

Environmental impact comparison of binder systems for sand moulding process using cradle-to-grave approach

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Abstract Growing demand for preservation of environment, conservation of resources and development of a sustainable society is driving manufacturers to make “greener” products and use “greener” processes. Foundry is considered one of the most environment polluting industries all over the world. The work presented in this paper compares environmental impacts of sand moulding process for four different binder systems, namely phenolic urethane no-bake, phenolic ester no-bake, phenolic formaldehyde and furan no-bake using a cradle-to-grave life cycle assessment (LCA) approach. The comparison is made using various impact categories, such as global warming, acidification, ecological toxicity, eutrophication, human toxicity and photochemical smog by ISO-FRED-14040 LCA method. Results of the study show that the phenolic urethane is most and the furan no bake binder is least harmful to environment and human health in most of the categories. Emissions from the phenolic ester no-bake binder system are most dangerous for human health. This study also revealed that the raw material acquisition phase consumes major portion of life cycle energy for mould making process.

1. Introduction

According to 50th census of world casting production, global casting production has surpassed 104 million metric tons per year in 2015. The world’s two top casting producing nations i.e. China and the U.S. reported about 1% reduction in casting production; however, India, third in the list reported about 7.5% increase in casting production [1]. Both ferrous as well as non-ferrous foundries are considered major sources of hazardous air pollutants (HAPs) worldwide. Majority of emissions in foundries come from processes such as core and mould making, metal melting, pouring, cooling and shakeout [2]. The preparation of moulds and cores require significant amount of sand. Various additives are mixed to the sand to provide enough strength to the mould and cores. A binder is one such additive added to the sand or sometimes may be a natural component of the sand, which gives cohesiveness to the sand particles. The binders used in mould and core making processes may be either organic or inorganic substances. When greater mould rigidity is required, binders stronger than the clay, i.e. chemical binders (resins) are added to the sand [2]. Chemically-bonded sand typically requires less energy in making of a mould as it does not need ramming; however this saving in energy is achieved at the cost of increased emissions by the use of chemical binders [3]. The organic binder systems have been used for many years and some of them like phenolic no-bake, furan no-bake and cold box have become very popular recently for producing high-quality castings of small to medium size. These binder systems were initially developed to provide enough strength to sand cores. Later on they began to be used to make mould as well given their capability to produce castings of superior quality and shortening the production cycles considerably [4]. The quantitative evaluation of energy requirement and emissions to air, water and land of various binders systems for mould and core making process help foundries to establish sustainable processes by choosing the most environment friendly binder system. This can be done via life cycle assessment approach.



Life cycle assessment (LCA) is a cradle-to-grave approach for assessing environmental impacts of products and processes. A LCA study produces a detailed quantitative balance sheet or inventory of inputs, e.g. energy and materials and outputs, e.g. emissions to the environment of a carefully defined system describing a product or a set of processes [5]. Figure 1 shows the life cycle assessment framework as defined by the International standards organization (ISO).

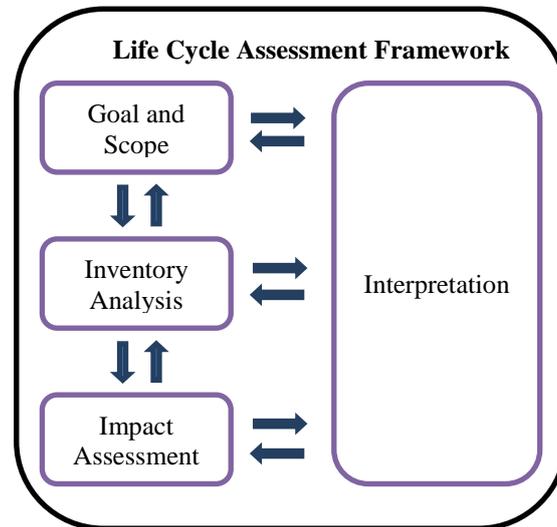


Figure 1. Life Cycle Assessment Framework [5]

2. Methodology

In this study, four life cycle phases of the sand moulds have been considered, namely 1) Raw material acquisition 2) Manufacturing 3) Use and 4) Disposal. Figure 2 shows a life cycle process flow diagram for sand moulds.

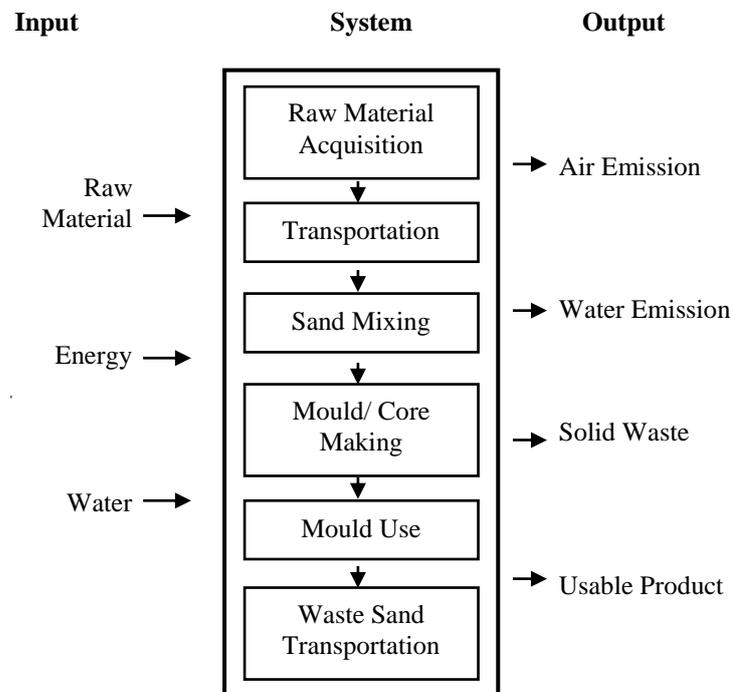


Figure 2. Process flow diagram for sand moulds: A LCA perspective

The methodology used to conduct life cycle assessment of sand molding process is given in Figure 3.

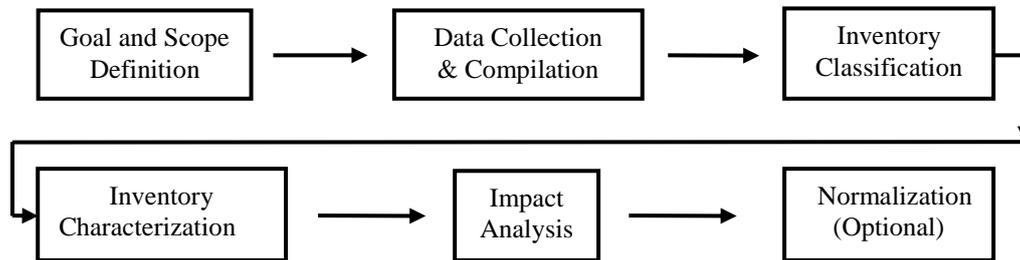


Figure 3. Methodology for Life Cycle Assessment

2.1 Goal and Scope Definition

This phase of LCA approach helps the user to define the system boundary and functional unit for the study.

System boundary: Life cycle analysis starts right from the raw material extraction with the gathering of raw materials from the earth through manufacturing and use of the product and goes up to end-of-life where materials are returned to the earth [6]. System boundary for the present study is shown in Figure 4 and involves raw material acquisition, transportation, manufacturing of cores and moulds, use and end-of-life disposal of waste sand. However, it does not include life cycle inventory associated with manufacturing of capital goods used during this process i.e. manufacturing of means of transportation, material handling system and equipments used in core and mould making process. Following assumptions have been made for the system boundary.

- Raw materials such as sand and binders are transported through an average distance of 100 kilometers.
- Waste sand is dumped 50 kilometers away from the facility.
- Diesel engine trucks are used for transportation of raw materials and used sand and other solid waste.
- 95% sand is recycled and remaining 5% is either land-filled or used in making of pavement blocks and doesn't pose any significant environmental damage.

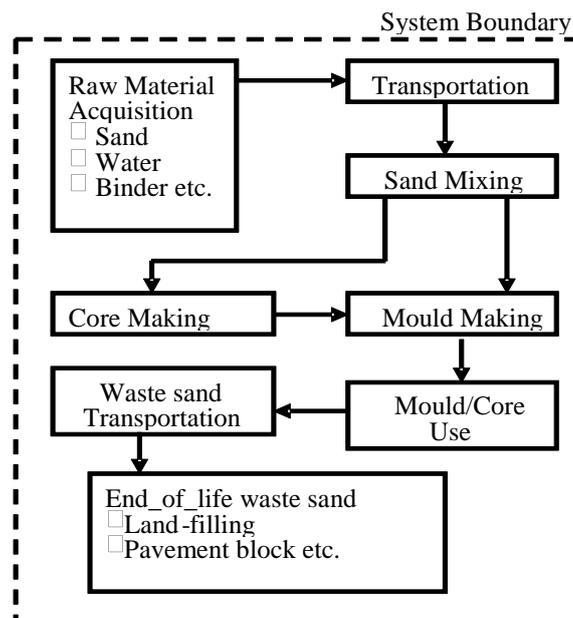


Figure 4. System boundary of core/mould making process for LCA

Functional Unit: A 20 kg sand mould chemically bonded with 3% binder system by weight.

2.2 Data collection

This is one of the most important steps for conducting LCA study of any product or process. Relevant data for present study were not easily available. Core and mould manufacturing related data were collected from some foundries located nearby Dewas industrial area situated in state of Madhya Pradesh (MP), India. However, binder system specific emission data were not available with the foundries and have been collected from published literature such as emission estimation technique manual, national pollutant inventory (NPI), Australia [7]. The emission and energy data have also been collected from casting emission reduction program (CERP) e-library [8], US environmental protection agency (EPA), USA and from Simapro 6 software database [2, 9, 10]. Vehicular emission data for transportation were collected from the website of Central pollution control board of India [10]. Assumptions for transportation distance for raw material acquisition and waste disposal are based on information obtained from the Dewas, MP, India based foundries.

2.3 Inventory classification and characterization

After collection and compilation, inventory is needed to be classified into various impact categories. Impact categories used in this study are according to ISO-FRED 14040 method. The impact categories considered for this study are global warming, acidification, eutrophication, human toxicity (carcinogens), human toxicity (non-carcinogens) ecological toxicity, photochemical smog and energy consumption.

Impact characterization uses science-based conversion factors, called characterization factors, to convert and combine the life cycle inventory (LCI) results into representative indicators of impacts to human and ecological health. The characterized impact of a single inventory parameter for a particular impact category has been calculated using the following formula [6].

$$CI_i = \text{Load} \times eqv_i$$

where, CI_i = Magnitude of characterized impact by the i^{th} inventory parameter in a particular impact category, $\text{kg} \times \text{eq}/\text{fu}$, fu = Functional unit, Load = Quantity of the i^{th} inventory parameter, kg/fu , eqv_i = Characterization factor of the i^{th} inventory parameter. Total environmental impact posed by a particular impact category is obtained using the following Equation [6].

$$CI = \sum CI_i = \sum \text{Load} \times eqv_i$$

Global warming Index (GWI) for phenolic urethane no-bake binder system has been calculated as shown in Table 1.

Table 1: Calculation of GWI for Phenolic urethane no-bake binder system

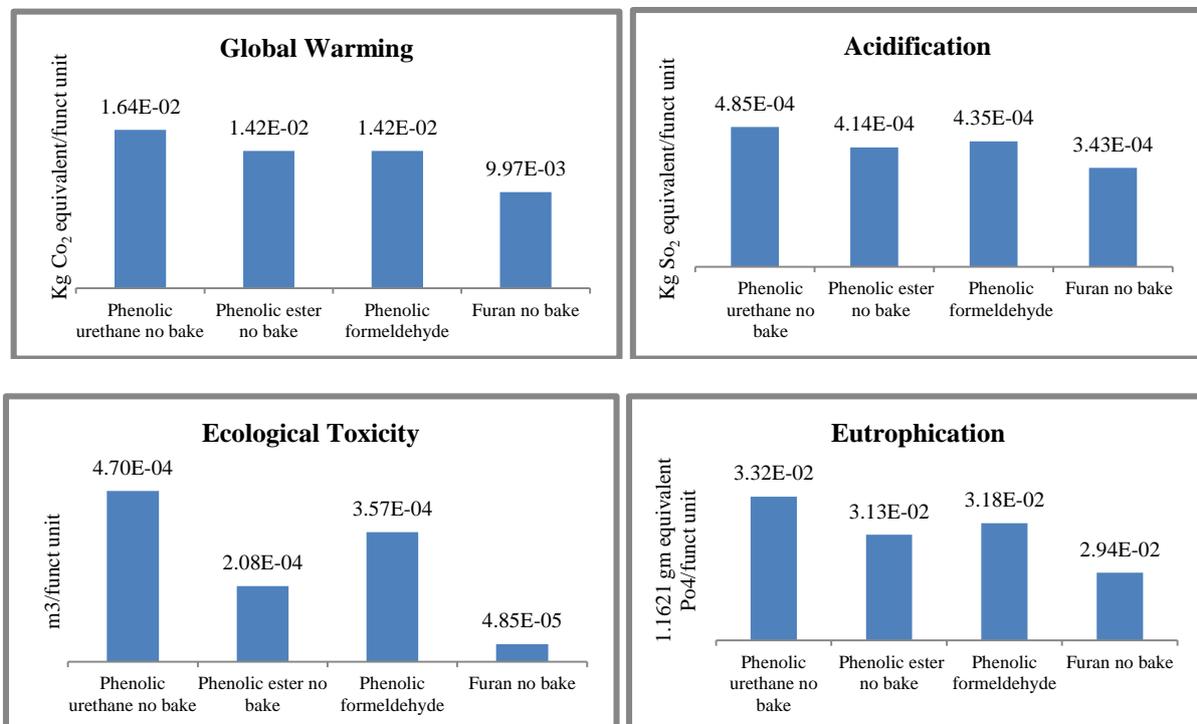
Inventory	Raw material acquisition Phase (Load)	G WP (eq _v)	GWI (C _i)	Manufacturing Phase	G WP	GWI	Use phase (Making of Casting)	G WP	GWI	Disposal Phase	G WP	GWI	Total GWI
Co ₂	0.000169	1	1.01E-04	0.009347	1	5.61E-03	0.002492	1	1.49E-03	0	1	0.00E+00	7.20E-03
Methane	0	21	0.00E+00	0.000458	21	5.77E-03	0.000272	21	3.42E-03	0	21	0.00E+00	9.19E-03
Total GWI			1.01E-04			1.14E-02			4.92E-03			0	1.64E-02

3. Impact Assessment and Interpretation of Results

Life cycle environmental impact by various binder systems is shown category-wise using bar charts in Figure 5. From the bar charts it is clear that phenolic urethane no-bake binder system is most harmful to environment in most of the categories, namely global warming, acidification, ecological toxicity and eutrophication. This is due to higher emission of methane, NO_x , SO_x , benzene and toluene during core and mould curing. However, it is less harmful than phenolic ester no-bake and phenolic formaldehyde binder systems in human toxicity (carcinogens and non-carcinogens) category.

Furan no-bake binder system is least hazardous in all the categories except photochemical smog category, due to relatively lower emission of benzene, methane and NO_x during curing process. In photochemical smog category, it is the most harmful system due to higher emission of phenol and formaldehyde during manufacturing of moulds and cores. Apart from this, phenolic ester no-bake binders found to be most dangerous in human toxicity (carcinogens) category due to higher emission and discharge of phenol to air and water respectively.

Phenolic formaldehyde is most environmental damaging in human toxicity (non-carcinogens) category, because of higher formaldehyde emission during manufacturing phase. In other categories, it is second most environment-damaging among the four binder systems. Phase-wise energy requirement for phenolic urethane no-bake binder is shown in the last bar chart. Raw material acquisition phase is most energy intensive process, as it includes energy required for transportation of raw materials to foundry. The core and mould making process is second most energy intensive phase in life cycle. End-of-life phase is least energy consumptive due to negligible quantity of waste sand.



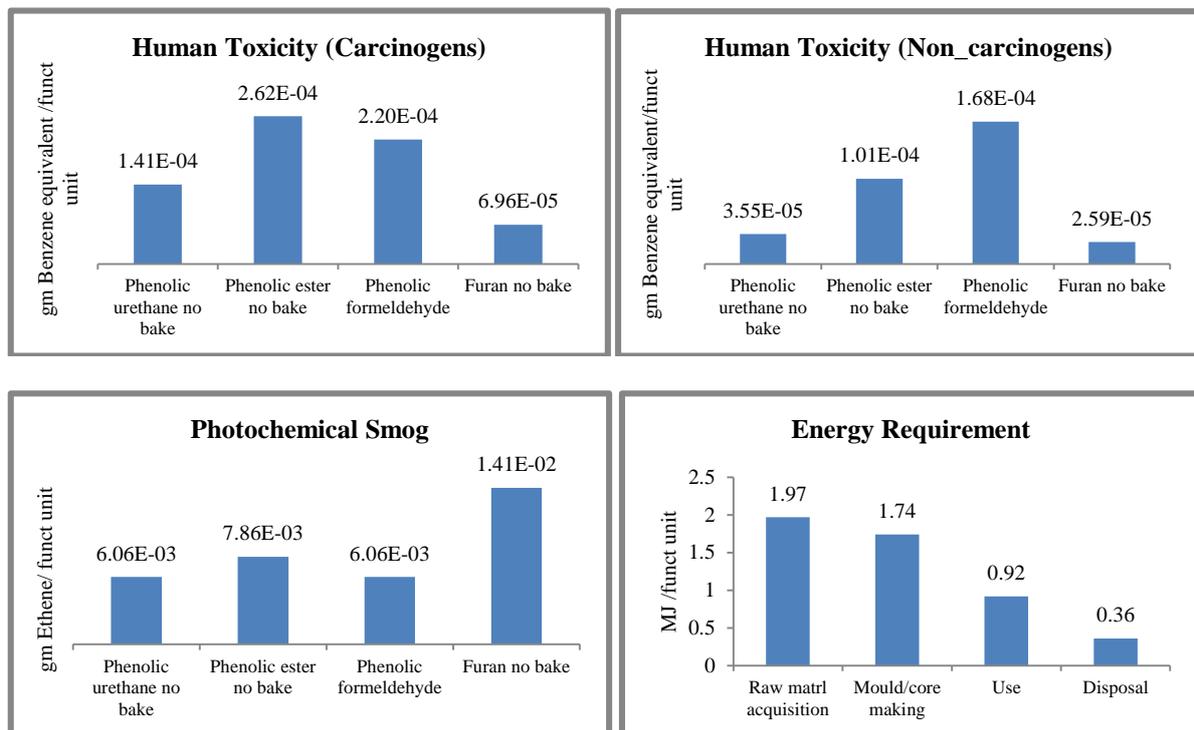


Figure 5. Life cycle environmental impact comparison of four binder systems for eight different impact categories

4. Conclusions

In this work, a quantitative evaluation of life cycle energy input to and emissions (air, liquid and solid) from the sand moulding process for four different binder systems is presented. The impact assessment was done using various impact categories as per the ISO-FRED-14040 LCA method. Result shows that there is no single binder system, which is most or least environmental damaging in all the impact categories. However, furan no-bake binder system proved to be least environment damaging in almost all the categories except photochemical smog. Phenolic urethane no-bake binder system should be avoided to use wherever possible, as being most environmental damaging. Use of furan no-bake binder system will surely reduce the harmful emissions to environment during manufacturing of core and moulds and will pave the path towards development of a sustainable process. The binder specific data for manufacturing phase and data related to upstream and downstream, i.e. for raw material acquisition and disposal phase were not available from the foundries and have been collected from various published literature as mentioned earlier. This may bring some differences in results for specific foundries and geographic regions.

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