Materials flow and life cycle analysis of a WWTP with intermittent cycle extended aeration system.

Garayo Junior, F.* and Dutra, W.**

*Federal University of Mato Grosso do Sul. Rua Lopes Trovão, 408, Cabreúva, Campo Grande/MS, Brazil.
**Federal University of Rio Grande do Sul. Rua dos Alpes, 40, Jardim dos Alpes, Gravataí/RS, Brazil.

Highlights:

- Combined use of Material Flow Analysis (MFA) and Life Cycle Analisys (LCA).
- Application of MFA/LCA in a wastewater treatment plant with ICEAS technology with a capacity of 120 L/s.
- MFA and LCA as tools to diagnose the main environmental impacts of a wastewater treatment plant.

Keywords: sustainability; environmental impact; emissions.

INTRODUCTION

Wastewater treatment plants (WWTPs) are used to separate pollutants from water, aiming to return it to the environment as clean as possible. However, this process of pollutant separation leads to residual emissions in soil, air, and water. Identifying and analyzing the environmental impacts of these emissions in the operation of wastewater treatment plants is relevant for adopting strategies to mitigate these impacts, especially in current times, where governments, municipalities, companies, and civil society are seeking to reduce their environmental impact and greenhouse gas emissions.

To assess the environmental impacts of a wastewater treatment plant during its operation, two complementary tools can be used: Material Flow Analysis (MFA) and Life Cycle Analysis (LCA). MFA is based on the law of conservation of matter, it systematically evaluates the flows and stocks of materials in a system, with defined boundaries and time periods, making it possible to visualize input flows of materials and output of waste, as well as identify their generating sources. LCA is a technique to quantify the potential environmental impacts associated with the stages of a product, service, or process from cradle to grave. It can be said that MFA is a preliminary step that subsidizes LCA.

This study proposes to evaluate, through Material Flow Analysis and Life Cycle Analysis, the environmental impacts of the operation of a wastewater treatment plant using an Intermittent Cycle Extended Aeration System (ICEAS).

METHODOLOGY

The "Imbirussú Wastewater Treatment Plant," the subject of this study, is located in Campo Grande/MS (Brazil), with an installed treatment capacity of 120 L/s. In 2021, it operated with an average inflow rate of 88.62 L/s, representing 10% of the sewage collected in the municipality.

The treatment adopted is the intermittent cycle extended aeration system (ICEAS). The process begins with a compact preliminary treatment, equipped with 6 mm mesh screens and aerated grit chambers for scum removal. The residues from the preliminary treatment are transported by a screw conveyor to a stationary bucket. Then, the effluent is sent for secondary treatment consisting of two tanks with a capacity of 60 L/s each, where aerobic reaction, sedimentation, and settling occur. Finally, tertiary treatment takes place with disinfection using sodium hypochlorite, applied in a baffled contact chamber.

For the application of MFA and LCA in “Imbirussú Wastewater Treatment Plant”, the product system presented in Figure 1 and a reference flow of 1 m³ of treated sewage were used. Data collection was carried out over 12 months through records of inputs and consumption of the system and effluent analysis bulletins.

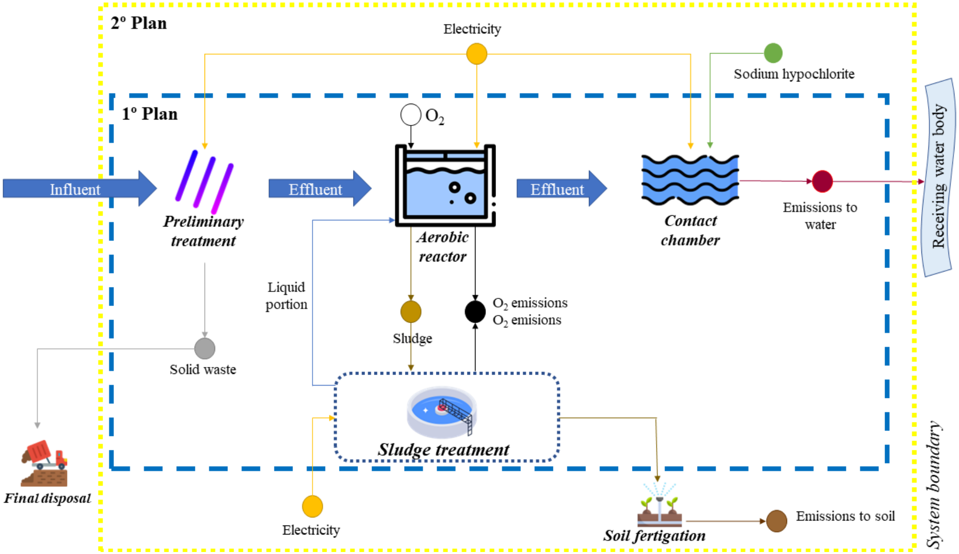

Figure 1. Product System of WWTP “Imbirussú” used for MFA/LCA.

For MFA modeling and calculation, Stan® software version 2.7 developed by the Institute for Water Quality, Resources, and Waste Management at the University of Vienna was used, inputing the masses of each unit process involved. For LCA, the ReCiPe 2016 Midpoint H impact assessment method from the OpenLCA LCIA 2.0.1 package was used, with the selection of the following impact categories: "global warming", "freshwater eutrophication" and "freshwater ecotoxicity."

RESULTS AND CONCLUSIONS

Figure 2 presents the results for MFA. It is observed that for input components, there are 1,076.00 kg/m³, 1.83 kg/m³, and 0.0069 kg/m³, respectively, for the affluent, oxygen and sodium hypochlorite, totaling 1,077.84 kg/m³. Regarding the process outputs, the results are the following for treated effluent, solid waste, sludge, CO2, and O2: 1,074.52 kg/m³, 0.07 kg/m³, 1.34 kg/m³, 0.30 kg/m³ and 1.6 kg/m³. It is verified that the process has no stock, that is, every material that enters has an output. The largest mass flows are still from the liquid portion, with the amount of concentrated solid residue and extracted as sludge being much smaller than the emission to the receiving water body. The low incorporation of O2 into the sludge is also notable (around 12%), most of which is lost to the atmosphere.

As for LCA, the results are consolidated in Table 1. It is observed that in the impact categories "climate change" and "freshwater ecotoxicity," electricity was the process that obtained the highest percentage contribution, with 81.58% and 75.91%, respectively. This was expected since the WWTP has a high energy consumption due to the extended aeration system, with electricity being the main input for its operation. Chlorine production comes in second place in these two categories, with 9.97% and 14.40%, respectively. In "freshwater eutrophication" category, the highest contribution, with 98.46%, is due to the direct release of phosphorus into the water body along with the treated effluent, while the other process contributions are residual. Finally, the two transportation processes involved have marginal contributions in the three categories analyzed. Mamathoni (2021) applied LCA to an extended aeration activated sludge system and also obtained high contributions of electricity in the impact categories, being 75% for the freshwater ecotoxicity category.

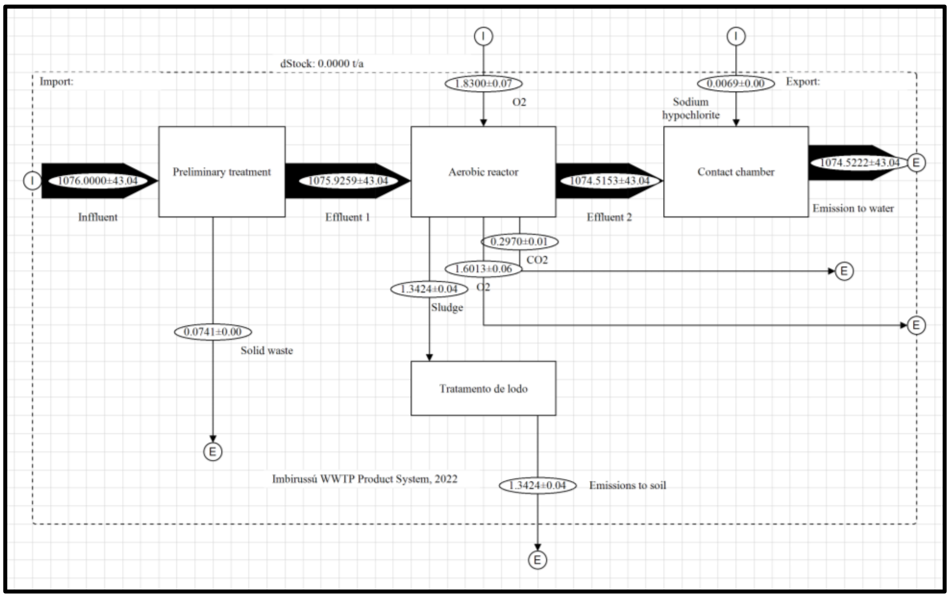

Figure 2 – MFA results.

Table 1. LCA results.

Impact category/process	Reference unit	Result	%
Climate change - GWP100	kg CO2-Eq	0,08778	100%
Electricity	kg CO2 eq.	0,07161	81,58%
Chlorine production	kg CO2 eq.	0,00875	9,97%
Waste transport	kg CO2 eq.	0,00737	8,40%
Chlorine transport	kg CO2 eq.	4,82178E-05	0,05%
Freshwater ecotoxicity - FETPinf	kg 1,4-DCB-Eq	0,00221	100%
Electricity	kg 1,4-DCB Eq.	0,00058	75,91%
Chlorine production	kg 1,4-DCB Eq.	0,00011	14,40%
Waste transport	kg 1,4-DCB Eq.	7,35643E-05	9,63%
Chlorine transport	kg 1,4-DCB Eq.	5,07583E-07	0,07%
Freshwater eutrophication - FEP	kg P-Eq	0,00146	100%
Effluent discharge	kg P eqv.	0,00143753	98,46%
Electricity	kg P eqv.	0,00001786	1,22%
Chlorine production	kg P eqv.	0,00000413	0,28%
Waste transport	kg P eqv.	0,00000048	0,03%
Chlorine transport	kg P eqv.	0,00000000	0,00%

The study allowed evaluating the material flows and life cycle analysis of a WWTP considering a flow of 1 m³ of treated sewage as a reference. The application of MFA and LCA in this study reinforces the practical applicability of these tools for environmental management and provides support for mitigating environmental impacts.

ACKNOWLEDGMENTS

We would like to express our sincere gratitude to the Federal University of Mato Grosso do Sul and the Federal University of Rio Grande do Sul for the institutional support provided. We also extend our thanks to Dr. Diego Lima Medeiros for generously sharing his extensive knowledge in Material Flow Analysis (MFA) and Life Cycle Assessment (LCA), which were essential contributions to the development of this work.

REFERENCES

Brunner, P. H., & Rechberger, H. (2005). *Practical handbook of material flow analysis: Advanced methods in resource and waste management.* Taylor & Francis e-Library.

Mamathoni, P., & Harding, K. G. (2021). Environmental performance of extended activated sludge and sequential batch reactor using life cycle assessment. *Cleaner Environmental Systems*, 2, 100039. https://doi.org/10.1016/j.cesys.2021.100039