damage.
Ozone depleting substances (CFCs, HCFC, etc.)	Blowing agent for insulation of LNG carriers, extinguishing agent, refrigerant for refrigerating machine.	Environment pollution.
Organotin compounds (TBT, TPT, TBTO)	Anti-fouling paint on ship's bottoms.	Contaminate sea products, potential hazardous effect on human health.
Glass wool	Glass wool board, glass wool felt, glass wool pipe, shell of glass fibre products.	Toxic as similar to asbestos.
Heavy metal—lead	Paints, cabling, batteries, motors and generators.	Damage to neurological system, hearing, vision, reproductive system, blood vessels, kidneys and heart, especially children's physical and neurological development.
Heavy metal—mercury	Light fittings, luminescent lamps, switches, thermometers.	Toxic, bioaccumulative and affect nervous system.
Oil and fuel (including hydraulic and lubricating oils, engine oil and grease)	Bunkers, bilges, fuel systems and engine room generally.	Poisonous through inhalation or consumption of contaminated water or fish. May result in fire and explosion.

Bilge water	Accumulated stagnant water in bilges.	Contain a range of pollutants: oil, inorganic salt, heavy metals, etc.
Ballast water	Fresh or salt water taken on board ballast tanks to adjust ship's trim and stability.	May contain bacteria and viruses, also persistent invasive organisms and sediments.
Polyvinyl chloride (PVC)	In many materials, including plastics, cable coatings, floor coverings.	May induce cancers, asthma, and impairment to human reproduction systems. Burning may generate carbon monoxide, and highly toxic dioxins and furans etc. Burial can release chemicals to groundwater.

Note: CFCs—Chlorofluorocarbons, HCFC—Hydrochlorofluorocarbon, TBT—Tributyltin, TPT—Triphenyltin, TBTO—Tributyltin oxide

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 shipbreaking 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 Figure 2.

Table 2 Detection methods and specifications of asbestos

Test method	Characteristics	Related regulations
PCM	Cannot identify the types of fibres; suitable for asbestos fibres length exceeding 5mm and aspect ratio exceeding 3.	USA: NIOSH 7400-1994, ASTM D 6620, ASTM D 7200-2006, ASTM D7201-2006; Japan: JIS K 3850-1-2000, JIS A 1481-2014; China: GB 16241-1999, HJ/T 41-1999.
PLM	Easy and cheap, not suitable for sample containing lots of asbestos fibres. False negative is one of its common defects.	China: GB/T 23263-2009, GB/T5480.4-2004; USA: NIOSH 9002-2002, EPA/600/R-93/116, HJ/T206-2005, JIS A1481-2014, JIS K 3850-4-2000, ELAP198.6 ISO 22262-1-2012.
TEM	Because of the advantage of resolution and	Air: ASTM D 5755-2003, ASTM D 5756-2002, ASTM

magnification, it is accepted by many international standards. But many countries such as China do not recommend using it because of high cost and complex sampling.

D 6281-2009, VASTM D7201-2006, EPA/600/J-93/167, ISO 13794-1999, ISO 10312-1995, EPA 540/2-90-005a, ASTM D 7200-2006, NIOSH 7402-1994, ISO 22262-1-2012;

Water: EPA/600/R-83-043, EPA/600/R-94-134;

Soil and products: EPA/540/R-97-028, ASTM D6480-1999, EPA/600/R-93-116.

SEM Higher resolution and magnification, easy sample treatment, available for elements of asbestos fibre. But defects exist in solid sample pre-processing.

ISO 14966 - 2002, ASTM D 7201 - 2006, ASTM D 7200-2006, ELAP Item 198.2, EPA-600/R-93/116, ON M 9405, ISO 22262-1-2012.

XRD Small amount of sampling, fast and effective, but expensive. Cannot identify asbestos when content lower than 1%.

EPA/600/R-93-116, JIS A 1481-2014, NIOSH 9000-1994, GB/T 15344-1994.

Note: PCM—Phase Contrast Microscopy; PLM—Polarized light microscopy; TEM—Transmission Electron Microscopy; SEM—Scanning Electron Microscopy; XRD—X-ray Diffraction; ASTM—American Society for Testing Material; NIOSH—National Institute for Occupational Safety and Health; JIS—Japanese Industrial Standards; ISA—International Standardisation Organisation; EPA—Environmental Protection Agency

Figure 2 Procedure of dealing with asbestos in green ship recycling yards

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 solid. Due to their non-flammability, chemical stability, high boiling point and electrical insulating properties, PCBs were widely used in various industries. It was also widely used in ship building industry in the 1970s~1980s. Exposure to PCBs can cause a variety of adverse health effects in animals and humans, including cancer and serious non-cancer health effects.

PCBs used to be a hot topic in the study of environmental science (Harrad *et al.*, 1994; Zhou *et al.*, 2001; Meijer *et al.*, 2003). In recent years, experts in the field of environment have paid more attention to persistent organic pollutants like PCBs, and have carried out a large amount of research, including PCBs and its formation, reaction, migration, transformation and toxicology; its identification and repair in high risk area; its pollution reduction, controlling and alternative technologies; the environment investigation and detection method; its migration and transformation in different medium; its basic characteristics and the quantitative structure - activity relationship studies; its toxicity and ecological impact; elimination method of its pollution; analysis of known and unknown sources of pollution, etc.

PCBs can be found in both the solid (waxy) and liquid (oily) forms in equipment and materials on-board ships especially the older vessels. Due to the difficult sampling and measurement process, instead a so-called grey list which inventories suspected materials and equipment that may contain PCBs with concentration of at least 50 ppm was drawn up in the early 90's (UNEP, 1992).

Detection of on-board PCBs is important for its subsequent handling. The major general method of detecting the PCBs is 8082 Method proposed by the United States, including the sample extraction and chromatography method. The 8082 Gas Chromatographic Method consists of application scope, overview of the methods, interference, equipment and raw materials, reagents, sample collection, preservation and preparation, operation, quality control and operation methods. The PCBs inspection is usually carried out in the United States, Germany, Japan and other developed countries. In China, there are clear legislative provisions about controlling wastes containing the PCBs, mainly for the PCBs wastes' controlling standards, testing methods, disposal methods and so on.

To remove the solid PCBs in the ship recycling industry such as cables, a cold mechanical way is to be applied, while burning is strictly prohibited. For liquid PCBs, such as capacitors and transformers, they are to be dismantled as one complete unit and sent to the professional company with certificate for the treatment. China has set up its own institution of the PCBs inspection and handling. The disposal procedure (Bi and Li, 2008) of PCBs in China is shown in Figure 3.

Figure 3 Procedures of recycling PCBs in China

3.3 Glass fibre

Glass fibre (wool) is a material consisting of numerous extremely fine fibres of glass. The use of a glass-wool reinforced composite in marine structures is becoming more common, particularly due to the potential weight savings (Li *et al.*, 2015). In ship building industry, glass wool board, glass wool felt, glass wool pipe, shell of glass fibre products are widely used. During ship recycling, the toxicity and waste recycling process methods of glass fibre require further improvement.

Glass fibre has increased in popularity ever since the discovery that asbestos causes cancer and its subsequent removal from most products. However, the safety of glass fibre is also being called into question, as research shows that the composition of this material can cause similar toxicity as asbestos (Infante *et al.*, 1996).

Glass fibre itself is non-toxic, but glass fibre monofilament is very fine, which is usually only a few microns in diameter. When monofilament is fractured into tiny filament, it is easily absorbed by the human body and deposited in the lungs (Bunsell, 2009; Hesterberg *et al.*, 2012). The damage of glass fibre on human body and environment is found mainly along following aspects: after contacting with the skin, sometimes it will cause local irritation and prurigo (Sertoli *et al.*, 1992); workers exposed to fibreglass may get conjunctivitis and keratitis; in severe cases, it may cause corneal haze and local abscess.

Glass fibre has not yet been listed as toxic and harmful items in Hong Kong Convention. Although the biological activity and pathological effect of glass fibre are not as severe as asbestos, the harm of glass fibre cannot be ignored. Because of the same toxic mechanism that the fibre dusts in the air cause damage to the human body, the treatment process and precautionary observations are the same as asbestos: no floating dust, keep materials wet in construction; workers should wear protection suit with goggles, gloves, protective masks or self-contained dust-proof respirators or respirators to avoid body parts being exposed to the air; the whole composite sheets can be recycled entirely after reasonable cutting or be used in heat insulating devices in transportation; the glass fibre products attached to pipelines can be collected, reworked and reshaped for reuse; the density of glass fibre in the air should be monitored in real-time; the dismantled glass fibre should be collected, disposed, recycled and reused in a reasonable way.

The recycling of glass fibre (wool) on the ship includes the recycling of glass fibre reinforced plastics, the recycling of glass fibre waste and the recycling of fibre reinforced polymer (FRP) waste, as shown in Table 3.

Table 3 Recycling methods of glass fibre

Glass fibre (wool)	Recycling methods	Details
Glass fibre reinforced plastics	Heat moulding	Heat moulding consists of injection compression moulding, extrusion moulding and direct moulding.
	Solvent	Dissolved in appropriate solvent, separate the fibre and matrix materials through the filter; these recycled fibre and polymer can be reused.
Glass fibre waste	Cleaning, crushing and recycling	Collect, clean, waterlog, transport and dehydrate the waste. After dehydration, the waste will then be sent to the storehouse for storage or reuse.
Fibre reinforced polymer (FRP) waste	Pyrolysis, crushing, energy recycling and hydrolysis or alcoholysis	Pyrolysis recycling and crushing recycling are the more economical and practical methods.

3.4 Solid foam

Solid foam, which is also called foam porous or sponge plastics, is often used in construction or packaging. Solid foam is well-known for its pollution threat to the environment, but its deeper toxic is yet to be accorded due attention. Solid foam generally refers to solid plastic on the ship. Solid plastic is a class of polymer materials formed with a large number of gas pores in the solid plastic materials. It is made by a mechanical method or chemical method.

At the stage of ship building and servicing period, solid foam does not apparently pollute the environment due to its stability. But in the ship recycling stage, since the construction and working environment are different from

the former, solid foam can bring a lot of problems to the environment which therefore requires detailed research. Most solid foam products are stable at room temperature without volatile toxicity, but the foaming additive used on site may be toxic. For example, chlorofluorocarbon (CFC), hydrochlorofluorocarbons (HCFC), and other non-environment friendly foaming agents will do harm to the environment and cause potential harm in the future.

In ship recycling process, the dismantling work involves a lot of solid foams. The forming (at building stage) of solid foam includes spraying, pouring, or pasting, so it is always firmly attached to the ship structure. During dismantling, the current splitting method of used solid foam is fire cutting, and there is no alternative option to date. It inevitably releases toxic smoke and threatens workers' health and the environment. During fire cutting, the common protections include ventilation and wearing protective breathing device. Due to the emission of toxic gases, there shall be atmospheric pollution as well.

In other industry fields, the commonly-used method is to use solvent to dissolve small solid foam. This method can only be applied on a small area of solid foam, while immersing and heating are necessary. The mixture liquid after dissolution contains chlorine and ozone-depleting ingredients. Therefore, this method is not applicable for dismantling a large area of solid foam.

A new type of environmental friendly solvent is being used for cleaning solidified polyurethane. Its components do not include chlorine or ozone consuming solvent. Compared with dichloromethane, acetone, and other solvents, the new solvent is more environmental friendly and possesses different chemical properties from some other alternatives. The recycling of solid foam is shown in Table 4.

Table 4 Recycling of solid foam

Hazardous material	Recycling methods	Details
Solid foam	Fire cutting	Protections include ventilation and wearing protective breathing device are needed.
	Environmental friendly solvent	For cleaning solidified polyurethane. Its components should not include chlorine or ozone consuming solvent.

3.5 Waste oil

Remnants of waste oil are mostly found in fuel bunker, oil container, oil drum and oil tank, gearbox, shaft, hydraulic system and oil pipe of various kinds of equipment, and oil sludge that may remain in fuel bunker. If remnant oil is not cleaned up in time, it would be hazardous to the health of human being and environment (Lin et al., 2007; Du 2012; Garmer et al., 2015).

The contamination of atmosphere by oil gas, volatile substance of oil and other hazardous gas, which upon being irradiated by solar ultraviolet light result in physical reactions that would generate photochemical smog, and produce carcinogenic substance and greenhouse effect, and destroy the ozone layer etc.

Remnant waste oil contaminates the soil and groundwater resource, causes salinization and poisoning of soil which leads to destruction of soil. The poison goes into the foods chain through crops, especially through the underground water, and finally harming directly the human being.

Different kinds of transfer operations equipment are applied, such as piping, valves, gauges, regulators, compressors, pumps, and other mechanical devices to transfer oil from the ship to onshore storage location. This equipment should be inspected regularly and repaired as necessary because of the high risk of spills during these operations. Following the removal of waste oil from the ship, the ship tanks and compartments may need to be cleaned to remove any residual oil or waste prior to additional ship scrapping activities.

Prior to workers entering a specific confined or enclosed space, a competent person must visually inspect the space for the presence of solids, liquids or other contaminants, and examine the space. The ship recycling facility is required to train workers who enter confined or enclosed spaces or other areas with dangerous atmospheres to perform their work safely.

3.6 Other hazardous materials

Apart from the above mentioned hazardous materials, there are many other hazardous materials such as heavy metal, bilge water, and ballast water, etc. (Neşer et al., 2008; Neşer et al., 2012; Hiremath et al., 2015).

Heavy metals are found in many parts of the ships such as in paints, coatings, anodes and electrical equipment. Exposure to heavy metal can result in lung cancer, cancer of the skin, intestine, kidney, liver or bladder (Neşer et al., 2012). In general, metal-based paints and oily wastes that are intended to protect ship surfaces from corrosion due to exposure to the elements may contain as much as 30 percent heavy metals (e.g., lead, barium, cadmium, chromium, and zinc). Therefore, workers must wear special masks to reduce the inhalation of organic volatiles when handling the paints containing heavy metals (Hayman et al., 2000; Deshpande et al., 2012). There are 3 methods to manage heavy metal in oily wastes. One is the chemical method which mainly includes chemical precipitation and electrolysis. It is mainly applied to the treatment of wastewater containing high concentration of heavy metal ions. Chemical method is the main method to treat heavy metal wastewater in China and overseas. Another method involves physical treatment which mainly includes solvent extraction separation, ion exchange, membrane separation and adsorption. Finally, the last method is the biological treatment. It removes heavy metals from wastewater by means of flocculation, absorption, accumulation and enrichment of microorganisms, such as biological adsorption, biological flocculation and phytoremediation.

The first step of dealing with bilge and ballast water is to test pollutant concentration of chromium in the bilge and ballast water prior to its discharge. This is due to the practice of adding sodium chromate to ballast water (and sometimes bilge water) to prevent algal growth during a ship's operation. Chromium may be present at high concentrations which will make the water a hazardous waste. During ship scrapping, bilge water and ballast water are routinely transferred from the ship's tanks or bilges to onshore storage tanks, or evaporation pits (ballast water only).

4 Case study

4.1 Case 1: Jiangmen Zhongxin Shipbreaking & Steel Co., Ltd

A ship recycling case of Jiangmen Zhongxin Shipbreaking & Steel Co., Ltd is presented in this study. The details about the Company is summarised in Table 5. The Company was built in 1984, undertaking shipbreaking activities for over 20 years. It has scrapped more than 500 ships from all over the world. During shipbreaking operations, the Company practises the concept of "Environmental Protection, Safety, Health and Recycle" in each disassembling step while strictly complying with national and international safety, environment regulations, standard, policies, such as IMO (International Maritime Organization), ILO (International Labour Organization), and Basel Convention, etc.

Table 5 Information of the ship yard

Items	Details	Quality
Working yard	400,000 m ²	
Working plant	20,000 m ²	
Dismantling method	Floating dismantlement along the wharf	
Coastline	1,600 m	
Capacity	6 disassemble quays, 4 quay berths where are able to berth and disassemble 6 ships each with 25,000 LDT scrap at the same time	
	Floating crane	12
	Deck crane	23
Hoisting equipment	Auto crane	15
	Frame crane	5
	Bridge crane	8
	Loaders	18
Land Transportation and Loading Equipment	Forklift trucks	3
	Transport vehicle	50
Others	Floating dock with lift capacity of 2,200t	

4.1.1 The dismantling procedures

The main procedure of ship dismantling in Jiangmen Zhongxin Shipbreaking & Steel Co., Ltd is shown in Figure 4.

Figure 4 Procedure of green shipbreaking

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Prior to dismantling operations, the following preparations are carried out: overall checking on-board, collecting related information and planning of ship-breaking; deployment of access gangway, and warning signs; open & free any gas; oxygen and explosion tests in sealed cabin; deployment of oil booms, and emergency facilities equipment.

Pre-cleaning includes removal of crew's supplies, furniture, tools, storage, spare parts and other sundries; pumping out and draining off the oil in oil tanks, oil pipes and the lubricant systems, and cleaning the tanks; removal of hazardous wastes (asbestos waste, PCBs, Freon, spent lead-acid batteries); removal of harmful and harmless insulation materials; removal of other dangerous (toxic, flammable and explosive) items such as dump oil, paints and high-pressure cylinder.

4.1.2 Disposal of the hazardous materials

(1) Asbestos

Asbestos is a known human carcinogen and can cause chronic lung disease as well as lung and other cancers. So it is specially treated during shipbreaking in the Company as follows.

- Qualified dismantling workers are hired who have been trained specially.
- Special cloths and tools are used, such as disposal cloth, groove, mask, special shoes, equipped with respiration devices, etc.
- Dedicated rooms especially for asbestos are built, such as tools and personal protection equipment (PPE) storage room, showering room, changing room, washing room, etc.
- Label with an obvious warning on ship or asbestos dismantling working area to prevent any entrance of non-asbestos dismantling workers.
- Make periodical physical checks and change the working position for workers who work in asbestos area.

- Make sure the workers strictly follow the procedures to dismantle the asbestos, to set up a confined area in asbestos area, to prevent explosion of asbestos dust into the air; moisten the asbestos parts to be dismantled by spraying with water, and dismantle as whole parts; NOT allowed to cut with cutter bar or burn surface of cable containing asbestos insulator (except for asbestos-free), moisten the cable before cutting with machine, to prevent generation of asbestos dust.
- A dedicated team of people should be assigned to supervise and monitor the asbestos area: supervise if the workers wear the protective equipment as required in the procedures; timed monitoring of the air in the environment surrounding the working place, to check if asbestos content out of limits.
- Put dismantled asbestos products and glass fibre into a certain-thickness plastic bag after moistening, then transfer to qualified treatment organisation for disposal.

(2) PCBs

PCBs can cause serious impact on immune system, reproductive system, nervous system and endocrine system, even cancer. Therefore, they are strictly treated in the company.

- The workers who remove and dispose the PCBs should be trained.
- The working place and environment should be monitored.
- When removing solid PCBs, the worker should not be in direct contact with PCBs, instead by wearing working clothes; when removing liquid PCBs (medium in transformer, capacitor), protective cloths, groove, shoes, mask should be worn. When necessary, respiration device should be used.
- If PCBs and PCB products are stored in the plant not more than 30 days, it is not necessary to prepare storage facilities for PCBs to be disposed. If the storage time is more than 30 days, maximum not exceeding 1 year, the storage facility should be built, by way of a constructed building or metal box.
- Transfer to special treatment unit for disposal.

(3) Waste oil and fuel

The waste oil and fuel cause hazard to human health and environment, so they need to be treated carefully. The processes of the waste oily disposal in the company are shown in Figure 5.

a. Set up safe cautions

b. Explosion test

c. Clean up oily substance in ship

d. Clean up oily substance in cabin

e. Clean up oily substance in bottom

f. Transfer the oily substance

g. Packing the oily sludge into barrel

h. Transfer the oily sludge

Figure 5 Operation processes of the waste oil disposal

(4) Sewage

There is a sewage disposal centre in the Company, which is put into operation since 2006, with daily disposal capacity of 150 tons of waste water. The operation process of the sewage disposal is illustrated in Figure 6.

Figure 6 Operation process of the sewage disposal

Meanwhile, other hazardous such heavy metals, PVC etc. are also disposed strictly by the Company. For example, comprehensive precautions are taken against lead poisoning for workers who operate with lead which include: monitor the concentration periodically, improve the production process, care for personnel protection of worker and perform occupational health check annually for the workers who are in contact with lead.

4.2 Case 2: Jiangyin Changjiang Ship-Breaking Yard

The yard in Changjiang Ship-Breaking Yard dismantled an LNG vessel named BUBUK, which was built in 1975 in France and is currently owned by the Government of Brunei, and managed by Shell International Trading & Shipping Company. She has a Gross Tonnage of 52,708mt, Length 233.97m, and Breadth 34.75m. She was built 40 years ago and is considered to have a considerably long operating life for a seagoing vessel. As the expense of repair and operating costs were more than the profits she can bring, she was sold during her last voyage and was towed to No.4 Dock of Changjiang Ship-Breaking Yard for dismantling in April, 2015. As the ship-owner is Shell, the dismantling procedure needs to meet a strict environmental protection level. Because BUBUK was built a long time ago and it is a LNG vessel which generally contains more hazardous and pollution materials than normal vessels, the shipbreaking process is much more difficult than normal vessels. Furthermore, the dismantling process is expected to last at least 4 months more than the normal dismantling procedure which usually takes about 4 months. The ship recycling procedure is shown as follows.

Figure 7 Ship recycling procedure

4.2.1 Preparation for shipbreaking and Pre-demolition cleaning

It is very important to prepare the ship for dismantling. Firstly, the yard should be cleaned, and all equipment should be working properly; whatever method the yard use to dismantle the vessel, the vessel should be moored and fixed well to minimise displacement of the vessel. Subsequently, the yard needs to carry out the overall checking on-board, collect related information and complete the planning of shipbreaking; place the access gangway and set warning signs and cut some holes for safety. At last the oil booms need to be placed in the water, which can contain the pollution within the booms, as shown in Figure 8.

Figure 8 Oil boom

The pre-demolition cleaning process can help the workers do their job easier when they start to cut the vessel. The workers need to empty the vessel by removing all the stuff they can move by hands, such as furniture, the crew's supplies, and storage area, pump out and draining off the oil in oil tanks, daily oil tanks, oil pipes and the lubricant systems. Cleaning the tanks is also extremely important for it can protect the environment and reduce the risk of explosion. Thereafter, the workers need to remove the hazardous wastes such as asbestos, PCBs, Freon, glass fibres, which are very dangerous for both the workers' health and environment. The workers need to be well trained and wear PPE.

The BUBUK took about one week for inspection and sanitary cleaning, three weeks for pre-cleaning, including removal of equipment and waste and hazardous materials. Due to the strict rules specified by Shell, the removal of asbestos took a lot of time.

4.2.2 Dismantling vessel on water

After pre-demolition cleaning, the main work of dismantling the ship will begin. The yards in China mainly dismantle the main body of vessels in an afloat way which means the vessel will be cut into big pieces in dock. The main body dismantling begins with the superstructure and deck part, and then engine room and the hull, and finally the bottom – see Figure 9.

1 The superstructure is dismantled from up to down and from outside to inside. The cutting usually follows the
2 welding lines. It is very important to use cold dismantling method for oil pipes. Using fire to cut the pipes is
3 strictly prohibited, especially for the engine room, where there are several kinds of hazardous materials and
4 dangerous gas. During the engine room dismantling period, it is mandatory to drain the remaining oil, gas and
5 water inside the equipment and to conduct gas-free check before cutting it. The connection pipe and parts with the
6 equipment should be dismantled first. The equipment for reuse should be dismantled with the base as a complete
7 unit. And the vessel's balance should be maintained at all times.

8 The hull cutting is a job that needs a lot of time and many workers. It is very important to keep trim and balance
9 in portside and starboard side. The dismantling work should start from the FWD to AFT, then the middle of the
10 ship; the transverse component should be dismantled first followed by the longitudinal component. The hull is cut
11 into blocks at docks in lifting-method, and moved ashore immediately to do the piece-cutting.

12 After dismantling the hull, the bottom is usually moved to the floating dock by Changjiang Yard. The residual
13 oily sludge and garbage are cleaned up first, and then the bottom is cut into blocks and lifted ashore.
14

Pre-cutting on the main deck

Cutting the hull

Cutting the whole tank including bottom

Open the engine room

Figure 9 Dismantling vessel on water

4.2.3 Piece-cutting on site

22 Piece-cutting is a kind of work that involves cutting the blocks into pieces on site. The workers should clean up
23 the residual oil and waste on the blocks so they can be disposed separately. As a requirement, the blocks are cut
24 into steel sheets, profiled materials and waste steel, and respectively placed in a certain place, as shown in Figure
25 10.

Fire cutting on site

Waste placed in certain locations

Different kinds of steel placed on site

Figure 10 Piece cutting on-site

4.2.4 Hazardous materials disposal

Asbestos

During the dismantling of BUBUK, asbestos was mainly located in the accommodation and the engine room – see Figure 11. The asbestos in the accommodation was made into panel with wood for fitting-out of the superstructure. The panelling throughout the accommodation was found to contain 3%-6% chrysotile and 10%-15% amosite. This made up around 60% of total weight of asbestos on-board. When dismantling the panelling with asbestos in the accommodation, the asbestos was removed under negative pressure to prevent air pollution. The workers were well trained and wore full asbestos PPE. After the whole day of work, the workers needed to take a shower in certain place to swill the fibre of the asbestos off, remove their PPE and dispose them. During the dismantling, firstly, the workers used some water to keep the panelling wet, which can reduce the fibre wafting through the air. Then the workers began to dismantle the panelling by hands. According to the rules, the panel which was removed should be as big as possible and the edge of the panelling should be sealed by adhesive tape. Thereafter, all the panel should be sealed into a special plastic bag. At last, the plastic bags were moved into a special warehouse called asbestos warehouse where an outsourced company will handle these wastes.

Warehouse to store the asbestos

Special vehicles used for asbestos cleaning

Shower room for workers

Workers with full PPE

Airlock to enter accommodation

Sealed paneling

Figure 11 Disposal of asbestos

PCBs

The bridge window rubber sealing, stairwell handrail covering and stairwell vinyl floor covering on the accommodation on BUBUK vessel were found to contain PCBs. Dealing with solid material or device contained liquid PCBs, the workers must have a reasonable protective measures, e.g. special protective uniform, gloves, masks, especially dismantling device (such as transformer, capacitor) with liquid PCBs. As to solid material, such as cables, workers should use cold cutting. Dismantling down cables were collected classification and piled up, the copper wires were dismantled with the wire stripping machine, aluminium and other non-ferrous metal and insulation envelope separation, recycling of non-ferrous metals.

The bridge window rubber sealing, stairwell handrail covering and stairwell vinyl floor of the accommodation on BUBUK vessel were found to contain PCBs – see Figure 12. Dealing with solid material or device containing liquid PCBs, the workers must undertake reasonable protective measures, e.g. special protective uniform, gloves, masks, especially dismantling device (such as transformer, capacitor) with liquid PCBs. As for solid material, such as cables, workers should use cold cutting. Cables were separately collected and piled up. The copper wires were dismantled with the wire stripping machine.

Figure 12 Handrail covering which contains PCBs

Glass fibre

Since BUBUK vessel is an LNG vessel, other heat insulation materials were applied on the vessel to replace glass fibre. To the shipyard's knowledge, the glass fibre only exists on the lifeboat which can be resold to some buyers instead of dismantling it.

Others

There were some other hazardous materials during dismantling BUBUK which would pollute the environment, especially in the superstructure and engine room, such as freon (containing ozone depleting substances), paint, rock wool, waste oil, bilge water and so on. They should be removed by well-trained workers according to the convention and operational procedures.

4.3 Comparison of the two cases

Two case studies in Jiang Men Zhong Xin Shipbreaking & Steel Co., LTD and Jiangyin Changjiang Ship-breaking Yard are carried out. Both of the two companies are following Hong Kong Convention and verified by DNV-GL classification. The dismantling procedures for the two companies are quite similar to each other. Both of them have strict procedures and methods for the disposal of hazardous materials on-board. For example, when dealing with asbestos, green recycling methods were applied for the two companies. Dedicated rooms especially for asbestos were built, workers wore personal protection equipment and strictly followed the procedures to dismantle the asbestos. Special rooms were set up to store the asbestos, which were delivered to qualified companies for further disposal.

5 Suggestions for hazardous materials disposal

Although the Hong Kong Convention and other international conventions have proposed environment friendly management of ship recycling, further measures and attention should be considered on the disposal of hazardous materials. Though the application of asbestos has practically been fully stopped nowadays (Pacheco et al., 2013), the ship recycling industry is still facing multi-faceted problems in handling asbestos-containing products. The use of asbestos has not yet reached its end. On the one hand, different countries are in different processes of banning asbestos; on the other hand, there is no unified identification of the dangers from different asbestos types. In the 1980s, some Western countries began to realize that asbestos hazards must be controlled (U.S. EPA, 1991), but the broad consensus worldwide occurred mainly in the first decade of this century. The life of a ship is generally up to thirty years, and many of the ships presently in service still carry asbestos products, hence ship recycling involves dismantling old vessels with much in-built asbestos products. However, nearly all of the present asbestos-related specifications focus on forbidding application of asbestos for new-built vessels. For removal, storage, transportation and disposal of existing asbestos wastes in ship recycling activities, there are many complex problems, such as worker's lung disease caused by microscopic asbestos fibres, contamination of water and soil due to difficult degrading of asbestos, and so on. Therefore, more specific, practicable, and easy-to-regulate regulations remain to be improved or developed. Measurements of asbestos fibre density in the air and asbestos content in products are the key issues of asbestos treatment. Some testing methods and allowable values have been proposed in international and indigenous standards. For the ship recycling industry, asbestos products are being widely handled for a long time. Though the overall quantity tends to be large, measurement is complicated by the variety of usage, hence efficient testing methods and density standards of asbestos specifically for ship recycling applications are to be established and/or improved. Suggestions for handling and disposing hazardous materials are summarised in Table 6.

Table 6 Suggestions for hazardous materials disposal during ship recycling

Hazardous materials	Current procedures	Suggestions
Asbestos	- Location of asbestos; - Identification and permission are provided	- Location of on-board asbestos product and assembly characteristics of equipment containing asbestos should be studied, and necessary equipment, process plan and operation

	<ul style="list-style-type: none"> - during vessel breaking; - Removing asbestos from ships; - Package, storage and transportation of asbestos; - Final disposal of asbestos, such as landfill. 	<ul style="list-style-type: none"> - specifications should be formulated; - Sampling, testing method and checking standard should be studied; - Operation standard of package, storage, transportation, disposal method and site requirement should be regulated; - Composition, authorisation, duty and supervision of the regulatory authorities should be normalised; - Operability and testability should be considered.
Solid foam	<ul style="list-style-type: none"> - Investigation on solid foam usage and treatment at site; - Dismantling methods: fire cutting, physical removal, or solvent spray; - Storage and recycling of wasted solid foam. 	<ul style="list-style-type: none"> - Green dismantling method of solid foam, especially on combination of physical removal and solvent spray; - Establishment of solid foam harmless demolition method and practical operating rules.
Glass fibre	<ul style="list-style-type: none"> - Removing it from ships violently, without personal protection 	<ul style="list-style-type: none"> - Sealing dust source: production machinery enclosed, globally or locally; - Ventilation: working at exposure site and discharging fibre dust after collection; - Wet operations: pre-moisture or spraying water can greatly reduce the amount of dust; - Personal protection: workers should wear appropriate dust mask and protective clothing.
PCBs	<ul style="list-style-type: none"> - Confirming the list of the PCBs products contained on board; - Location and characteristics of substance of the PCBs on board; - Package, storage and transportation of PCBs; - Final disposal of PCBs, such as incineration. 	<ul style="list-style-type: none"> - Improve the list of the PCBs products contained on board; - Refine the location and assemble characteristics of substance of the PCBs on board, and prepare for operational procedure of demolition; - Establish a more scientific, accurate, rapid, and economy sampling, extraction and testing method for the PCBs with the latest study result; - Improve the follow-up treatment after dismantling, including temporary packaging, transportation, treatment, and site requirements; - Study the composition, authority, responsibilities and basis of the regulation; - Pay more attention to the operability and testability of PCBs.
Waste oil	<ul style="list-style-type: none"> - Pumping waste oil from ship to onshore tanks; - Cleaning the ship tanks and pipes; - Transportation to specialised treatment agencies. 	<ul style="list-style-type: none"> - During the pumping and cleaning up of the waste oil and oil sludge, ventilated test, explosion test and oxygen content test should be carried out; - Cleaner must be trained; - Prohibition in wearing shoes with nails, and clothes that can generate static electricity; - Cofferdam should be built up around the ship and adsorbent should be prepared to prevent and control the leakage of oil.

At present, most of shipbreaking companies are in developing countries. They lack good processing technology and processing specification. Shipowners should not only demonstrate concern for environmental standards but also acknowledge their responsibility and ability to influence them. This will be heartening for the maritime community as it strives to improve on environmental performance. Nowadays, shipowners do acknowledge that they have a role to play but appear reluctant to do so without governments making the first and most important steps in enforcing regulations within the yards. There are two methods for shipowner to take responsibility in ship recycling.

First, the ship owner can participate in the formulation of Ship Recycling Facility Plan to design the details of dismantling ship and the list of hazardous materials. Shipowner should also monitor the recycling process to ensure safe and environmentally friendly procedures.

Second, the shipowner can set up funds to offer subsidies to ship recycling facilities. There are two approaches to set up funds. One is ship recycling responsibility insurance, referring to the shipowner assurance on the insurance company for the ship, to ensure that insurance company pays the ship recycling facility a deposit which is equal to the increase in cost due to green recycling when the insurance company has confirmed the results of the

investigation of green ship recycling. The other one is ship recycling special account. It refers to establishing a special green recycling reserve account for each ship, and the shipowner deposits reserve in instalment account to ensure that the increased cost of the ship in green recycling is compensated.

6 Conclusions

Although ship recycling has been efficient in providing a ready supply of steel and other metals for re-use, there has been a severe cost in terms of lives lost and local environmental impact. The demolition of ships has been widely associated with dangerous practices and pollution.

The end-of-life ships usually contain many kinds of hazardous materials such as asbestos, PCBs, glass fibre, solid foam and waste oils, etc. which will cause safety and environmental problems if they are not handled properly. There exist different methods dealing with different kinds of hazardous materials, but advanced measures and techniques remain to be developed to enhance the protection of the environment and human health. Unfortunately, the recycling process is not currently considered in the ship design process, where the main focus is cost and quality. In other industries, such as automobile and electronics product manufacturing, “design for recycling” has become an important issue. It will make ship recycling easier as well as improve health, safety and environmental conditions on ship recycling yards if some concepts of “design for recycling” are applied, such as reducing the amount of hazardous materials, keeping track of these harmful materials during design, construction and operation, increasing accessibility of wiring and piping, and so on. We envisage findings from this study can contribute to a more sustainable shipping industry by providing advanced methods and tools related to the environmental protection issues.

Two case studies about the green disposal procedures of main hazardous materials of Jiangmen Zhongxin Shipbreaking & Steel Co., Ltd and Jiangyin Changjiang Ship-Breaking Yard have been carried out. For dangerous materials that may harm the personnel and the environment, both two companies have adhered to strict procedures and methods during recycling. A strong finding of this study is that, in order to ensure the sustainable development of ship recycling industry, shipbreaking companies should make full use of the Hong Kong Convention and European regulation, and improve their own technology and management method in handling on-board hazardous materials.

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