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Life cycle assessment of caustic soda production: a case study in China

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ABSTRACT

Life cycle assessment was conducted to estimate the environmental impact of caustic soda production. Electricity and raw salt production accounted for >90% of the overall environmental burden. These findings can be attributed to electrical consumption for bipolar electrolysis and brine extraction, diesel consumption for generating electricity during well production, and direct heavy metal emissions during drilling fluid loss and waste disposal. The key factors in reducing the overall environmental impact include optimizing raw salt production, electricity, and steam consumption efficiency, choosing drilling fluids with less toxic heavy metals (e.g., arsenic, barium, molybdenum, selenium, vanadium, beryllium, and nickel), minimizing brine leakage during brine transport, reducing the volume of drilling fluid lost, and decreasing the transport distance from brine buyers to suppliers.

1. Introduction

Caustic soda is one of the most widely used industrial chemicals, such as in the pulp and paper, alumina, textile, electroplating, detergent, and wastewater industries. It is generally produced through the electrolysis of sodium chloride solution with mercury, diaphragms, or membrane cells. The global production of caustic soda is approximately 80 million tons per year (European IPPC Bureau, 2013), with China as the largest producer and consumer worldwide (CMAI, 2010). At the end of 2012, the caustic soda production in China has reached 27 million tonnes. Caustic soda production via the membrane cell technique was approximately 23 million tonnes, which accounted for >85% of the total caustic soda production of China (China Industrial Competitive Intelligence Network, 2013). However, the Chinese caustic soda industry still uses obsolete production technology, as well as suffers high production costs, negative environmental effects, and an unbalanced development between caustic soda and chlorine products. In addition, the caustic soda industries in China and the EU consume large amounts of electricity: approximately 5% of the industry sector in China and 3% in the EU (National Bureau of Statistic of China, 2012; Ministry of Industry and Information Technology of China, 2012; European IPPC Bureau, 2013). These factors are important in global carbon reduction. Accordingly, Chinese government officials have focused on constructing caustic soda plants.

Life cycle assessment (LCA) is a “cradle-to-grave” approach for evaluating the environmental effects of a product, process, or activity. LCA identifies and quantifies the energy and materials used and the waste discharged into the environment and assesses the impact of such usage and disposal. LCA is widely used in government policy-making, strategic planning, marketing, consumer education, process improvement, and product design worldwide. However, few studies have analyzed the impact of the caustic soda industry on the environment via LCA (Alvarez-Gaitan et al., 2013; Boustead, 2005), and none of them involved China. The caustic soda industry is both resource intensive and energy intensive. Considering the rising cost of electricity, the caustic soda industry needs a technological breakthrough to decrease energy consumption and increase electrochemical transformation (Lima and Mirapalheta, 2010). The impact of this industry on the environment needs to be assessed because of its significant contribution to carbon emissions. The caustic soda industry also emits numerous toxic compounds into the local environment, such as heavy metals and organochlorine compounds. Many compounds associated with chlorine are toxic and cannot be completely eliminated through any method (Harris, 1999). Certain water-soluble and particle-bound byproducts in aquatic discharges of the caustic soda industry are harmful to human health (Bosch et al., 2009). This study aims to establish a database on the Chinese caustic soda industry, conduct

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sensitivity analysis, identify the main pollution processes, present suggestions for improving energy efficiency and reducing pollution, and to compare the results with those of other countries.

2. Materials and methods

2.1. Functional unit

The functional unit provides a quantified reference for all related input and output of the studied product, process, or activity system (ISO 14040, 1997). In this study, 1 t of 100% caustic soda was used. All materials, wastes, emissions, and energy consumption levels are based on this functional unit.

2.2. System boundary

A system boundary was set via the cradle-to-gate approach. The scenario involves raw material production, infrastructure, transport, energy (e.g., diesel and coal-based electricity) generation, direct emissions, well drilling, brine extraction, raw salt, caustic soda production, and waste disposal. Fig. 1 shows the system boundary and flow of main materials. Mass allocation was also considered in this study.

2.3. Methodology

The life cycle impact assessment (LCIA) results were calculated at the midpoint level using the ReCiPe E method (Goedkoop et al., 2009; Schryver et al., 2009). The IMPACT2002+ (Jolliet et al., 2003) and TRACI (Bare et al., 2003) methods were used to check the robustness of the results obtained using ReCiPe. These methods are the most commonly used indicator approaches for LCA analysis. Specifically, the ReCiPe method uses impact mechanisms that have a global scope and considers a broad set of midpoint impact categories (i.e., climate change, ozone depletion, human toxicity, photochemical oxidant formation, particulate matter formation, ionising radiation, terrestrial acidification, freshwater eutrophication, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, agricultural land occupation, urban land occupation, natural land transformation, water depletion, metal depletion, and fossil depletion). The IMPACT 2002+ method includes 15 midpoint categories (i.e., carcinogens, non-carcinogens, respiratory inorganics, ionizing radiation, ozone layer depletion, respiratory organics, aquatic ecotoxicity, terrestrial ecotoxicity, terrestrial acidification/nutrification, land occupation, aquatic acidification, aquatic eutrophication, global warming, nonrenewable energy and mineral extraction), whereas the TRACI method has 9 midpoint categories (i.e., global warming, acidification, carcinogens, non-carcinogens, respiratory effects, eutrophication, ozone depletion, ecotoxicity, and smog). In addition, normalization was applied to compare midpoint impacts and to analyze the contribution of each midpoint impact to the overall impact. The normalized factor of midpoint impact was determined using the ratio of the impact per unit of emission divided by the per capita world impact for the year 2000 (Wegener Sleeswijk et al., 2008). The detailed methodology and complete characterization factors for ReCiPe are available on the website of the Institute of Environmental Science of Leiden University of the Netherlands (http://www.cml.leiden.edu/research/industrialecology/researchprojects/finished/recipe.html), those for IMPACT2002+ are at the University of Michigan Risk Science Center website, http://www.sph.umich.edu/riskcenter/jolliet/impact2002+.htm, and those for

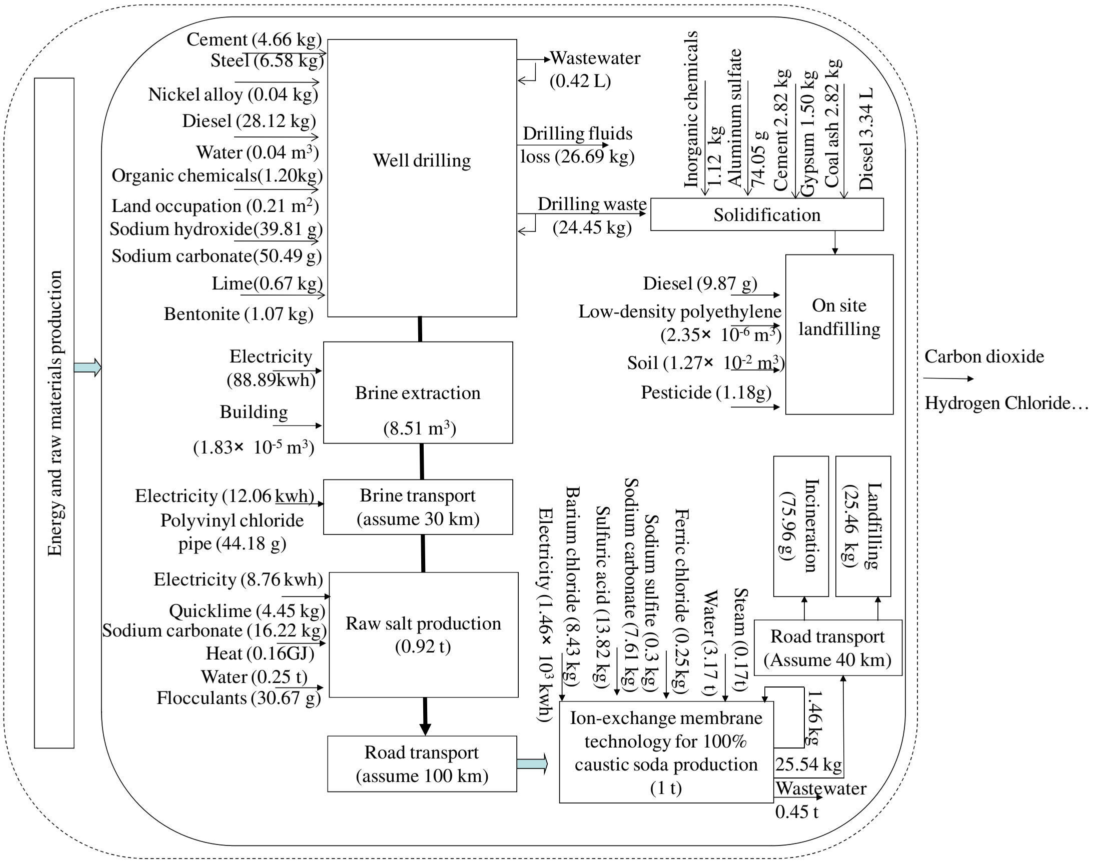

Fig. 1. System boundary and material flow.