CHEMICAL ENGINEERING TRANSACTIONS

VOL. 114, 2024

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Petar S. Varbanov, Min Zeng, Yee Van Fan, Xuechao Wang

ISBN 979-12-81206-12-0; **ISSN** 2283-9216

DOI: 10.3303/CET24114113

Life Cycle Assessment of Electro-submersible Pumps System Enhanced with Permanent Magnet Motor

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Climate change has triggered environmental awareness around the world with the use of clean technologies that help to control the inventory of Greenhouse Gas (GHG) emissions in their operations, but the calculation of environmental mitigation requires the knowledge of Life Cycle Assessment (LCA) in the production processes. Oil Artificial Lift Systems use Permanent Magnet Motors (PMM) as a viable option in their configuration, which is why it is important to know the Greenhouse Gas Inventory of these alternatives. This research compares the Greenhouse Gas inventory for the Life Cycle Assessment (LCA) of the product of an Electro-Submersible Pumps System (ESPs) with a Normal Induction Motor (NIM) and a Permanent Magnet Motor (PMM). First, the Functional Unit (FU) and LCA were defined according to the ISO 14067:2018 standard. Then the Greenhouse Gas Inventory was carried out according to ISO 14064-1:2019. As results, 5 defined stages of the LCA were determined. 14 activities related to the LCA were found. For the Electro-Submersible Pumps System (ESPs) with MIN, 999.9 kg of raw material were calculated, 1491.66 kW/h for manufacturing, 1491.66 kW/h for storage and 5.77E04 kW/h for use. For the ESPs with PMM 656 kg of raw material were calculated, 1491.66 kW/h for Manufacturing, 1,491.66 kW/h for storage and 4.72E04 kW/h for use. A 18.99 % improvement in the GHG emissions inventory was achieved due to a substantial 18.19 % decrease in energy consumption in the Greenhouse Gas Inventory. The values showed a reduction of 18.99 % of the Carbon Footprint (CF) for the ESPs with the application of new technology. The use of clean technology through the use of PMM could be a feasible alternative in Ecuador, since LCA accounts for 96.39 % of total CF.

1. Introduction

Climate change affects all regions of the world. The polar ice caps are melting, and sea levels are rising. In some regions, extreme weather events and floods are becoming more frequent, while in others, heatwaves and droughts are being recorded (López Feldman et al., 2016). Greenhouse Gas (GHG) emissions such as a) Carbon Dioxide (CO_2, b) Nitrous Oxide (N_2O) and the fluorinated gases (HFC, PFC and SF6) are released into the atmosphere and trap the sun's heat, leading to global warming and climate change (Fernández, 2013). These gases come mainly from human activities such as: a) electricity generation, b) manufacturing, c) deforestation, d) transportation, e) food production, among others. The majority of greenhouse gas emissions are generated in industrial processes, of which 9.7 % correspond to oil activities. Artificial oil lifting occupies 93 % of cases Electro-Submersible Pumps System (ESPs) in wells (Ramírez Chiles, 2014). However, there are few studies on the quantification of GHG emissions and their inventories throughout the Life Cycle Assessment (LCA). In 2022, 197 countries agreed to: a) quantify and b) report GHG emission inventories, generated by the execution of anthropogenic activities and sinks using similar and traceable methodologies.

In the oil extraction industry, the technology used to configure the ESPs is a function of the final production rates and the type of oil in the reservoir. Although the technology of motors and spare parts already comes from a previous engineering that is carried out in a simulator called AutographPC®, this computer tool only has the Normal Induction Motors (NIM), which are the ones provided by Baker Hughes for its worldwide clients, which limits the analysis with other engines that are not constant in the program memory. In spite of, due to the high

Paper Received: 7 June 2024; Revised: 25 August 2024; Accepted: 19 November 2024
Please cite this article as: Córdova M., Córdova J.A., Silva F., Paredes M., Serrano G., 2024, Life Cycle Assessment of Electro-submersible Pumps System Enhanced with Permanent Magnet Motor, Chemical Engineering Transactions, 114, 673-678 DOI:10.3303/CET24114113

costs of electrical energy consumption and competition in the sector to gain new clients, those provided with this service have seen the need to generate innovative projects with new ESPs adjustments that allow customers to new model alternatives not only to pay less electricity consumption but also to meet the goals of their management systems and the reduction of taxes by the Ecuadorian government for using cleaner technologies. Therefore, quantifying an LCA for an ESPs with new engine and component technologies to achieve these benefits becomes a necessary task. It is possible to mention that companies dedicated to artificial oil lifting protect their innovations with patents and intellectual property registrations in the competent bodies of each country where they carry out their operations to avoid copying their ESPs configurations. Therefore, they do not usually disclose their results explicitly unless it is to ratify the authorship of some new technology or in oil congresses that they consider relevant with the aim of achieving a possible service offer with new clients.

To develop a comprehensive GHG emissions at the organizational level, the reference guide is ISO 14064-1:2019. However, different methodologies help provide more details on the three Scopes defined by this standard, including a) the World Business Council for Sustainable Development (WBCSD) and World Resources Institute (WRI) GHG Protocol (Meza-Lopez et al., 2021), which categorizes energy emissions into 15 subcategories, and b) the Intergovernmental Panel on Climate Change (IPCC) guidelines (US EPA, 1999), allowing flexibility in inventory calculations using methods of varying complexity. The methodology for calculating the GHG emission inventory is based on consolidating available data into a summative data register and applying emission factors for each emission source. However, the concept of organization does not fully contribute to the understanding of GHG emission control, as it only considers polluting activities within the administrative environment of the company. Currently, GHG emission inventory calculations take into account not only a single activity or project but the entire Life Cycle Assessment (LCA) of the Product or Service. A viable alternative for this is to use the ISO 14067:2019 standard (Suer et al., 2021). This standard helps calculate the GHG emission inventory by defining a Functional Unit (FU) according to ISO 14040:2006/A2:2021, influencing an environmental impact result, such as the Carbon Footprint (CF), for the entire manufacturing process of the product or service (Córdova et al., 2018). Therefore, proposing environmental management and control in process activities without creating a GHG emission inventory is not feasible. On the other hand, local government-promoted air quality measurements follow specific methodologies to quantify pollutant emissions at exposure points, not considering the specificities outlined in the ISO 14067:2019 family of standards for quantifying kg of CO_2 equivalent for year (CO_2 eq/year), such as: a) the LCA of the product determined by ISO 14044:2006/A2:2021 and b) energy and mass balances at each stage of product or service manufacturing. However, not all GHG emission inventory cases need to quantify CO_2 eq/year until the final processes, as sometimes the output is an input for another production system. To address this premise, two production cycle options are considered: a) from cradle to grave and b) from cradle to gate (Sánchez et al., 2007).

When processes involve many activities and input resources, computational tools are used to handle complete GHG emission inventory databases and facilitate quantification. Among the most commonly used inventory and LCA calculation tools are: a) CCalC2, b) OpenLCA, and c) GEMINIS, which considers inventories as inputs to simulate and study atmospheric processes and global changes in production activities and organizations (Vásquez et Al., 2022). Although business initiatives to reduce CF and GHG emission inventory are numerous, it is crucial to consider the most feasible alternatives. In the manufacturing of an ESPs, innovations and solutions to reduce GHG emissions are costly. However, efforts can be concentrated on saving electrical energy, as this resource is used continuously for operation. While induction motors provide a reasonable Productivity Index (PI), Permanent Magnet Motors can be used to reduce electricity consumption, increase flow, and PI. This research calculated and compared the LCA using CCalC2 (Anđelić et al., 2019), under normal manufacturing conditions of an ESPs assembled with a Permanent Magnet Motor series 440 of 11.16 m and 120 Hz, and one with a Normal Induction Motor 450 in a field operated by Baker Hughes as a viable environmental solution.

2. Methodology

2.1 Life Cycle Analysis (LCA) of the product

To quantify GHG emissions, it is necessary to map the LCA processes of the product or service (Bhatia et al., 2011). This map provides a comprehensive breakdown of: a) services, b) input and output materials at each unit process, and c) the energy required to move a product or by product through the activities of its LCA. This results in a more efficient GHG emissions inventory.

To determine the LCA in the assembly of an ESPs, actual data on materials, equipment and energy consumption must be taken into account. In this research, average data from 18 oil wells under similar production conditions and reservoir fluid properties with their temperature and pressure variations, known as Pressure-Volume-Temperature (PVT), were used. The location and installation facilities of the ESPs in the oil fields were those provided by Andes Petroleum in block 14 of the Ecuadorian Eastern. The main data on the inventory of materials, equipment, transportation times of materials from suppliers to the pre-assembly workshop and subsequent location at the ESPs installation site were the averages calculated by Baker Hughes operational staff in the period 2022 - 2023. The GHG emissions generated by transport vehicles are those recommended by CCalC2 for a 22-ton truck.

In addition, recycling of the ESPs at LCA was not considered in this research because the reuse or repowering of the engines occurs simultaneously when Baker Hughes' in-shop materials inventory requires it, and the department's information considers costs similar to the acquisition of a new engine with a recycled one.

Figure 1 describes the basic content of the process map for the LCA of a product or service that is applied to the manufacturing of an ESPs operated by Baker Hughes.

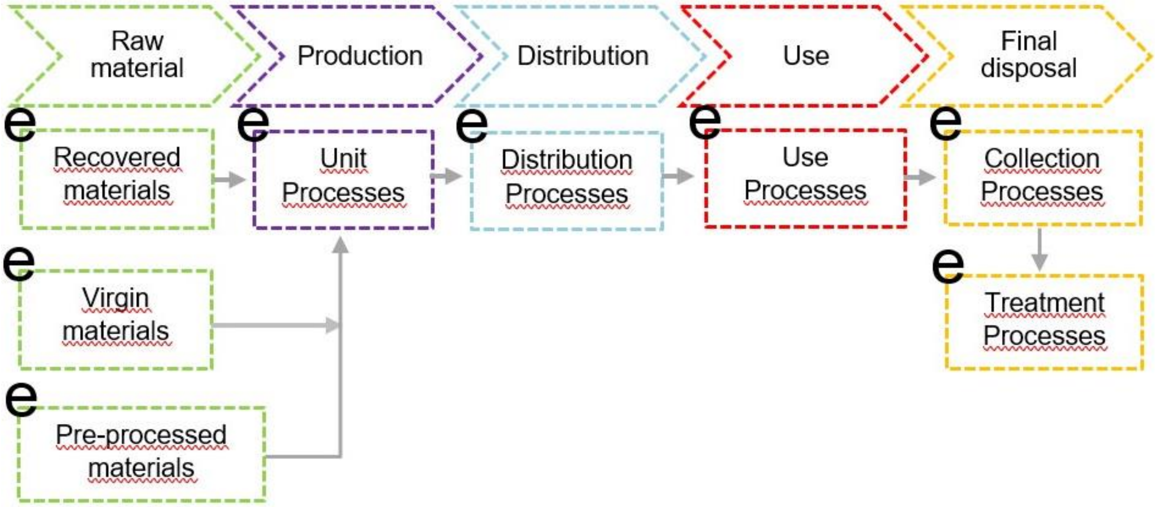

Figure 1: Life cycle assessment of a product. The gray arrows indicate material transport. e=energy. Adapted from GHG Product life cycle accounting and reporting standard

2.2 Greenhouse Gas (GHG) Emissions Inventory

The inventory first requires defining the inputs and outputs of each of the processes outlined in the LCA of the product or service. For the researcher's convenience, ISO 14027 provides guidelines for activities and unit processes for the manufacturing of some products (Moré et al., 2022). While these Product Category Rules (PCR) help standardize manufacturing activities, they do not cover all manufacturing cases and even less so for services. Next, the GHG emissions must be quantified for: a) materials and b) energy sources at each stage of the LCA defined for the product or service. To quantify, it is necessary to establish the quantity of the reference product or service for the entire inventory calculation, establishing a Functional Unit (FU) according to ISO 14067 (Mas-Alique, et al., 2013). This research considers a ESPs assembled by Baker Hughes as the FU. Finally, the carbon dioxide equivalent (CO_2 eq.) weight of the entire inventory is summed and calculated, requiring ISO 14067:2018. To deepen the analysis of the inventories, GHG emissions are classified according to ISO 14064, grouping the quantities into three sources: a) direct, b) indirect, and c) energy. To determine the GHG emissions inventory in the LCA of manufacturing an ESPs. The following inputs were defined: a) Electric Submersible Pump*, b) Electrical energy, c) Transportation energy, d) Packaging and e) Waste. This for each stage of the LCA.

3. Results

3.1 Result of the Life Cycle Assessment (LCA) of the manufacturing of an ESPs

To obtain the priority activities, the macro activities detailed in the ESP manufacturing procedures developed by Baker Hughes were selected. The materials, equipment and energy consumption required to prepare the LCA of the manufacturing of an ESP were taken from actual data for one year of use under normal operating conditions. In addition, a study of the times and movements of the materials and vehicles required in each of the manufacturing stages according to the Baker Hughes ESP assembly procedures was carried out to determine the total energy use. To assemble an ESP at Baker Hughes, 14 activities were identified in the manufacturing process from the cradle to the grave.

Although the input materials involve individual manufacturing processes with the generation of GHG emissions, the CCalC2 database was used. The inventory process map of the LCA of an ESPs does not include final disposal or delivery to competent bodies for waste treatment since, at Baker Hughes, the majority of components are reused and upgraded due to environmental policies and goals. The LCA of the ESPs manufactured with both the IM and the PMM, produced and operated by Baker Hughes, includes the averages of actual consumption from 38 wells, validated by the engineering department. Figure 2 provides a more graphical representation of the LCA.

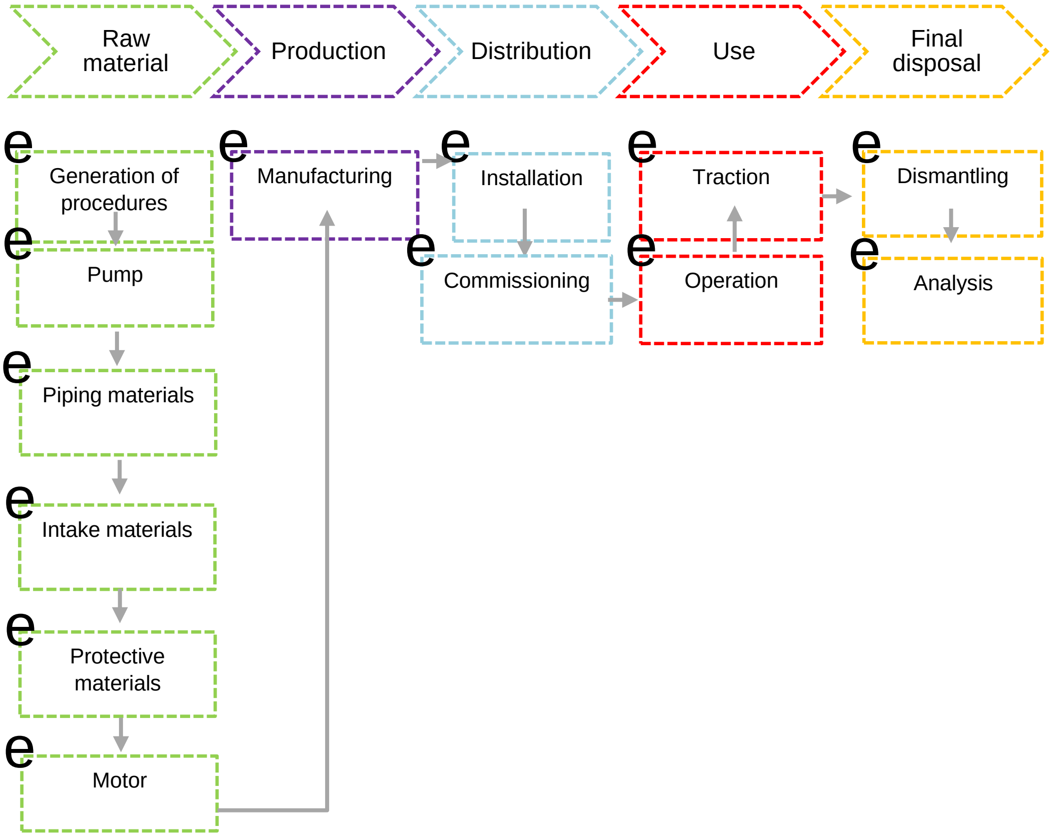

Figure 2: Life cycle assessment for the assembly of ESPs. Gray arrows indicate material transport. "e" represents energy.

3.2 Result of the GHG emissions inventory in the assembly of an ESPs

The quantities of greenhouse gas emissions were calculated in the assembly of an Electric Submersible Pump with a Normal Induction Motor of 60 Hz, series 450. Table 1 shows the accumulated results at each stage of manufacturing, considering historical data from Baker Hughes' Engineering department. The ESPs consists of: a) Pipe materials, b) Inlet materials, c) Protector materials, and d) Motor. The Functional Unit is 1 ESPs manufactured by Baker Hughes.

The calculated data are the average of the PVT conditions of the 18 reference wells using the PMMs. These are: oil gravity range of 788 to 920 kg/m^3, gas gravity between 0.65 to 1.276, separator pressure and temperature of 2.86 MPa and 52 °C. Some of the ESP configuration data are results of the nodal analysis resulting from the engineering design in PROSPER and the design of the elements with AutographPC® developed by Baker Hughes personnel.

Table 1: Greenhouse Gas Inventory for Electric Submersible Pump with Normal Induction Motor

Parameters	Unit	Raw material	Manufacturing	Storage	Use
Electric Submersible Pump*	kg	997.90	0	0	0
Electrical energy	kW/h	0	0	0	5.77E04a
Transportation energy	kW/h	0	1,491.66	1,491.66	0
Packaging	kg	0	0	0	0

Table 2 shows the results of the GHG emissions inventory with the use of a Permanent Magnet Motor manufactured by Baker Hughes. The energy expenditure includes the movement of materials to Baker Hughes locations and then to end-use sites. The ESPs consists of: a) Pipe materials, b) Inlet materials, c) Protector materials, and d) Motor. The Functional Unit is 1 ESPs manufactured by Baker.

Table 2: Greenhouse Gas Inventory for Electric Submersible Pump with Permanent Magnet Motor

Parameters	Unit	Raw material	Manufacturing	Storage	Use
Electric Submersible Pump*	kg	997.90	0	0	0
Electrical energy	kW/h	0	0	0	4.72E04
Transportation energy	kW/h	0	1,491.66	1,491.66	0
Packaging	kg	0	0	0	0

With these greenhouse gas emissions inventory data, the CCalC2 Software shows a calculated Carbon Footprint value for the Submersible Electric Pump with Normal Induction Motor of 23,436.60 kg CO_2 eq/UF, while the Carbon Footprint of the Product for the Submersible Electric Pump with Permanent Magnet Motor showed a value of 18,984.60 kg CO_2 eq/UF. The values showed a reduction of 18.99 % of the Carbon Footprint for the ESPs with the application of new technology. Figure 3 shows the results of the CF with the GHG emissions inventory calculated for the assembly of ESPs with PMM.

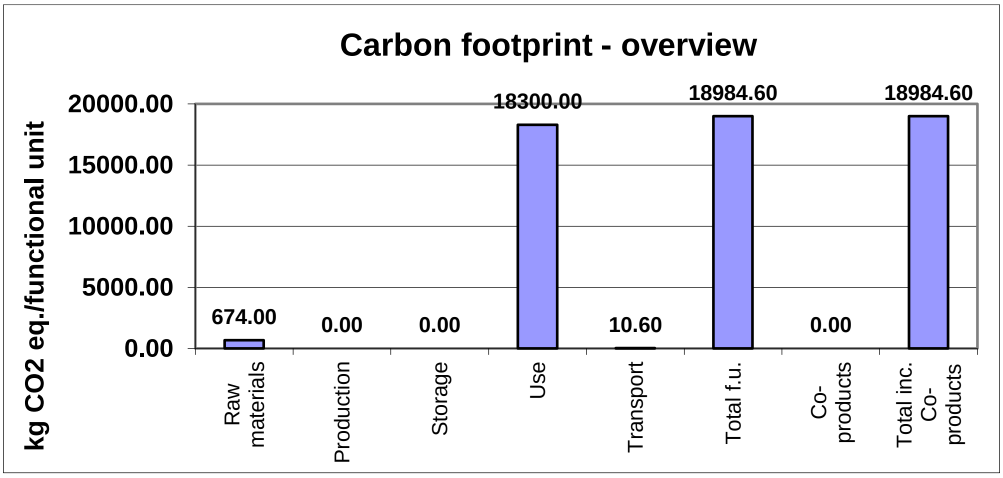

Figure 3: Carbon footprint for the assembly of ESPs with PMM. Adapted from CCalC2 Software

3.3 Discussion

Although the results of the application of GHG emissions show a significant decrease, a comprehensive diagnosis should be conducted considering Carbon Footprint and Environmental Indicators. Environmental improvement efforts in the oil extraction area are limited to determining control measures only in administrative processes, with most focusing on restrictions on office materials or saving electricity consumption. No related studies are found, and there is no guidance in PAS 2050 or ISO 14044 defining the LCA map of manufacturing a ESPs. Information regarding: a) required inputs, b) materials, c) activities, and d) tasks in the ESPs manufacturing process is restricted and available only to Baker Hughes personnel due to intellectual property and rights reasons, making data collection and inventory disclosure for comparison challenging.

The savings in unit units (USD) and environmental cost would be exemplary with the application of PMM since more than 90 % of the oil wells in Ecuador use artificial lift of oil with ESPs.

4. Conclusions

For the Life Cycle Assessment (LCA) in the manufacture of an ESPs with Baker Hughes technology, 5 stages were determined: a) Raw Material, b) Production, c) Distribution, d) Use, and e) Disposal. Fourteen activities related to the Life Cycle Assessment (LCA) in the manufacturing of a Submersible Electric Pump at Baker Hughes were identified, considering the concept: from cradle to grave. For the Electric Submersible Pump with Permanent Magnet Motor, 999.9 kg of Raw Material, 1,491.66 kW/h of energy for Manufacturing, 1,491.66 kW/h for storage, and 5.77E04 kW/h for Use were calculated. For the Electric Submersible Pump with Permanent Magnet Motor, 656 kg of Raw Material, 1,491.66 kW/h of energy for Manufacturing, 1,491.66 kW/h for storage, and 4.72E04 kW/h for Use were calculated. The values showed a reduction of 18.99 % of the Carbon Footprint for the ESPs with the application of new technology.

A 18.99 % improvement in Greenhouse Gas Emissions was achieved due to a substantial 18.19 % reduction in energy consumption in the GHG Inventory by using the PMM in the ESPs Pump manufactured by Baker Hughes. The LCA defined for the manufacture of an ESPs could serve as a baseline for calculating environmental attenuation of any technology whether in materials, storage, use and recycling although only for petroleum types similar to those taken as reference in the study with an oil gravity range of 788 to 920 kg/m^3, gas gravity between 0.65 to 1.276, separator pressure and temperature of 2.86 MPa and 52 °C. The use of clean technology through the use of PMM could be a feasible alternative in Ecuador, since LCA accounts for 96.39 % of total CF.

Acknowledgment

We thank the Baker Hughes Engineering Department for their help in this work, especially engineer Juan Carlos Córdova for allowing the use of sensitive information and resource allocation for the research team.

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