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A novel approach to estimating potential maximum heavy metal exposure to ship recycling yard workers in Alang, India

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HIGHLIGHTS

► Conceptual framework to apportion pollution loads from plate-cutting in ship recycling.
► Estimates upper bound (pollutants in air) and lower bound (intertidal sediments).
► Mathematical model using vector addition approach and based on Gaussian dispersion.
► Model predicted maximum emissions of heavy metals at different wind speeds.
► Exposure impacts on a worker's health and the intertidal sediments can be assessed.

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ABSTRACT

The 180 ship recycling yards located on Alang–Sosiya beach in the State of Gujarat on the west coast of India is the world's largest cluster engaged in dismantling. Yearly 350 ships have been dismantled (avg. 10,000 ton steel/ship) with the involvement of about 60,000 workers. Cutting and scrapping of plates or scraping of painted metal surfaces happens to be the commonly performed operation during ship breaking. The pollutants released from a typical plate-cutting operation can potentially either affect workers directly by contaminating the breathing zone (air pollution) or can potentially add pollution load into the intertidal zone and contaminate sediments when pollutants get emitted in the secondary working zone and gets subjected to tidal forces.

There was a two-pronged purpose behind the mathematical modeling exercise performed in this study. First, to estimate the zone of influence up to which the effect of plume would extend. Second, to estimate the cumulative maximum concentration of heavy metals that can potentially occur in ambient atmosphere of a given yard. The cumulative maximum heavy metal concentration was predicted by the model to be between 113 $\mu g/Nm^3$ and 428 $\mu g/Nm^3$ (at 4 m/s and 1 m/s near-ground wind speeds, respectively). For example, centerline concentrations of lead (Pb) in the yard could be placed between 8 and 30 $\mu g/Nm^3$. These estimates are much higher than the Indian National Ambient Air Quality Standards (NAAQS) for Pb (0.5 $\mu g/Nm^3$).

This research has already become the critical science and technology inputs for formulation of policies for eco-friendly dismantling of ships, formulation of ideal procedure and corresponding health, safety, and environment provisions. The insights obtained from this research are also being used in developing appropriate technologies for minimizing exposure to workers and minimizing possibilities of causing heavy metal pollution in the intertidal zone of ship recycling yards in India.

1. Introduction

It is projected that the world's maritime community will have to scrap 10 to 15 million tons dead-weight of ships every year for at least 10 years in a row in the near future in order to exhaust the present stock-pile of end-of-life vessels currently possessed by commercial fleet owners, ships owned by governments, privately owned by individuals for leisure, obsolete oil exploration rigs and drilling platforms as well as defense vessels. Lately, one finds a peculiar kind of unplanned obsolescence of otherwise "worthy to sail" ships around the world because of the passage of stricter standards and desire for upgrading ships by incorporating recent technological advancements including high-tech on-board technologies and newer alternatives to ship architecture. As a result, the need for creation of competent infrastructure to dismantle ships is expected to climb throughout the world in the immediate future (Asolekar, 2012).

The international protocol popularly called as the "Hong Kong Convention" is currently being negotiated based on the draft formulated by the International Maritime Organization (IMO) under the auspices of UNO because it has been recognized by the ship owners and maritime regulators that dismantling (i.e. breaking) of end-of-life ships is an

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essential activity and it needs to be regulated. Now that the IMO, international shipping community and regulators of maritime activities are possessed of the challenge of creating additional ship recycling facilities all over the world; strengthening the facilities in Asia including those in India, China, Bangladesh and Pakistan is being considered as the most pragmatic strategy. In addition, in order to get rid of the load of existing "ready to dismantle" ships globally; several ship repairing yards and some ship building yards too are being motivated and helped in ship breaking and recycling around the world.

Ship dismantling is one activity that no developed country is undertaking at commercial scale as it stands today; other than the Asian players including India, Bangladesh, China, Turkey and Pakistan. Nearly half of the world's ships are being dismantled and recycled in India — of which nearly 95% are dismantled in Alang–Sosiya coastal region in the State of Gujarat in India. The ship recycling operation at Alang–Sosiya yards combines the old traditional ship recycling practices to save resources and energy with the application of engineering and management knowledge to organize the dismantling processes in a sustainable manner. The above mentioned coastal region is a 12 km-long coastal strip in which nearly 180 ship recycling yards have been working over the past four decades. The cumulative capacity of the yards in Alang happens to be of the order of 3.5 million tons/year (Asolekar, 2012).

It is hypothesized that the basic thrust of "ship recycling" should be to achieve the maximum degree of reclaiming and reusing of as much material as possible by organizing the whole process; starting from dismantling to recycling of objects and materials to breaking of steel sheets and scrap to supporting steel re-rolling mills as well as supporting markets for the recovered products. Above all, the entire dismantling and recycling operation need to be carried out in an eco-friendly manner as well as without posing risk to the workforce involved in the dismantling yards. It was recognized at the outset that the potential environmental impacts and occupational risks are comparable irrespective of dismantling methods (i.e. beaching, dry dock, floating platform, etc.) because the essential steps and operations are comparable in any layout of dismantling yard and the extent of mechanization and manual work in the yard.

Cutting of paint-coated sheet metal and painted structural elements in a ship is not unique to ship dismantling. Similar operations are also performed during the course of repairing and upgrading the ships, both, from the locations in dry-docks as well as from key side and port locations. Cutting and scrapping of plates or scraping of painted metal surfaces happens to be the commonly performed operation during ship repairing as well as breaking. These operations are known to be contaminating sediments in and around bays and dry docks — which has been investigated to an extent by the researchers in the past.

For example, some efforts have been made in the recent past to quantify the toxicity of antifouling paint applied on the ship-hull surface and the impact of antifouling paint on the soil sediment environment of ship maintenance facility. Karlsson et al. (2006, 2010) studied the toxicity of antifouling paints used on the hull surface of ships and leisure boats in Sweden leisure boat facility to prevent biofouling. Toxicity effects of five commercially available antifouling paints were studied and concluded that the toxicity of paints used to paint leisure boats is more than the paint used for the painting of ship hull surface and are major sources of Cu and Zn like metals. Turner et al. (2008) studied the discarded paint chips collected from leisure boat maintenance facility at the Kingsbridge estuary SW, England and concluded that the Cu was the most abundant metallic component in the antifouling paint used on hull surface and marine contamination may arise directly, from relatively inert particulates, or indirectly, via release of Cu from chips to interstitial waters and its subsequent adsorption to local sediment. In a similar kind of study, Schiff et al. (2004) measured dissolved Cu contributions from recreational vessel antifouling coatings.

Further, Turner et al. (2009) also analyzed soil near boat maintenance facility at Malta and concluded that soil near boat maintenance facilities are contaminated by antifouling paint particles containing high concentrations of metals such as Cd, Cu, Pb and Zn. Zhou et al. (2007) studied the spatial distribution of heavy metals in Hong Kong's marine sediments and their human impacts and one of their findings stated that the source of heavy metals in the marine sediments is mainly due to the activity of ship repainting and repairing. However, almost no effort has been made to address the air pollution and the corresponding occupational risk posed to the yard workers engaged in ship repairing and ship breaking sector so far.

Therefore, this research is aimed at uncovering the basic process involved in plate cutting operation which is known to be posing the highest environmental damage on one hand as well as posing occupational health hazard to the workers involved in the activity. It is well known that the paint systems installed on hull surfaces and internal surfaces of sheet metal and structural elements of ship have been one of the major concerns associated with metal cutting operation using hand-held cutting torches. Irrespective of fuel used and the corresponding combustion products emitted during the course of open-air plate-cutting operation; the pollutants emerging from combustion of paint from the plate surface aggravates the exposure of the workers to the toxic trace metals present in the fumes.

It is in this context, the effort of estimation of maximum potential concentrations of heavy metals present in fumes emerging from burning of paint systems while cutting the painted surfaces using hand-held torches, should be seen from a much broader perspective of characterizing and roughly quantifying the exposure to toxic trace metals through the respiratory mechanism. Such enquiry is critical for the development of regulatory response and work place standards for maximum allowable limits for a variety of toxic metals in the form of ambient atmospheric aerosols. Thus, it must be appreciated that the learnings from this research may contribute to formulating regulatory strategies and standards and therefore need not be viewed of limited "local" applicability. In fact, the estimation approach developed and presented in this study can be used by ship dismantling and repairing yards anywhere in the world.

The primary objective of this work is to develop a methodology to quantify heavy metal emissions from ship-recycling yards during plate-cutting operations. The second objective is to develop heavy metal dispersion profiles at various wind speeds for actual site conditions in a ship-recycling yard. The third objective is to locate and estimate maximum expected concentrations of toxic trace metals in suspended aerosols in ambient air; based on a vector-addition methodology developed in this study.

2. Site description

Ship recycling in India is primarily carried out in India on the western coast of the Gulf of Cambay (lat. 210 5′ 210 29′ N; long. 720 5′ 720 15′E) on the adjoining coasts of Alang and Sosiya villages in the State of Gujarat, India. Alang–Sosiya has a high tidal range ~13 m, a gentle slope of ~10° on a sandy beach overlain stable bedrock (most suitable for beaching of the ships) and is home to the largest ship recycling yards in the world. Ship recycling sector is highly labor intensive and directly or indirectly employs around 60,000 people (IMF, 2006). Of the total 171 ship recycling yards, 92 are in Alang and 79 in Sosiya over a 12 km-longstretch as shown in Fig. 1.

Typically, obsolete ships at the end of their lives are grounded on the sandy beach utilizing its own momentum and tides and subsequently dismantled. Nearly 350 ships (about one ship per day) are dismantled and recycled every year at Alang–Sosiya. The cumulative weight of ships expressed as Light Displacement Tonnage (LDT) dismantled per year at Alang–Sosiya yards is around 2.5 million LDT (GMB, 2008). The average weight of the ship dismantled at Alang–Sosiya is around 10,000 LDT (UNESCO, 2004).

The economics of ship-recycling is centered on steel recovery, which is therefore the key operation at Alang–Sosiya ship-recycling yards. Typically at any yard, the obsolete ship is first stripped entirely