Life cycle assessment of ships

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The paper gives an overview of the main issues of Life Cycle Assessment (LCA) of a product. The types, levels and main components of LCA are briefly discussed. The holistic approach of LCA of any product is outlined. The solid waste management hierarchy is presented. The main categories of Environmental Impact Assessment (EIA) are highlighted. The modern approach of Design for Environment in the shipbuilding industry is presented. The LCA of ships is addressed with particular emphasis on the methods commonly used to reduce energy consumption and environmental impacts. The rationalization of materials used in shipbuilding and ship scrapping is emphasized. The importance of using LCA of ships is highlighted.

يقدم البحث نظرة شاملة على دورة حياة أى منتج . يناقش البحث أنواع ومستويات والعناصر الأساسية لمنظومة تقييم دورة حياة المنتج . يقدم البحث عناصر منظومة ادارة المخلفات الصلبة . يوضح البحث العناصر الرئيسية لمنظومة تقييم الأثر البيئى . يقدم البحث عناصر الاسلوب الحديث لتقييم دورة حياة السفن بهدف الحفاظ على البيئة . يوضح البحث الطرق المستخدمة لترشيد الطاقة وتقليل التأثيرات البيئية فى مراحل تقييم دورة حياة السفينة . يوضح البحث منظومة ترشيد استخدام الموارد فى صناعة بناء السفن وكذلك فى مرحلة تخريد السفن. يؤكد البحث على اهمية استخدام منظومة تقييم دورة حياة السفن.

Keywords: Life cycle assessment, Environmental impacts, Risk assessment, Design for environment, Waste management, Energy efficiency, Shipbuilding, Ship scrapping

1. Introduction

Over the past 20 years, environmental issues have gained greater public interest and recognition. Particular emphasis is placed on the increasing problems of greenhouse gases that threaten to change the climate and the increasing consumption of chemicals that reduce the ozone layer. Also, the public is now becoming more aware than ever that the consumption of manufactured products and the daily services and activities of our society adversely affect supplies of natural resources and the quality of the environment.

Environmental protection requires the development and application of methods to identify and reduce the adverse environmental effects of human services and activities. There is now a growing awareness of the need to radically decrease *waste* streams from production and consumption processes. This awareness has not only brought about the implementation of improvements in the currently used production processes but has also led to increased circulation of materials. Industry has not always been able to make use of all reusable available materials, as collection of materials for reuse has not always been an efficient and successful process.

Recycling is a means of reducing waste streams and accordingly reducing the demand for waste treatment. The objective of an efficient material production and recycling scheme should not only be to just recycle but also to minimize the resource utilization and associated emissions of all streams of materials in the production cycle.

Life Cycle Assessment (LCA) of a product, is used to identify, evaluate and minimize energy consumption and environmental impacts holistically, across the entire life of the product. LCA is, therefore, a systematic way of examining the environmental impacts of a product throughout its life cycle, from raw materials extraction through the processing, transport, use and finally product disposal. LCA is sometimes called a “cradle-to-grave” assessment. LCA could be used also to assist companies to identify and assess opportunities to realize cost savings by making better design and more friendly products, more effective use of available resources and improving waste management systems.

2. Basic concept of LCA

LCA adopts a holistic approach by analyzing the entire life cycle of a product from raw materials extraction and acquisition, materials processing and manufacture, material transportation, product fabrication, transportation, distribution, operation/consumption, maintenance and repair and finally product disposal/scrapping.

The solid waste management hierarchy of the product disposal system includes waste prevention, waste minimization at source, reuse, recover, repair, recycle, incineration (with or without energy recovery) and landfill. Fig. 1. shows the input and output of any industrial process, including energy and environmental impacts.

3. Main components of LCA

The main components of LCA are shown in figs. 2 and 3.

3.1. Inventory analysis

It is the identification and quantification of energy and resources used and environmental releases to air, water and land for all the processes within the system boundary. The results generate an inventory of the environmental burdens. The system boundaries includes the main production sequence (extraction of raw materials up to and including final product disposal), handling and transport operations, production and use of fuels, generation of energy (electricity and heat, including fuel production) and disposal of all process wastes.

3.2. Environmental impact assessment

Environmental impact assessment (EIA), is the technical qualitative and quantitative characterization and assessment of the consequences on the environment. The impact analysis addresses ecological and human health consequences and resource depletion and could be divided into three sub-phases:

- Classification: sorting of parameters into different environmental Effect categories.
- Characterization: calculation of the potential contribution of the environmental Loading to each Effect category.
- Valuation: assessment of the total Environmental Impact of the life cycle.

The main elements EIA of are shown in fig. 4. EIA should address the following issues:

- Resources: energy, water, and land.

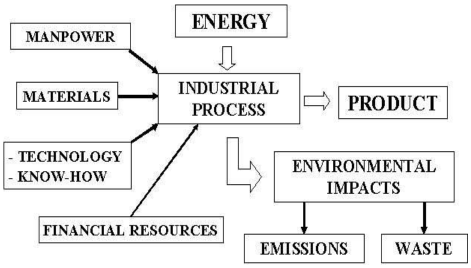

Fig. 1. Input/Output of industrial processes.

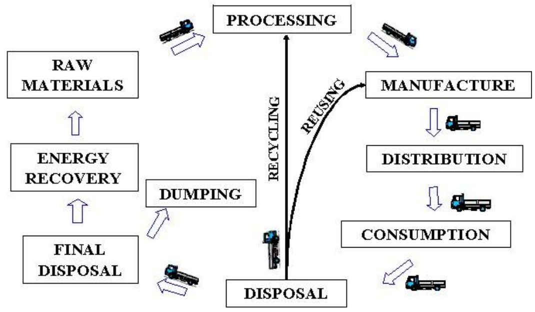

Fig. 2. Life cycle main components.

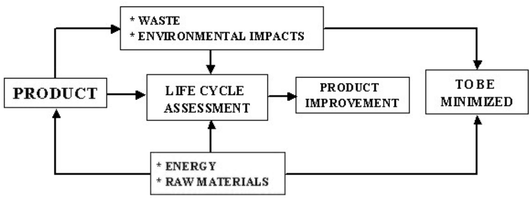

Fig. 3. LCA of a product.

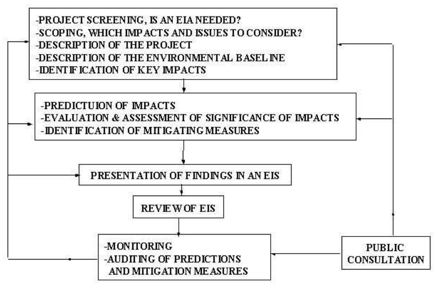

Fig. 4. Main elements of EIA.

• Human health: toxicological impacts, non-toxicological impacts, etc.
• Global warming: GHG emissions.
• Depletion of stratospheric ozone: widespread use of CFC.
• Acidification.
• Habitat alterations and impacts on biological diversity.
• Risk assessment: environmental hazards, health hazards, etc.

3.3. Improvement analysis

It is the evaluation and implementation of opportunities to reduce environmental burdens. This could be achieved by the efficient use of natural and man-made materials and in a cost effective manner, better measurement of environmental impacts, minimization of consumption and management of wastes by recycling/ reuse of waste as a raw material, using clean technologies, polluting less, cleaning up the pollution, using risk assessment and management.

Therefore, LCA could be defined and categorized as follows:
Conceptually: LCA is a process guiding the selection of options for design and improvement.
Qualitatively: LCA is an assessment of key environmental burdens or releases at the different stages of the life cycle of a product.
Methodologically: LCA is a quantitative inventory of environmental burdens or releases, evaluating the impacts of those burdens or releases and considering alternatives to improve environmental performance.

3.4. Types of LCA

The main types of LCA are:
Simplified LCA: is based on approximate figures and general assumptions.
Screening LCA: is based on some standard data representing average values and is used when the key Environmental issues for improvement in a products life cycle has to be identified.
Detailed LCA: is based on improved quality of data instead of average industry values and is used when a thorough evaluation of the specific key issues including risk assessment is required.

3.5. LCA in the shipbuilding industry

LCA in the shipbuilding industry should consider and assess: environmental impacts, energy consumption, rational use of construction and outfitting materials, rational use of energy in all stages and phases of ship design, construction, outfitting, operation, maintenance and repair and finally the outcome of ship scrapping see fig. 5.

4. Environmental dimension in ship design

The environmental dimension in ship design should be an integral part of a rational approach to ship design, see fig. 6. This approach is sometimes called ship design for environment (DFE). The main objective of ship DFE is to make safety, economy, and environmental protection an integral part of the ship design process, ship manufacture, operation, maintenance and repair and finally ship disposal. This holistic approach should cover the following main issues: satisfaction of IMO and other national and international conventions, satisfaction of statutory requirements, satisfaction of classification society requirements, satisfaction of national and international safety requirements, satisfaction of performance requirements, rational use of materials, minimization of energy demands, ensuring cleaner production and the minimization of environmental impacts.

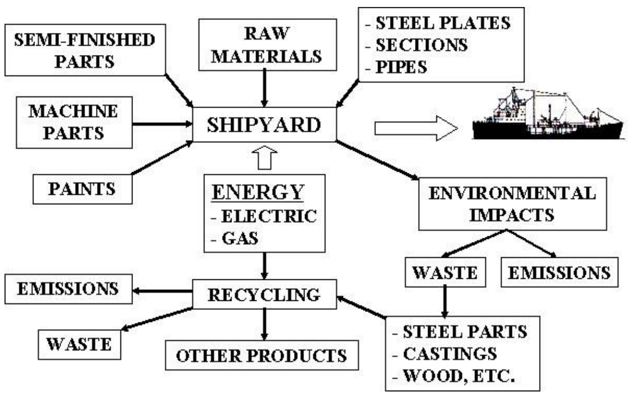

Fig. 5. Ship life cycle.

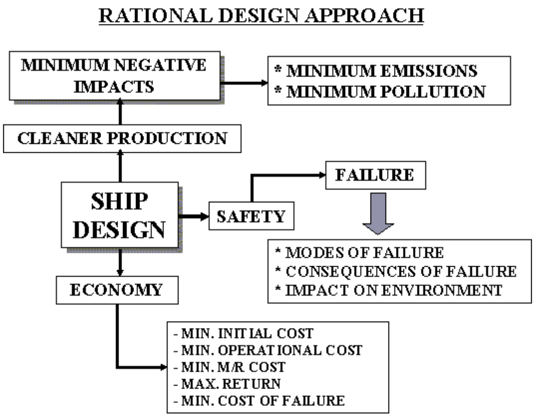

Fig. 6. Rational design approach.

5. Rational use of raw and processed materials

The main materials commonly used in the shipbuilding industry, which require rationalization, are: steel plates and sections, welding coils and rods, castings, forged parts, timber, paintings, etc. The rational use of these materials should not only reduce energy consumption and the negative environmental impacts but should also have positive economic gains. Therefore, the minimization of the negative environmental impacts and wastes in ship construction could be achieved by the efficient use of ship construction materials (steel plates, profiles, sections and all other construction materials), efficient use of welding rods, efficient use of paints, etc. The emissions of welding electrodes over its life cycle are given in fig.7

6. Environmental impacts of ship operation

The environmental impacts of ship operation should be considered for both modes of operation at sea and in ports. The environmental impacts should be also considered for both conditions of normal ship operation and also when a ship experiences an accident, see fig. 8. The control/minimization of the negative environmental impacts during sea operation require, reduction/control of exhaust gas emissions (CO_2, NO_x, SO_x, particulate), sewage treatment, noise reduction, control /treatment of contamination of ballast water, control of damage to marine life, handling /control of garbage by efficient stowage/ incineration, reduction/control of the harmful impact on the marine life induced by underwater coatings and anti-fouling paints, control/reduction of fouling at sea chests so as to improve the efficiency of heat exchangers and pumps see fig. 9.

ITEMS OF LCA	PARTICLES	NOx	CO2
•RAW MATERIALS	24%	59%	84%
•PRODUCTION	1%	6%	7%
•TRANSPORT	1%	23%	6%
•USE	74%	12%	3%
	100%	100%	100%

Fig. 7. LCA of welding electrodes.

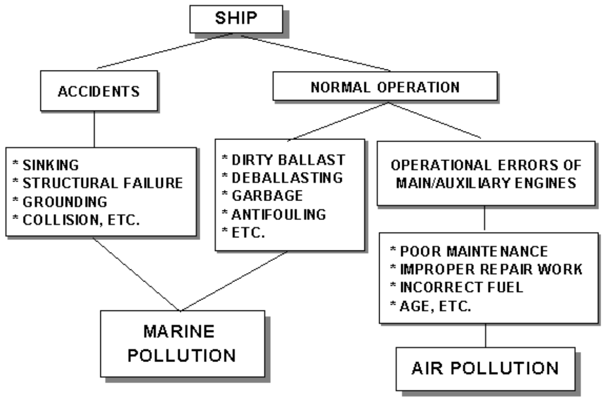

Fig. 8. Environmental impacts of ship operation.

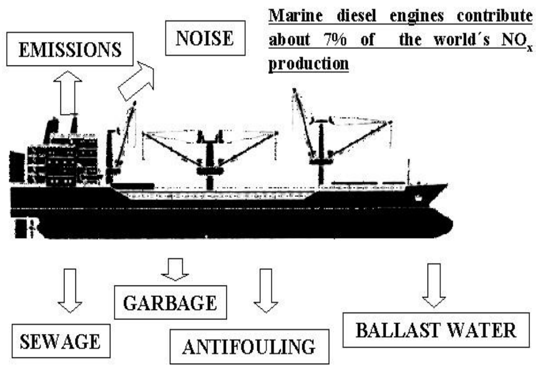

Fig. 9. Environmental impacts.

7. Ship design aspects affecting energy - efficiency of ship operation

Improving energy efficiency of ship operation could be fulfilled by improving ship routing, optimum design of hull shape, maximization of volumetric and deadweight cargo capacity, using efficient propulsion system, minimization of propulsion power for the required ship speed, rational selection of the percentage of sea margin, improving rudder design, maximum use of the heat energy of exhaust gases, etc. see Fig. 10. Over-estimation of the percentage of sea margin could lead to unnecessary increase of the installed power of the main engines. This will have deleterious effects not only on the economy of ship operation but will also have increased negative environmental impacts.

8. Energy used in the shipbuilding industry

The energy used in the shipbuilding industry could be divided into direct and indirect energies. The indirect energy used in the shipbuilding industry is commonly used for the manufacture and production of the following main items: steel plates and sections, main and auxiliary engines, equipment, fittings, welding coils and electrodes, paints, etc.

The direct energy required in shipyards for ship construction is used for the following processes: handling and transport of raw materials, fabricated sections and blocks, fabrication processes (cutting, forming, welding), assembly of steel plates and sections, construction of 2D and 3D blocks, erection and assembly of blocks on berth or in dock, outfitting operations, tests and trials. Figs. 11, 12 show the energy demands and emissions for forming and welding operations of steel plates. Figs. 13, 14 show energy demands and emissions for gas cutting and assembly operations.

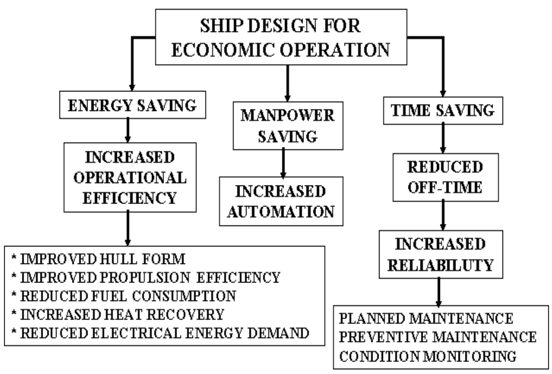

Fig. 10. Ship design for economic operation.

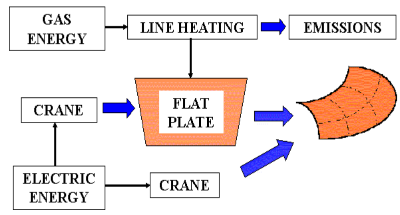

Fig. 11. Energy demands for plate forming line heating.

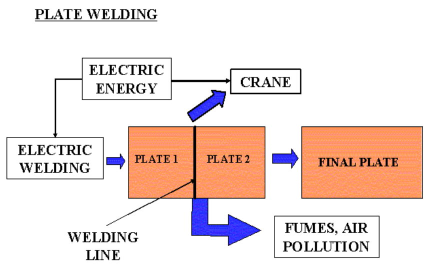

Fig. 12. Energy demands for plate welding.

9. Measures taken for energy saving in ship construction

The measures commonly taken at the design stage to improve the efficiency of ship construction are: reduction of hull steel weight, use of alternative materials, High Tensile Steel, (HTS), and reduction of weight and power requirements of engines, machines, equipment and fittings. The main measures commonly taken at the fabrication stage to save energy consumed in ship construction are: rationalization of inter-process material handling and transportation reduction/ improvement of bending & forming operations (2D and 3D forming) using press forming instead of line heating methods, using large sizes of steel plates, particularly plate width, improving welding operations, improving accuracy of edge preparation, minimization of welding lengths, maximization of down-hand welding, minimization of cutting lengths of steel plates, widespread use of computer-aided marking and cutting, minimization of scrap and wastes by the efficient use of plate nesting, minimization of rework.

10. Minimization of solid wastes in ship scrapping

Ship scrapping is becoming an important industry in several countries as the number of ships that has to go out of service is increasing significantly every year. The outcome of ship scrapping includes, see fig. 15: usable/ recycled steel plates, sections, pipes and profiles, usable stiffened panels, blocks and 2D sections, usable/recycled cast steel, cast iron and forged steel, usable/recycled non-ferrous metals (copper, brass, bronze, manganese- bronze, nickel, aluminum-bronze, copper-nickel, aluminum, white metal, zinc, etc.), usable non-metallic materials, usable deck cranes, other cranes and winches, usable main engines, diesel generating sets, alternators, boilers, purifiers, pumps air bottles, etc., usable distribution panels, main and sub-switch boards, machinery, equipment, fittings and furnishings, usable electronic, electrical and communication equipment, repairable engines, machinery, equipment and fittings, scrap materials, etc.

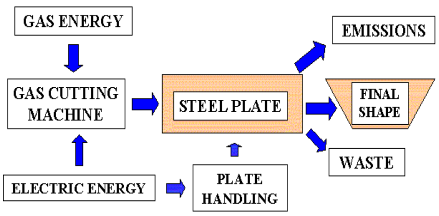

Fig. 13. Energy and emissions of gas cutting.

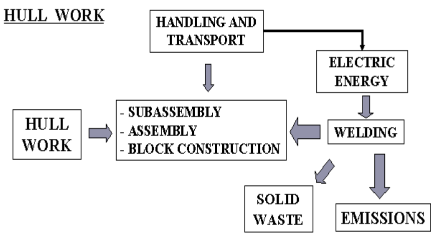

Fig. 14. Energy and emissions of assembly work.

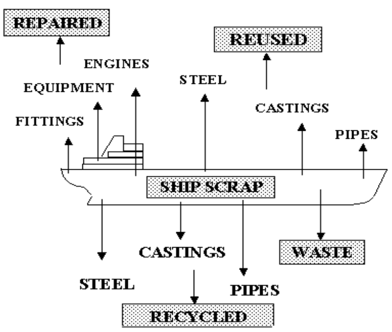

Fig. 15. Ship scrapping main elements.

The outcome of ship breaking and scrapping should be rationalized so as to protect our natural resources, improve energy efficiency, minimize the negative environmental impacts, minimize wastes, etc. Waste management in ship breaking and scrapping should not only have significant economic opportunities but should also have positive impact on social development and environmental protection.

11. Conclusions

The main conclusions drawn up from this paper are:

1. Life Cycle Assessment of ships could be used to assist shipbuilding and ship repair companies to identify, quantify and assess opportunities to minimize energy consumption, control/reduce negative environmental impacts and to realize cost savings by making more effective use of available resources.
2. Ship Design for Environment is a design approach to make safety, economy, and environmental protection an integral part of ship design process, ship manufacture, operation, maintenance, repair and disposal/ scrapping.
3. The rational use of shipbuilding materials should not only have positive effects on the control/reduction of the negative environmental impacts and energy consumption but should also have positive economic gains.
4. Waste management in ship breaking/ scrapping should not only have significant economic opportunities but should also have positive impact on environmental protection and social development.

References

[1] M.A. Shama, “Energy and Environment in Engineering Education”, AEJ, September, Egypt (1997).

[2] UNEP, “Environmental Management Tools, Industry & Environment”, Vol 18, April (1995).

[3] J. Glasson, “Environmental Impact Assessment, the Next Steps”, Built Environment, Vol.20 (4), UK- (1994).

[4] UNEP, “Cleaner Production Worldwide”, Vol. II (1995).

[5] Maxime Kleinpeter, Energy Planning & Policy, John Wiley & Sons (1995).
[6] M.A. Shama, "Climate Change, Causes and Consequences, an Engineering Overview", Workshop on Climate Change, April, Egypt (1997).
[7] Glasson, and others, Introduction to Environmental Impact Assessment, UCL Press, UK (1994)
[8] L.G. Lindfors and others, Nordic Guidelines on Life Cycle Assessment (1995).
[9] L. Richard Storch and others, Ship Production, second ed. SNAME, U.S.A. (1995).
[10] M.A. Shama, Shipyard Engineering, Lecture Notes, Naval Architecture and Marine Engineering Dept., Faculty of Engineering, Alexandria University, Egypt (1997).
[11] M.A. Shama and several authors, Costs of C02 Abatement in Egypt Using Both Bottom- Up and Top- Down Approaches, Energy Policy, USA (1994).
[12] M.A. Shama, Ship Casualties Types. Causes and Env. Impacts, AEJ, April, Egypt (1995).
[13] M.A. Shama, H.W. Lehata and A.B. Mahfouz, "Shear Strength of Damaged Coastal Oil Tankers under Vertical Shear Loading", AEJ, April, Egypt (1995).
[14] M.A. Shama, "Ship Structural Failures: Types Causes and Environmental Impact", AEJ, July, Egypt (1995).
[15] M.A. Shama, "Impact on Maine Environment of Ship Structural Failures and Casualties", AEJ, Jan., Egypt (1997).
[16] M.A. Shama, "Implementation of Energy and Environment Topics in Engineering Curricula", Workshop, Faculty of Engineering, Alexandria University, Egypt (1997).
[17] M.A. Shama, "Life Cycle Assessment of Ships", UNESCO Workshop on LCA, Alex, Egypt (1995).
[18] M.A. Shama, "Energy and Environment in Ship Manufacturing Processes", 8th Int. Symposium on Practical Design of Ships and other Floating Structures, PRAD's 2001, Sept., China (2001).

Review paper contributed by the Author.