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Life Cycle Assessment to Identify Environmental Improvements in an Aerobic Waste Water Treatment Plant

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Currently, reduce the environmental impacts generated by industries is vital; that is the reason why many companies are changing their processes to biotechnological processes which seem to be more sustainable alternatives. The Life Cycle Analysis (LCA) is an internationally accepted tool that allows environmental assessment of products and processes. In addition, LCA has been used to identify environmental improvement opportunities in different production systems and, that is the reason why it has been selected to be used on this research in order to diagnose the environmental performance of a Waste Water Treatment Plant (WWTP) of a cattle benefit plant.

The system studied was a WWTP located in Cúcuta (Colombia), which treats 118.477 kg/day of water from cattle benefit plant. The stages of the WWTP are: screening, grit removal, primary sedimentation tank, homogenizer, grease traps, activated sludge reactor, secondary sedimentation tank, slow down flow filter and drying bed. In this paper the process diagrams and the mass and energy balances were constructed with information provided directly by the cattle benefit plant. The impact analysis was carried out using the software SIMAPRO 7.0 and the following impact categories were evaluated: climate change, eutrophication, photochemical oxidation, depletion of the ozone layer, acidification and biotic exhaustion.

It was found that the environmental impacts of the WWTP of the cattle benefit plant are generated mainly due to the high electricity consumption in screening, homogenizer, and slurry reactor. Eutrophication was also observed due to the enrichment caused by the increase of the amounts of nutrients, which affected decomposition of excess of organic matter in the water so it could not be a complete mineralization of the nutrients it possesses.

All the calculations were carried out using the Ecoinvent data bases. Favourable indicators were observed comparing the environmental profiles of the biological WWTP under study with the environmental indicators of a physicochemical WWTP of cattle benefit plant located in Bucaramanga (Colombia). The potential environmental impacts were lower in all the impact categories evaluated.

1. Introduction

Today it is vital to reduce environmental impacts generated by industries in all its processes, and in particular for those stages where there are water flows. At the industry level the water cycle includes: water withdrawal from natural resources, water treatment to satisfy the required quality standards for different uses, water distribution, water consumption, and wastewater treatment, however, the WWTP is one of the most critical stage because although the impact of water emissions into the natural ecosystems is reduced, there are increased costs and other environmental impacts (Godin et al. 2012). For example, in conventional water treatment, nutrients - notably nitrogen and phosphorus - are biologically and physical-chemically converted and removed from the water but there are still other substances that are not completely removed (Fang et al. 2016).

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One of the most popular methodologies used to evaluate the potential environmental impacts caused by WWTPs is the Life Cycle Assessment (LCA) (Morera et al. 2015). LCA is a standardized method (ISO 14040-14044:2006), which is used to estimate the impact over a wide range of environmental impact categories (global warming, acidification, eutrophication, human toxicity, etc.) from the construction to the operation and dismantling of WWTPs (Corominas et al. 2013).
This research is focused on the environmental evaluation of a biological WWTP in cattle benefit plant using LCA, owing to this plant was built in order to avoid the use of chemicals as raw materials and, as consequence, generate lower environmental impact. To verify that this goal had been achieved, data obtained from this biological WWTP was compared with a physicochemical WWTP of another cattle benefit plant located in a nearby city.

2. Methodology

In this research, the methodology used involves the environmental impact evaluation integrated with process analysis from the perspective of the standardized LCA, contained in ISO 14040 – 14044: 2006. To evaluate the potential environmental impact assessment, the LCA methodology was applied to a biological WWTP of a cattle benefit plant located in Cúcuta (Colombia). The phases described below were performed:

2.1 Goal definition and scoping

Mass and energy, inputs and output streams, were identified thanks to a block diagram of the process that was elaborated considering the unit operations involved from the waste water reception to the treated poured water. The data collected regards to 2012. The information generated during the development of this research was the basis for defining the purpose and scope of this study, the inventory analysis, evaluation of the potential environmental impact and its interpretation (Ruiz et al. 2015).
The biological WWTP studied consists of the following units:
Screening: this system is composed of five screens with cylindrical shape, which have a slope of 5 % with a length of 2.25 m. The screens are driven by motors with a power of 1/3 hp and a number of gear motors that spin them at 30 rpm. Its function is to prevent the passage of solid material such as the rumen contents and blood clots.
Grit removal: it consists of a hydraulic structure which removes particles of a specific size (mainly sand with 2 or more mm diameter); its dimensions are: 3 m long, 1.38 m wide and 0.76 m tall. The system allows to remove the dissolved solids in the water suspension, which can be easily decanted.
Primary sedimentation tank: in this system the settleable solids are retained, in order to prevent further sludge accumulation in the system. Its dimensions are: length 13.2 m, width 2.05 m, height 1.32 m - 1.88 m, and a volume of 43 m^3. It operates with a hydraulic retention time (HRT) of 3.18 hours.
Homogenizer: the WWTP needs an appropriate liquor mixture in the activated sludge reactor, where the mixing process takes place; this is done in order to make a pre aeration of the flow and thus, it can be maintained constant. The homogenizer implemented in the plant has 5.20 m long, 2.05 m wide, 6.10 m high, volume 127.4 m^3 and HRT 0.88 days.
Activated sludge reactor: in this step the activated sludge meets the waste water flow. At this stage the waste water possess organic matter into a colloidal solution. The reactor is a contact aerobic process where oxygen is admitted continuously by a stepwise bubble aeration system. The dimensions of this reactor are: length 5.20 m, width 2.05 m, height 6.10 m, 127.4 m^3 volume and HRT of 0.88 days.
Secondary sedimentation tank: The aim of this process is to remove all flocks leaving the activated sludge reactor and to reuse them through a recirculation process to ensure a biological balance in the reactor. Its dimensions are: length 5.2 m, width 2.1 m and height 3.2 m.
Slow down flow filter: it is a way to remove organic matter through a slow filtration process; the porous granular medium when receives water with enough organic load dissolved, tends to form a biofilm around the grains thereof, which feeds the microorganisms present.
Drying bed: its objective is the sludge dehydration by spreading it on a layer of sand with a thickness between 20 cm to 25 cm. After these, the mud is able to be used as filler or fertilizer. It is important to note that for small populations , i.e. having treatment plant with flow rates less than or equal to 100 l/s, this process proved to be very effective, but for populations over 20,000 inhabitants it must be used a more advanced technique.

2.2 Life-cycle inventory

The life cycle inventory (LCI) was evaluated based on the stages that make up the WWTP. This LCI was performed using information provided by the company and the material and energy balances were made with the detailed information obtained. In order to establish the goals and scope of the LCA, mass and energy balances were verified based on the inputs and outputs. According to this information, the process was quantitatively described. Each unit of the process was associated to relevant data. Some stages of the process were excluded of this analysis (Ruiz et al. 2014).

2.3 Environmental impact analysis

In this part, the relationships between the process stage and its environmental impacts were established. The Environmental Impact Analysis (EIA) was made using SIMAPRO 7.0 software. This made it possible to know the environmental profile of the WWTP and to evaluate six impact categories which were: acidification, eutrophication, global warming, abiotic depletion, ozone layer depletion and photochemical oxidation. It is noteworthy that in SIMAPRO 7.0 it can be observed graphically how each process associated with the production of the raw materials used in the WWTP and the internal changes are increasing or decreasing the impact values in each category evaluated.

2.4 Interpretation and results comparison with physicochemical WWTP

The results of the LCI were combined with the EIA in order to evaluate the uncertainties and elaborate a report with the conclusions and recommendations that could be drawn from the study (Amaya et al. 2009). Also, the EIA of the biological WWTP were compared with the results obtained from a WWTP of benefit of cattle located in Bucaramanga (Colombia).

3. Results and analysis

The results are presented and discussed for each step described in the methodology.

3.1 Goal definition and scoping

The goal of this study was to assess the potential environmental impact associated to the WWTP of a cattle benefit plant located in Cúcuta, province of North Santander, Colombia. The scope was defined by considering the product, the geographical and temporal boundaries, and the functional unit. The functional unit defined for this study was 1 kg/s of waste water treated. This unit is basic for the results comparison with the WWTP of a cattle benefit plant located in Bucaramanga, province of Santander, Colombia. The geographical boundary was defined by the location of the plant, the temporal boundaries for this assessment were defined by the production data, gathered in 2012. Besides, neither the construction nor the maintenance of the plant was taken into consideration. Likewise, economic and social factors were not included. Also, a cradle and a grave were established for the raw materials involved in the process. Regarding the assignation, the hierarchy proposed by ISO 14040-14044:2006 standard was followed. The results of this research seek to identify the actions that the company can implement in order to minimize the environmental impacts evaluated.

3.2 Life-cycle inventory

As mentioned in the methodology, this phase refers to the mass and energy balances. Figure 1 shows the main streams in the process.

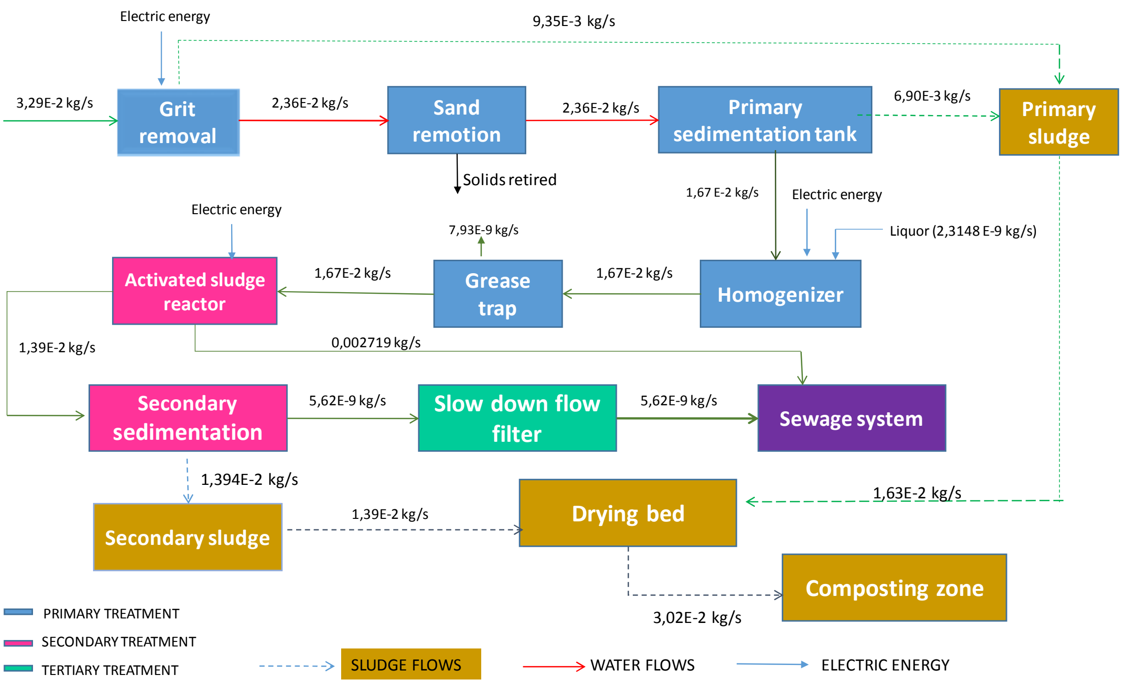

Figure 1: Representative mass and energy flows of WWTP of a cattle benefit plant located in Cúcuta (Colombia).

Environmental and energy flows for the different raw materials and processes involved in the life cycle of WWTP were calculated using mass and energy balances data provided and from the Ecoinvent V3 database.
It is noteworthy that the power consumption could not be quantified for each treatment unit, however, the company could verify in one of its counters that the electricity consumption associated with the WWTP is 1.44 E-4 kWh/s.
The average values of physicochemical parameters calculated in the water input of the system are shown in Table 1. This information was used to characterize the waste water from the cattle benefit plant.

Table 1: Average values of the physicochemical parameters of wastewater entering the WWTP

Parameter	Units	Average value
COD	mg/l COD	7,547
DBO5	mg/l DBO_5	4,438
Nitrates	mg/l NO_3	223.42
Nitrites	mg/l NO_2	3.88
Sulphates	mg/l SO_4	657.16
Phosphates	mg/l PO_4	266.16
Alkalinity	mg/l $CaCO_3$	801.16
Temperature	°C	28.43
pH	pH units	7.72
Settleable solids	ml/l h	530
Total solids	mg/l	4,500
Total suspended solids	mg/l	1,873
Volatile suspended solids	mg/l	1,498
Fixed suspended solids	mg/l	375

The removal percentage of contaminants associated with each stage of the WWTP is shown in Figure 2. The primary treatment stage consist of: grit removal, sand remotion, primary sedimentation tank, homogenizer and grease trap. Secondary treatment stage is composed by activated sludge reactor and the secondary sedimentation tank. The slowdown flow filter is the only process unit in the tertiary treatment stage.

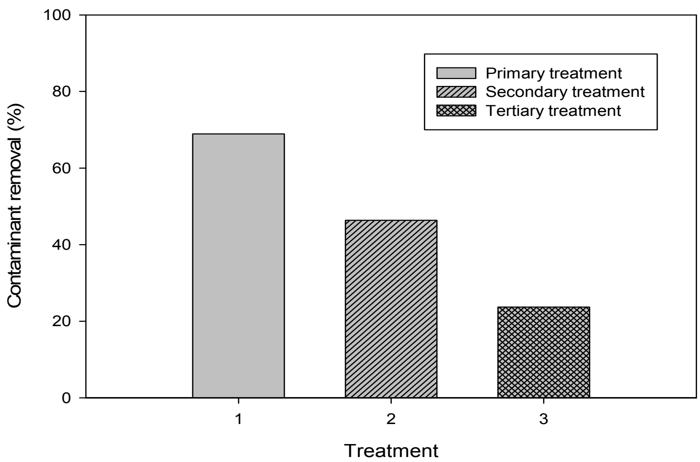

Figure 2: Percentages of removal of contaminants associated with WWTP stages, relative to their respective inlet.

3.3 Environmental Impact Analysis

The mass and energy balances were introduced in SIMAPRO 7.0 in order to identify the environmental impacts generated by the WWTP. The environmental profile was performed using the EDP 2013 method, which consider the six impact categories listed above. As it can be seen in Figure 3, in almost all impact categories evaluated, environmental damage comes from electricity use. The only impact category that does not follow this trend is eutrophication impact category, where the impact is due to the contaminants remaining in the water despite treatment. The percentage in the eutrophication category associated with the use of electricity is only 6%.

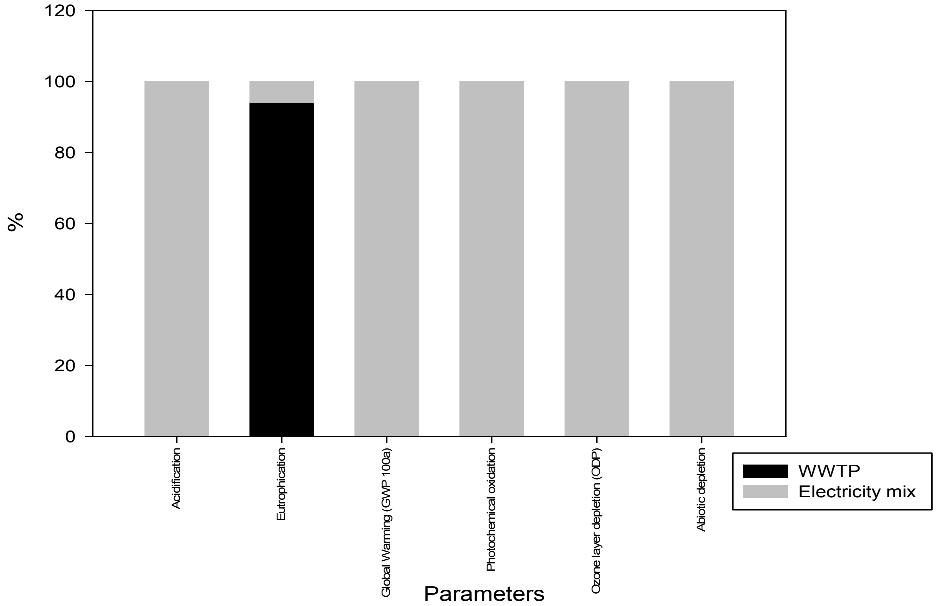

Figure 3: Environmental profile of the WWTP of a cattle benefit plant located in Cúcuta (Colombia).

It was found that the environmental impacts associated with the photochemical oxidation are mainly due to the emission of sulphur dioxide and sulphur monoxide. Other emissions related to this potential environmental impact category are methane and isoprene. These substances are usually generated by the decomposition of organic matter in biological processes.
Lastly, factors largely attributed to eutrophication are: phosphates, chemical oxygen demand, nitrogen oxides and nitrates. It is noteworthy that the compounds mentioned above are generated by the cattle process, which means that they are not generated within the WWTP, however, there are impacts caused by this substances that WWTP fails to remove.

3.4 Interpretation and comparison with physicochemical WWTP

Since the environmental impacts of the process of the WWTP arise mainly because of the high electricity consumption in the screening stage, homogenizer, and slurry reactor, it is necessary to make an energy efficiency study to analyse whether there is equipment that need to be replaced by others with lower electric energy consumption, equipment that is working more hours than necessary or that require maintenance.
Table 2 shows the comparison between the biological WWTP and the physicochemical WWTP. The impact categories evaluated in both systems were global warming, eutrophication, and acidification. The amount of water treated in physicochemical WWTP is higher compared to the biological treatment due to the high demand of Bucaramanga cattle benefit plant. Moreover, the potential environmental impacts associated with the physicochemical WWTP are attributable to the high concentration of the chemical reagents used for the process, and its incomplete dissolution in the contaminated water. This situation generates excess reagents and high load of organic matter that is not easily removed, hence water BOD_5 increases promoting eutrophication and increasing toxicity.

Table 2: Environmental comparison of WWTP based on 1 kg/s of treated water

	Biologic WWTP	Physic-chemical WWTP
Capacity (kg/s)	0.0329	19.384
Global warming ([kg CO_2 eq]/[kg/s])	0.013	1.596
Eutrophication ([kg PO_4 eq]/[kg/s])	7.37 E-05	3.11 E-04
Acidification ([kg SO_2 eq]/[kg/s])	7.34 E-05	3.34 E-02

An important factor in generating potential environmental impacts in the physicochemical WWTP was the sludge produced by the process. Wastewater sludge treatment is an environmentally sensitive problem in terms of both energy and pollutants (Houillona et al. 2005). This sludge has a significant weight in the impact categories of global warming, eutrophication and acidification because it absorbs large amounts of organic matter and chemical additives, which then are emitted to the atmosphere as greenhouse gases and substances with acid components. Dosing of aluminium sulphate in flocculation, sodium hydroxide, chlorine gas and lime used in disinfection are considered major contributors to toxicity increase in resulting sludge. It has been shown with a comprehensive inventory of the sewer system infrastructure that it has greater contributions than the WWTP on half of the studied range of impact categories (Risch et al. 2015).

Considering the above, it was concluded that biological treatment is friendlier with the environment since biological systems do not use chemical additives that alter the sludge produced, so sewage sludge can be used in other production systems. In the case of physicochemical treatments not only the sludge do not break down easily but also in most cases it cannot be used, which produces potential environmental impacts harmful to water bodies and the surrounding community.

4. Conclusions

Since in five of the six categories of impact evaluated the electricity consumption percentage contribution is almost 100%, it was identified that in order to improve the environmental performance of the WWTP located in North Santander, it is necessary to know exactly the individual electrical consumption of each equipment involved in the system. The establishment of strategies to reduce the individual and collective consumption and the benefits of the implementation of an alternative electricity generation systems in situ need to be studied in order to correct and mitigate potential environmental impacts

From the comparison between the results of the LCA of biological WWTP with a physicochemical WWTP, it can be inferred that the biological one is more environmental friendly for the treatment of waste water, not only because it promotes conditions of degradation of organic matter but also because it allows obtaining by-products such as sludge which can be treated and incorporated into a new process.

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