Journal of Cleaner Production 89 (2015) 159–164

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Life-cycle assessment of a civil explosive

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ARTICLE INFO

Article history:
Received 11 June 2014
Received in revised form
3 November 2014
Accepted 7 November 2014
Available online 15 November 2014

Keywords:
Environmental impacts
Emulsion explosive compositions
Life-Cycle Impact Assessment (LCIA)
Primary energy

ABSTRACT

To reduce the environmental impacts of civil explosive production, it is essential to adopt a life-cycle perspective. The main goal of this article is to present a comprehensive Life-Cycle Assessment of civil explosive production and assess the environmental impacts of five alternative explosive compositions in order to identify the compositions with lower impacts and opportunities for improvement. A detailed inventory was implemented, based on data collected from a specific European company. Three complementary Life-Cycle Impact Assessment (LCIA) methods were used to assess primary energy, six environmental impacts (CML method) and three toxicity impacts (USEtox method). The results obtained with the CML and USEtox were compared with a recent LCIA method (ReCiPe), aiming at improving the robustness of our conclusions and understanding the differences between LCIA methods. The results showed that the main contributor for the ten impact categories is the emulsion explosive composition, mainly due to ammonium nitrate production. The comparison of five alternative emulsion explosive compositions showed that the inclusion of sodium nitrate leads to a reduction in impacts. A contribution analysis carried out with ReCiPe provided similar conclusions with those calculated with CML; however ReCiPe and USEtox calculated different toxicology impacts, due to different substances coverage and characterization factors.

1. Introduction

The world production of civil explosives has been increasing, mainly due to the growing demand of mining, extraction and construction industries. A world production of 11 million tonnes of civil explosives was estimated for the year 2012 (Global Industries Analyst, 2008), which will increase to 16 million tonnes in 2018 (Global Industries Analyst, 2013). The main users are coal mining (about 68% of the total demand), quarrying and non-metal mining (16%) together with metal mining and construction (16%) (Apodaca, 2014).

The main types of civil explosives are ANFO (ammonium nitrate and fuel oil), emulsion explosives and dynamites. For many years, the concern with the production of commercial explosives focused on risk assessment. More recently, due to increasing environmental requirements, companies producing civil explosives have begun to implement environmental management practices. However, to reduce the environmental impacts of civil explosive production, it is essential to identify and quantify the impacts adopting a life-cycle (LC) perspective, which can be accomplished with the support of the Life-Cycle Assessment (LCA) methodology (ISO 14040, 2006). Nonetheless, the literature on this topic is very scarce, and only one LCA that assessed civil explosive production was found (Kellenberger et al., 2007); other LCA focused on military explosives (Hochschorner et al., 2006; Hägvall and Tryman, 2010) and demilitarization processes (Alvebro et al., 2009; Ferreira et al., 2013). Kellenberger et al. (2007) developed a simplified model for the civil explosive production with important data limitations, since almost no industry production data was available. Data about raw materials were obtained by personal communication, but all other inputs and outputs were estimations.

The main goal of this article is to present a comprehensive LCA of the production of a civil explosive. The civil explosive considered is an emulsion explosive, which is prepared with a matrix (ammonium nitrate and water with a mixture of oils and emulsifiers) and a sensitizing agent. An LC model ("cradle to gate") was developed for the entire emulsion explosive production process, including explosive components, emulsification, sensitization, packaging and transportation. A detailed inventory was implemented, based on primary data collected from a specific European company producing emulsion explosives, which is representative

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http://dx.doi.org/10.1016/j.jclepro.2014.11.027
0959-6526/

of similar industrial processes taking place in developed countries. The name of the company was kept anonymous due to a confidentiality agreement to obtain industry process data.

A second goal is to assess the environmental impacts of five alternative explosive compositions in order to identify the compositions with lower impacts and opportunities for improvement. Three complementary Life-Cycle Impact Assessment (LCIA) methods were used to assess ten impact categories: primary energy, six environmental impacts (CML method) and three toxicity impacts (USEtox method). In addition, the results obtained with the methods CML and USEtox were compared with those calculated with ReCiPe, a recent LCIA method, aiming at understanding the differences between LCIA methods and improving the robustness of our conclusions.

The article is structured in four sections, including this introduction. Section 2 presents the life-cycle model and inventory. The main results are presented in Section 3. Finally, the last section draws the conclusions together.

2. Life-cycle model and inventory for emulsion explosive production

Life-Cycle Assessment is a methodology to quantify potential environmental impacts associated with the full life-cycle of product systems (ISO 14040, 2006), handling the process as a chain of subsystems exchanging inputs and outputs (Malça and Freire, 2006). An LCA study shows where the most relevant environmental problems arise (Kjaerheim, 2005), thus supporting the identification of environmentally preferable solutions and opportunities for improvement of environmental performance (ISO 14040, 2006; Jasch, 2000; Fijał, 2007).

This section describes the LC model and Inventory developed to assess the emulsion explosive production carried out by a specific European company, which is representative of similar processes that occur in developed countries. This company produces exclusively emulsion explosives with an annual production (2013) of 10 000 tonnes, 70% of which incorporating aluminum. The model follows a cradle-to-gate LCA and covers the following processes: transport of raw material, emulsification, sensitization and packaging. Fig. 1 presents the LC model flowchart for the emulsion explosive production. The emulsification, sensitization and packaging are distinct processes, but sequential, which were modeled as a single process.

The functional unit was defined as 1 kg of TNT equivalent, corresponding to 4.5 MJ of energy content (Keshavarz, 2005). The corresponding reference flow includes materials and energy associated with the production of 1.45 kg of emulsion explosive, since it was considered that 1 kg of emulsion explosive has 3.14 MJ of energy content.

Table 1
Mass balance Inventory for the emulsion explosive production (per kg TNTeq).

Constituents	Amount
Inputs	
Ammonium Nitrate	1.06 kg
Water	0.16 kg
XPS	0.03 kg
Mineral oil	0.13 kg
Polycarboxylate	0.07 kg
Packing	
Polyethylene	0.05 kg
Outputs	
Emulsion explosive (includes packing)	1.50 kg
Ashes	0.002 kg
Inert material	0.003 kg

A detailed LCI was implemented based on process data (from the year 2010) provided by an European company; whilst secondary data was obtain using the Ecoinvent v2.2 database (http://www.ecoinvent.ch/). The components used in the preparation of the emulsion explosive were i) ammonium nitrate added in the form of prills (granules) with a diameter of 1–2 mm, ii) water, iii) mineral oil (liquid), iv) an emulsifier (liquid) and v) a sensitizing agent (hollow microspheres with 70 microns of diameter, considered as extruded polystyrene, XPS). Data for the emulsifiers were not provided due to confidentiality, and two alternative emulsifiers were considered: Polycarboxylate (base composition) and Carboxymethyl (alternative composition).

Tables 1 and 2 provide the mass and energy inventory of the emulsion explosive production. Table 3 details the transportation data for the emulsion explosive constituents. The LC model includes the indirect impacts associated with the production and transport of materials and energy inputs, assuming the electricity mix for Portugal and naphtha as fuel used in the industrial boiler. The waste treatment of minor process outputs, such us inert material (plastics, metals, paper) and ashes were left out of the system boundary due to lack of information.

Table 4 presents five alternative emulsions explosive compositions, which are based in alternative oils, sensitizing agents, emulsifier agents and addition of materials in the matrix to assess potential environmental improvements in production of the emulsion explosive. The base composition represents the baseline emulsion composition described before. In the composition #1 and #2, aluminum and sodium nitrate are added to the base composition, respectively, assuming that aluminum displaces an equal mass quantity of the matrix and sodium nitrate displaces an equal mass

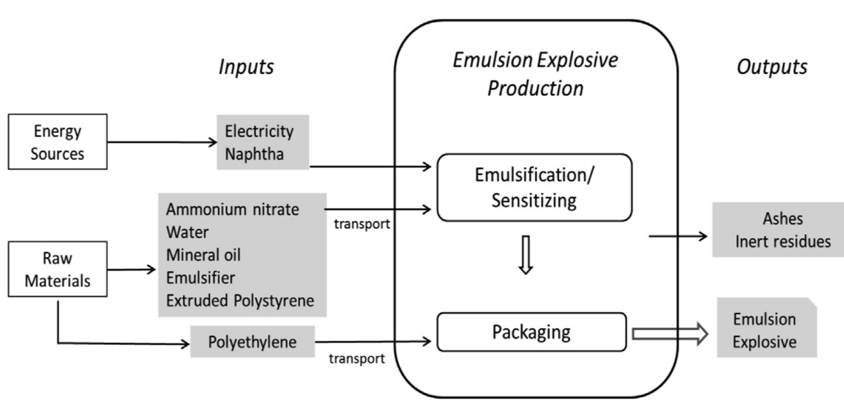

Fig. 1. Flowchart representing the emulsion explosive production.