CHEMICAL ENGINEERING TRANSACTIONS

VOL. 45, 2015

A publication of AIDIC
The Italian Association of Chemical Engineering
www.aidic.it/cet

Guest Editors: Petar Sabev Varbanov, Jiří Jaromír Klemeš, Sharifah Rafidah Wan Alwi, Jun Yow Yong, Xia Liu

ISBN 978-88-95608-36-5; **ISSN** 2283-9216 DOI: 10.3303/CET1545073

Environmental Assessment of Remediation Technologies for Mercury Containing Wastes using LCA Approach

Yailen Busto[a], Edesmin W. Palacios*[,b], Filip M.G. Tack[c], Luis M. Peralta[d], Xiomara Cabrera[d], Elena R. Dominguez[d], Liz M. Rios[d]

[a]Technological University of Israel, Francisco Pizarro street and Orellana Avenue E4-142, Quito, Ecuador
[b]Central University of Ecuador, University Citadel between Bolivia and Salgado street, Quito, Ecuador
[c]Bioengineering Science Faculty, Gent University, Coupure Links 653, 9000B, Gent, Belgium
[d]Central University of Las Villas, Camajuani street km 5 ½, Santa Clara, Villa Clara, Cuba
wsaudades@gmail.com

Mercury cell chlor-alkali plants are not anymore considered a good industrial practice and the Integrated Pollution Prevention and Control of the European Union has indicated that chlor-alkali installations require obtaining licenses based on the Best Available Techniques. The purpose of this paper is to present the findings on the environmental impact study of current and future technologies to remediate mercury contaminated wastes from a chlor-alkali Cuban plant using Life Cycle Assessment (LCA) approach. The future remediation alternative consists on the proposal of thermal treatment to remove Hg while the current option includes the waste stabilization and disposal. The environmental impact assessments for both technological alternatives have been compared regarding their impact and damage categories using LCA. From an environmental point of view, a significant reduction on the human health impact (95.4 %), ecosystem quality impact (83 %) and impact on resources (78.5 %) would be achieved in comparison with the existing treatment applied by the chlor-alkali Cuban plant. The proposed thermal treatment technology is a significant costs project, but represents considerable benefits for the environment and human health.

1. Introduction

The chlor-alkali industry represents the third major mercury user worldwide (AMAP/UNEP, 2008). In this process, very large quantities of liquid mercury are used as a cathode in electrolytic cells to produce chlorine, sodium hydroxide and hydrogen by electrolysis of brine solution (Southworth et al., 2004).

The negative impacts of mercury pollution on the environment are mainly due to its potential of biomagnification, bioconcentration and bioaccumulation throughout the food chain (Yi et al., 2011). One of the major concerns from the chlor-alkali mercury emissions is the mercury solid waste generated by the industrial process. In the future there will be fewer and fewer mercury cells operating, as the older plants are shut down or converted into membrane cell technology. During the remaining life of mercury cell plants, however, measures should be taken to minimize current and future mercury emissions from handling, storage, treatment and disposal of mercury-contaminated wastes (Directive 2008/1/EC, 2008).

In the United States, the management and ultimate disposal of mercury hazardous wastes is controlled by US EPA (2008) regulations known as the Land Disposal Restrictions (LDRs) (40 CFR, Part 268). Under the current LDR program, the US EPA has established thermal recovery (e.g., roasting/retorting) as the best demonstrated available technology (BDAT) for treatment of wastes containing more than 260 mg/kg of mercury. For treatment of wastes with less than 260 mg/kg of mercury, other extraction technologies (e.g., acid leaching) or immobilization technologies (e.g., stabilization/solidification) may be considered (US EPA, 1997).

In Cuba, the main source of mercury pollution is located in the central region of the country, in Sagua La Grande city. The Elpidio Sosa chlor-alkali plant, which currently still is in use, has a daily production capacity of 48 t of chlorine gas and 108 t of caustic soda at 50 % concentration.

Please cite this article as: Busto Y., Palacios E.W., Tack F.M.G., Peralta L.M., Cabrera X., Dominguez E.R., Rios L.M., 2015, Environmental assessment of remediation technologies for mercury containing wastes using lca approach, Chemical Engineering Transactions, 45, 433-438 DOI:10.3303/CET1545073

Environmental methods are based on the Environmental Impact Assessment (EIA) of a treatment, process or project in general. To evaluate the environmental impact of a treatment or process, several qualitative (Leopold and Conesa Matrix) and quantitative (Externalities Calculation and Battelle-Columbus method) methods have been developed (Conesa, 2000). Several methods are investigated and used for evaluating the sustainability of actions or green remediation strategies. Among these, the Life Cycle Analysis (LCA) and the Net Environmental Benefit Analysis (NEBA) are the most used (Roccaro and Vagliasindi, 2013). Nowadays, the methodology of Life Cycle Impact Assessment (LCIA) is regarded as the most efficient method to evaluate qualitatively and quantitatively the environmental impact with a comprehensive analysis of the proposed technology.

The LCA is an ISO standardized and widely used methodology, the aim of which is to evaluate the environmental burdens of a product/process over its entire life cycle by the modelling and calculation of the resources used and the emissions produced (Puccini et al., 2013). Since the last decades, this methodology has been established as a highly appropriate tool to quantify emission sustainability indicators of development (Heijungs et al., 2010). Most research reports regarding environmental impact assessment of mercury employing LCA methodology have been focused on its use in lamps (Eckelman et al., 2008). The mercury flows in Europe and the world as well as the impact of decommissioned chlor-alkali plants was studied by Concorde (2004). Moreover, studies that use LCA methodology to compare the environmental impact of different thermal treatment processes for hazardous wastes have been done (De Vos et al., 2007). Nevertheless, a lack of surveys about using LCA to evaluate the environmental impact of current or future technologies to remediate specifically mercury contaminated wastes from chlor-alkali plants has been observed.

The purpose of this paper is to present the findings on the environmental impact study of current and future technologies to remediate mercury contaminated wastes from a chlor-alkali Cuban plant using Life Cycle Assessment (LCA) approach. The future remediation alternative consists on the proposal of thermal treatment to remove Hg while the current option includes the waste stabilization and disposal.

2. Material and methods

2.1 Description of the remediation alternatives

In the present study, two remediation alternatives were considered. The future remediation alternative consisted on the proposal of thermal treatment to remove Hg while the current option included the waste stabilization and disposal at Cuban chlor-alkali plant.

The proposed thermal treatment plant to treat the mercurial waste generated by chlor-alkali Cuban plant at pilot scale can be divided into a mercury waste pre-treatment system, a thermal treatment system, a mercury recovery system and a co-products recovery system. The mercury waste pre-treatment system includes the waste extraction from the niche (excavator), an equipment to contain and to feed the mercurial waste into the trays (feed hopper), an equipment to transport the mercurial waste to the drying machine (conveyor), an equipment to reduce the waste moisture content (drying) and a machine for crushing the mercurial waste (mill). The thermal treatment system includes the oven (furnace) while the mercury recovery system includes an energy recovery machine for the outgoing gases (heat exchanger) in which the mercury condensation occurs and a sedimentation equipment to recover the metallic mercury (sedimentation tank). The final stage of the process incorporates a co-products recovery system with a water recovery system (storage tank) and a treated waste recovery system (retention hopper).

The current remediation process carried out by the electrochemical Cuban factory involves the stabilization and disposal in concrete niches. The mercury containing waste is produced by mixing the exhausted mercury of the electrolytic cell with sodium sulphide in a first step and with sodium chloride, calcium carbonate, magnesium hydroxide and diatomaceous earth in a second step. This mercury waste is currently unsafely disposed in concrete niches. Contact with ground water or rain may cause mercury to leach and contaminate the soil and underground waters. The elevated mercury content of this mercurial waste as well as the high toxicity levels have been previously reported by Busto et al. (2011).

2.2 Life Cycle Assessment (LCA) methodology

The environmental impact assessment was carried out using the SimaPro 7.3.2 software and the Ecoinvent database (Ecoinvent, 2007). In order to evaluate the environmental impact of the proposed thermal treatment technology and the current stabilization and disposal option, a comparative analysis using LCA methodology was done. The environmental impact assessment was addressed for this Scenario following the four standardized steps (Goal and scope definition, Inventory analysis, Impact assessment and Interpretation) of the LCA methodology according to ISO 14 040 regulation.

3. Results

3.1 Environmental impact assessment by LCA approach - Goal and scope definition

The goal in this study was the comparison of the environmental performance of the current mercurial waste treatment that is carried out by the chlor-alkali Cuban plant (existing scenario) with the proposed thermal treatment technology (future scenario). Although the present scenario is based on a proposal alternative (which it is actually not in use), the time frame for comparison was assumed as a current situation with the focus on this year. The functional unit used was 1 day of treatment of 3 t of mercurial waste (reference flow) in the chlor-alkali Cuban plant in 2014. It is worth mentioning that all input and output flows were referred to this functional unit.

3.2 Environmental impact assessment by LCA approach – Inventory analysis

For the inventory analysis, the input and output flows for the both alternatives were calculated considering the four systems involve (the proposal thermal treatment) and the three stages involve (the current alternative applied by the ELQUIM plant). Mass and energy balances were conducted to determine all process streams. Figure 1 shows the general description of the scenario.

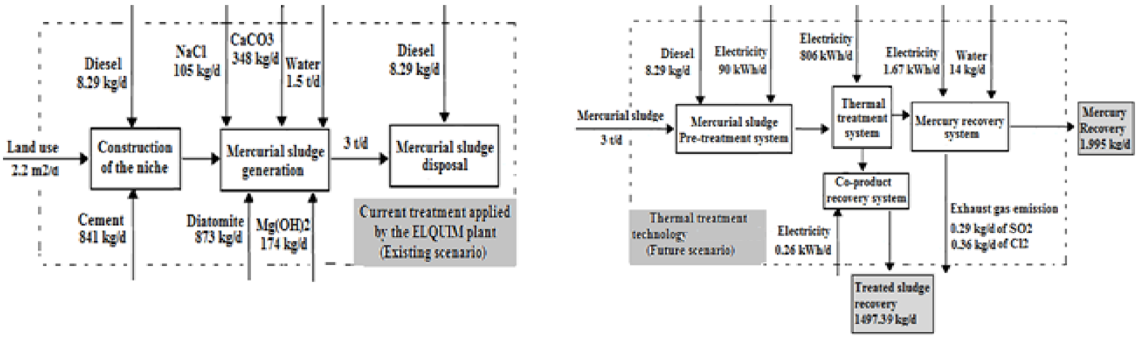

Figure 1: General description of the Scenario

In Table 1 detailed information of the input flows considered for the impact assessment of the proposed thermal treatment technology is shown. It is worth to mention that the boundary of the system only accounts the developed process to treat the mercury containing waste, considering that the thermal plant has been already installed. The land use needed for earlier stages (e.g. to build the thermal plant) was not considered. Moreover, all values of electricity and water consumption have been calculated considering the corresponding equipment design equations for the functional unit established.

Table 1: The input flows considered in the LCA of the proposed thermal treatment

Process system	Operation	Equipment	Resource	Consumption
Pre-treatment	Extraction	Excavator	Diesel	8.29 kg
	Transport	Conveyor belt	Electricity	0.22 kWh
	Milling	Rod mill	Electricity	84.5 kWh
	Drying	Exhaust gas	Electricity	5.6 kWh
Thermal treatment	Thermal	Electric resistance furnace	Electricity	804 kWh
	Thermal	Exhaust gas	Electricity	1.12 kWh
	Thermal	Air blower	Electricity	0.38 kWh
Mercury recovery	Condensation	Heat exchanger	Electricity	1.67 kWh
	Sedimentation	Sedimentation tank	Water	14 kg
Co-products	Transport	Conveyor belt	Electricity	0.26 kWh

In Table 2 detailed information of the input flows considered for the impact assessment of the current technology applied by the chlor-alkali Cuban plant are shown. The boundaries considered for the existing treatment included the land use because this alternative starts with the construction of the niche. The values of the chemical compounds added to form the mercurial waste were determined considering the composition of the waste reported by the electrochemical plant. For the analysis was considered that the excavator used for the extraction and movement of the land (first stage of the process) was employed for the waste disposal in the concrete niche. The amount of concrete needed (18.5 sacks of cement) to construct one niche of 2.2 × 2.2 × 1 m of dimensions was reported by ECOI 25 industry (ECOI 25, 2012).

Table 2: The input flows considered in the LCA of the current treatment applied by the ELQUIM plant

Process system	Operation	Equipment	Resource	Consumption
Construction of the niche	Extraction	Excavator	Diesel	8.29 kg
	Land movement		Land	2.2 m^2
	Construction		Concrete	841 kg
Mercurial waste generation	Chemical products addition	-	Water	1,500 kg
			$CaCO_3$	348 kg
			$Mg(OH)_2$	174 kg
			Diatomite	873 kg
			NaCl	105 kg
Mercurial waste disposal	Disposal	Excavator	Diesel	8.29 kg

3.3 Environmental impact assessment by LCA approach – Impact assessment

The evaluation was conducted analyzing the effect of the resources used (water, chemical compounds, diesel, concrete, land use) and emissions generated (no emissions) on the environment expressed by impact categories and damage categories according to the Eco-indicator 99 (H) V2.04/ Europe EI 99 H/H/Weight method. It is important to remark that, even when the current technology applied by the factory does not produce emissions, as the Hg has not been removed represents a potential risk.

3.4 Environmental impact assessment by LCA approach – Interpretation

The environmental impact assessment between the existing scenario and the future scenario based on a unique punctuation is represented in Figure 2. A comparative analysis demonstrated that the future scenario impacts 89 % less than the existing scenario in to the environment.

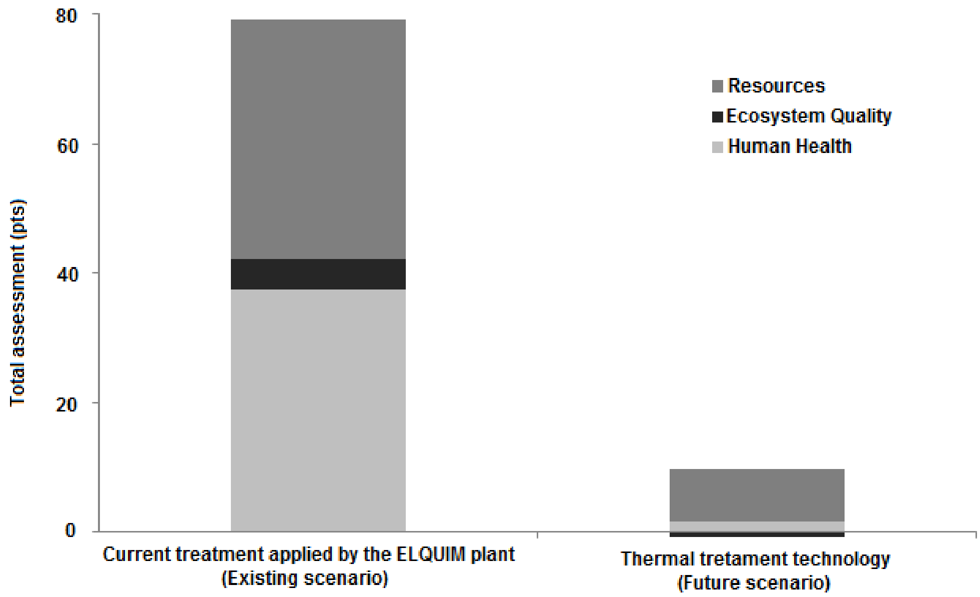

Figure 2: Comparative analysis using LCA expressed in a unique punctuation

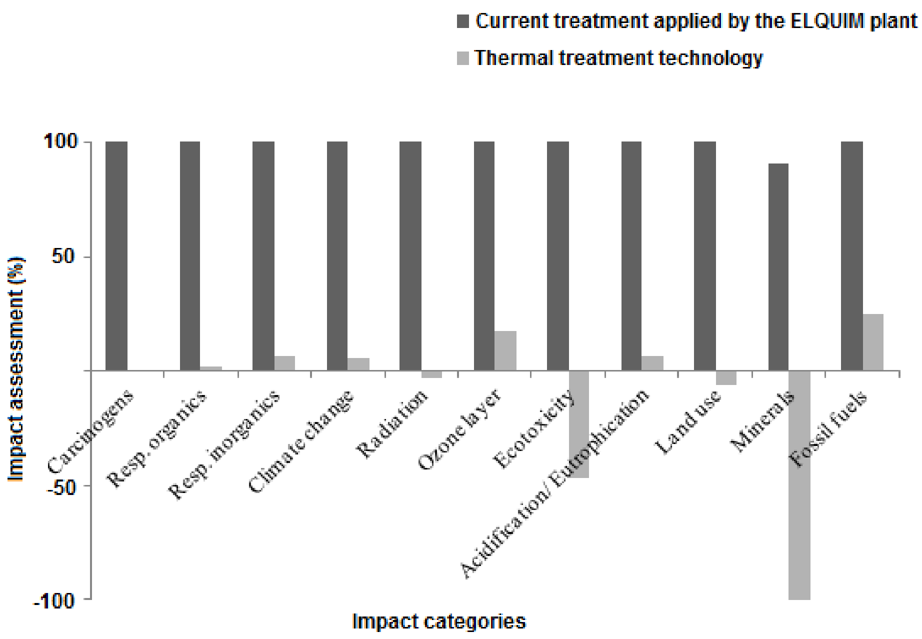

Figure 3: Comparative analysis using LCA expressed in Impact Categories

The current treatment employed by the ELQUIM factory (existing scenario) impacts in the same way in the human health and resources damage category. This phenomenon is associated with the high amount of chemical products that are used to stabilize the mercury solution that comes from the chlor-alkali production process as well as the high amount of cement needed to build the niches for the further mercurial waste disposal.

A comparative analysis of the behaviour of the existing and future scenario based on their effects on the impact categories was also evaluated (Figure 3). The existing scenario has a significant and negative effect on fossil fuel, respiratory inorganics, carcinogens and climate change impact categories. This is linked with the high consumption of chemical products, cement and diesel. In the future scenario the main impacted category is the fossil fuel (24.6 %). This is associated with the fossil fuel consumption required to supply the amount of electricity needed in the thermal treatment process. However, the use of green energy could achieve a substantial reduction on this impact category. Nevertheless, the future scenario has a lower effect in all impact categories than the existing scenario.

On the other hand, the future scenario gives a reduction of 100 % of minerals and 47 % of terrestrial ecotoxicity impacts which result from a direct reduction of mercury emissions from landfill disposal as the mercury contaminated waste is treated and the mercury is recovered. The negative values observed for the impact categories of minerals, ecotoxicity, land use and radiation; reflect the environmental benefits of the avoided mercury emissions. This effect is associated with the high efficiency of mercury recovery avoiding ecotoxicity problems by Hg pollution which represents less extraction of the mineral (Hg) for its commercial use and no land use is required during the technological process.

4. Conclusions

The potential changes in environmental impacts that may arise from the mercury levels reduction have been assessed. The current treatment applied by the Chlor-alkali Cuban factory (existing scenario) did not contribute in any measure to mercury level reduction as it is based on stabilizing and disposing the mercury contaminated waste in niches. The future scenario which involves thermal treatment technology represents an attractive treatment alternative from environmental point of view for Cuban conditions. This comparative environmental study clearly demonstrated that remediation actions focus on to reduce and/or to eliminate the mercury pollution generated during chlor-alkali production process is more suitable than stabilization and disposal actions. For Cuban conditions, the implementation of the proposed thermal treatment technology although stand for a project of significant costs, represents considerable benefits for the environment and human health. If it consider the proposed thermal treatment technology as an annexed mercurial waste treatment plant to the Chlor-alkali Cuban factory could substantially reduce the project costs. The total proceeds from the chlor-alkali industry would significantly minimize the negative impact of the costs of the proposed technology. These findings could be important for decision makers in the chlor-alkali industry sector to develop novel environmental policies.

References

Amap/Unep, 2008, Technical Background Report to the Global Atmospheric Mercury Assessment. Arctic Monitoring and Assessment Programme/UNEP Chemicals Branch. UNEP Chemicals website <www.unep.org/chemicalsandwaste/Portals/9/Mercury/Documents/Publications/Technical_background_report.pdf> accessed 02.04.2015

Busto Y., Cabrera X., Tack F.M.G., Verloo M.G., 2011, Potential of thermal treatment for decontamination of mercury containing wastes from Chlor-alkali industry, Journal of Hazardous Materials, 186, 114-118.

Concorde E., 2004, Mercury flows in Europe and the world: The impact of decommissioned chlor-alkali plants. Final report for European Commission, Brussels, Belgium, <www.ec.europa.eu/environment/chemicals/mercury/pdf/report.pdf> accessed 28.02.2014

Conesa V.F., 2000, Methodological Guide for the Environmental Impact Assessment. 3rd Ed. Mundi-Prensa, Madrid-Barcelona-México.

De Vos S., Gortzen J., Mulder E., Ligthart T., Hesseling W., 2007, LCA of thermal treatment of waste streams in cement clinker kilns in Belgium. Comparison to alternative treatment options, <www.febelcem.be/en/waste-treatment/IT-A-R-2007-036-Febelcem.pdf> accessed 28.02.2014

Directive 2008/1/EC, 2008, Directive of the European Parliament and the Council of 15 January 2008 concerning integrated pollution prevention and control, Brussels, Belgium <www.europa.eu/legislation_summaries/environment/waste_management/l28045_en.htm> accessed 20.01.2012

Eckelman M.J., Anastas P.T., Zimmerman J.B., 2008, Spatial assessment of net mercury emissions from the use of fluorescent bulbs, Environmental Science and Technology, 42, 8564-8570.

Ecoi 25, 2012, Construction Enterprise Engineering Works, 25, Santa Clara, Cuba <www.villaclara.cu/paginas-amarillas/ecoing-25> accessed 29.05.2014 (in Spanish).

Ecoinvent, 2007, Ecoinvent: The life cycle inventory data version 2.0. Swiss centre for life cycle inventories, Dubendorf, Switzerland, <www.esu-services.ch/data/ecoinvent/> accessed 29.05.2014

Heijungs R., Huppes G., Guinée J.B., 2010, Life cycle assessment and sustainability analysis of products, materials and technologies. Toward a scientific framework for sustainability life cycle analysis, Polymer Degradation and Stability, 95, 422-428.

Puccini M., Seggiani M., Vitolo S., Iannelli R., 2013, Life cycle assessment of remediation alternatives for dredged sediments, Chemical Engineering Transactions, 35, 781-786, DOI:10.3303/CET1335130

Roccaro P., Vagliasindi F.G.A., 2013, Sustainable remediation of a closed solid waste landfill site: development and application of a holistic approach, Chemical Engineering Transactions, 35, 217-222.

Southworth G., Lindberg S., Zhang H., Anscombe F., 2004, Fugitive mercury emissions from a chlor-alkali factory: sources and fluxes to the atmosphere, Atmospheric Environment, 38, 597-611.

US EPA (United States Environmental Protection Agency), 1997, Mercury Study Report to Congress, Vol. III: Fate and Transport of Mercury into the Environment. EPA-452/R-97-005, Washington, USA <www.epa.gov/ttn/oarpg/t3/reports/volume3.pdf> accessed 21.01.2012

US EPA (United States Environmental Protection Agency), 2008, Land Disposal Restrictions Regulations for Mercury-Containing Non-wastewaters. R 40 CFR Part 273, Washington, USA <www.epa.gov/epawaste/hazard/tsd/mercury/treatmnt.htm> accessed 20.01.2012

Yi Y., Yang Z., Zhang S., 2011, Ecological risk assessment of heavy metals in sediment and human health risk assessment of heavy metals in fishes in the middle and lower reaches of the Yangtze River basin, Environmental Pollution, 159, 2575-2585.