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Life Cycle Assessment of a Package Type IFAS Reactor Considering Different Operational Scenarios.

Rana Pratap Singh*, **Nitin Kumar Singh, Dharmender Yadav, Komal Jayaswal, and Absar Ahmad Kazmi.**

Department of Civil Engineering, Indian Institute of Technology, Roorkee, India- 247667

ABSTRACT

Life cycle assessment (LCA) approach was used to evaluate and compare the environmental impacts associated with seven different operational scenarios of an integrated fixed film activated sludge (IFAS) reactor treating municipal wastewater. Life cycle inventories have been used as an input to Simapro Software for performing LCA and CML baseline V3.02 method has been employed. For the CML baseline method, the results were processed to express the environmental performance in ten impact categories including abiotic depletion, global warming, ozone layer depletion, human toxicity, fresh water eco-toxicity, marine aquatic eco-toxicity, terrestrial eco-toxicity, photochemical oxidation, acidification, and eutrophication. The results showed that the major environmental impacts is caused due to electricity consumption during all the operational scenarios of an IFAS reactor. Among all the seven operational phases considered, the high DO phase (4.5 mg/L) showed the highest environmental impacts whereas the intermittent aeration phase with the highest ratio of non-aeration to aeration time showed the minimum environmental impacts except in eutrophication impact. It was observed that the better effluent quality reduced the eutrophication load on the environment.

Keywords: Life cycle assessment (LCA), Integrated fixed film activated sludge reactor (IFAS), SimaPro, Wastewater treatment

Corresponding author
Email: rps.eng@gmail.com

INTRODUCTION

From environmental perspective, decentralized wastewater treatment systems are reported to impose lower burdens on the environment as compared to centralized systems by offering lesser footprint, financial efficiency, less installation timeframe, options for water reuse and local community empowerment [1-3]. To date, various decentralized systems have been implemented across the world with wide range of configurations and technologies. However, to enable the latest improvement of these more assessment study is necessary to recognise the methodologies that will decrease the whole environmental impact of a system [4]. Life cycle assessment (LCA) is an important and logical tool which compiles and estimates input, output, and potential environmental impacts of any product, process or a system throughout its life cycle [5-6]. In 1997, LCA was first applied for wastewater treatment systems in Netherland [7] as they have considerable environmental impacts throughout their life cycle due to consumption of energy, usage of chemical, generation of sludge, and emissions of toxic gases. Thereafter until now, various scientists and engineers have applied it for decentralized as well as centralized wastewater treatment systems using different inventories, boundary conditions, functional units and impact assessment methods [8]. Some authors suggested that several deviations of a decentralized treatment system were similar or superior than a centralized wastewater treatment plant in terms of economic costs, GHG emissions, resource consumptions, human health impacts, and ecosystem impacts. Whereas other studies utilized LCA to determine optimal designs of specific decentralized technologies. The outcomes and conclusions after these studies vary meaningfully due to modifications in the choice of the assessments and the technologies studied, revealing that careful attention is necessary when applying LCA to decentralized systems in order to draw valuable decisions for available options [9].

Recently IFAS technology based systems were introduced for wastewater treatment. A detail collection of these systems is given in our previous studies [10]. To ensure the suitability of these technologies at the field, a detail and integrated assessment is required to investigate its development and operational impact on human health and environment. The results of this study may be used as a reference for similar future projects to determine its applicability in developing countries. The main goal of the study was to compare the environmental burdens associated with different operational phases of an IFAS reactor treating municipal wastewater under actual treatment conditions to assess its sustainability.

METHODOLOGY

A large number of standard impact assessment methods are available in SimaPro software. However, In this study CML baseline 2000 method was chosen for LCA comparison of different operational scenarios of an IFAS reactor.

Goal and scope definition

The aim of this LCA study was to evaluate the environmental impacts of a small-scale wastewater treatment plant. The treatment plant features a reactor using integrated fixed film activated sludge (IFAS) process. More detail about the plant, technology and process are available in previous study [10]. A total of seven operational phases (1 steady state, 3 intermittent aeration, 3 dissolved oxygen phases) were considered in this study. During the different operational scenario, parameters were changed and same are used in LCA software as input parameters. More details about the operational scenarios are given in Table 1. Alum powder was also used during the reactor operation in order to achieve phosphorus precipitation and to enhance biomass settling in all operation except the steady state operation.

Table 1: Summary of operational scenario of IFAS reactor

Experimental phase		Description (reactor/blower condition)
Steady state[1]		DO ~3 mg/L
Variable DO[2]	Phase – I	DO ~0.5 mg/L
	Phase - II	DO ~2.5 mg/L
	Phase – III	DO ~4.5 mg/L
Intermittent aeration[2]	Phase – I[3]	2.5 h on /0.5 h off

	Phase – II[3]	2 h on/1 h off
	Phase – III[3]	1.5 h on/1 h off

[1] Flow was set as 64.8 m^3/d.
[2]Flow was set as 50 m^3/d.
[3]Blower speed was set corresponding to 2.5 DO.

System boundaries and functional unit

The choice of the system boundaries is an important step within the assessment of wastewater treatment facilities or technologies [11]. Therefore, the system boundaries of this study were established as shown in Fig. 1. Only the operational phases are taken into consideration in the LCA because it has the highest impact to the environment [12]. Demolition phase has been exempted in this study, as most of the waste is being recycled. In the present study, functional unit (FU) was defined as one cubic meter of treated wastewater.

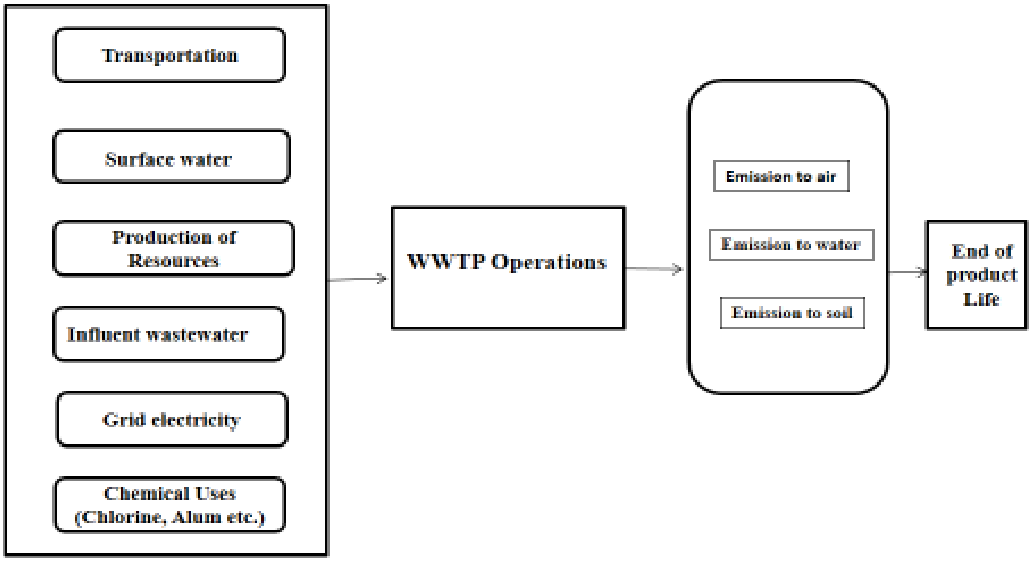

Fig 1: Scope and system boundary of investigated lifecycle

Inventory analysis

Life cycle inventory (LCI) step is the most important phase of LCA study and it concerns with collection of data and calculation procedures require to complete the inventory [13]. Following the goal and scope definition, LCI analysis was conducted regarding operational phase. All the inventory related to operational was prepared using the following data: inputs from nature and techno-sphere, electricity consumption in operation, air (biogenic) emissions, emission to water and soil. The operational data was compiled by our technical team, previous research and local municipalities. Following are the description of each data collection step:

Electricity usage

For operational phase, hydro power (in India) was assumed to be the main source of reactor run. During the operational phase, electricity is consumed to pump the wastewater, sludge streams, alum dosing, and to run the blower for aeration. The electricity consumption data were collected by noting down the theoretical rating of pumps, while blower power calculated from the performance curve provided by the manufacturer as well as the computed working hours.

Inputs from nature and techno-sphere

A total of four inputs during the reactor operation were considered in this study, including usage of fresh water, air from the atmosphere (through blower), electricity, and alum powder for enhance settling.

Emission to air, soil and Water

Effluent impact was accounted in terms of biological oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), total nitrogen (TN) and total phosphorus (TP) content. The Effect of sludge disposed for land fill purposes, was accounted using mixed liquor volatile suspended solid (MLVSS) concentrations, total nitrogen content (TN), and total phosphorus (TP) content of waste sludge using stoichiometric conversion ratio [14].

Data on heavy metal concentrations in sewage sludge was measured during the steady state phase only, and assumed to be constant in all operational scenario. Emissions of biogenic air pollutants (CH_4, CO_2 and N_2O) were estimated using average consumption figures and emission factors found in the literature [15-18]. Non material emissions, social and economic issues are not taken into consideration.

Impact assessment and results interpretation

Impact assessment is the main step in computing the environmental impacts of various activities in LCA. According to the existing literature [19-22,12] the following impact categories were selected for this purpose: Abiotic depletion, Acidification, Eutrophication, Global warming, Ozone layer depletion, Human toxicity, Fresh water eco-toxicity, Marine aquatic eco-toxicity, Terrestrial eco-toxicity, Photochemical oxidation. Interpretation of LCA results is the last and most important step in LCA where recommendations and suggestions should be provided in such a way so that the global impact of the system on the environment must be minimized. In this section, the impact of all operational phases is compared with each other. Operational inventory used for impact assessment is presented in Table 2.

Table 2 Inventory data for IFAS reactor in different operational phases

Operational phase	Inputs				Outputs											
	From atmosphere		From techno-sphere		Emission to air (g)			Emission to soil (g)			Emission to water (g)					
	Air (Kg)	Water (m^3)	Electricity (KW)	Alum (g)	CO_2	CH_4	N_2O	Metals	TN[a]	TP[a]	COD	BOD	SS	TN	TP	Metals
Steady state	32.66	A fixed amount of 0.01 m^3/m^3 of wastewater treated is considered for miscellaneous purposes.	1.33	Nil	221	4.3	0.35	Cd: 0.0001 Fe: 0.7907 Cu: 0.0294 Mn: 0.0207 Zn: 0.0790 Pb: 0.0004 Ni: 0.0002 Co: 0.00	2.8	1.2	50	25	35	15	2.20	Cd: 0.0059 Fe: 0.5990 Cu:0.0330 Mn: 0.0421 Zn: 0.1735 Pb: 0.043 Ni: 0.0010 Co: 0.0012
IA Phase - I	29.40		1.21	30	312	5.8	0.39		4.8	2.0	34	18	15	11	0.88	
IA Phase – II	23.52		1.13	30	317	5.8	0.38		3.7	1.5	30	14	16	12	1.25	
IA Phase – III	21.16		1.10	30	310	5.7	0.39		3.7	1.6	42	19	15	11	1.43	
DO Phase – I	28.22		1.19	25	280	4.5	0.07		2.6	1.1	85	46	59	43	0.77	
DO Phase – II	44.10		1.67	30	301	4.8	0.36		7.1	3.0	61	31	38	14	0.93	
DO Phase – III	63.50		2.01	48	331	5.3	0.36		0.5	0.2	25	9	15	14	0.59	

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All values are based on 1 functional unit i.e. 1 m^3; Density of air considered, 1.225 Kg/m^3; [a]Based on average waste sludge, VSS and stoichiometric content of sludge

RESULTS AND DISCUSSION

LCA includes all the inputs and the outputs related to each process for assessing the impact of the system. Inputs or outputs of the processes can have direct impact (such as resources depletion) or indirect environmental impact (such as impacts during manufacturing of chemicals). Bearing these considerations in mind, qualitative LCA results of IFAS reactor during its operation phases is discussed in this section. The results obtained in this study have allowed a qualitative evaluation.

Impact of various operational phases

The LCA of operational phases of an IFAS system was performed by considering the functional unit as 1 m^3 of treated wastewater, to draw attention the importance of the choice of a wastewater treatment configuration. Inputs of each process during operational phases of an IFAS reactor are amount of water and air required, energy consumption, transportation, and chemicals usage etc. The outputs are characteristics of water, air and soil emissions.

Hence, in order to reduce the impacts of electricity usage, energy saving solutions should be applied in this phase. Similar results have been reported in previous studies [18]. The only impact category that does not follow this trend is eutrophication, where the impact is due to the contaminants remaining in the water despite treatment. This could be minimized by increasing the nutrient removal efficiency by adding primary anoxic before aerobic unit.

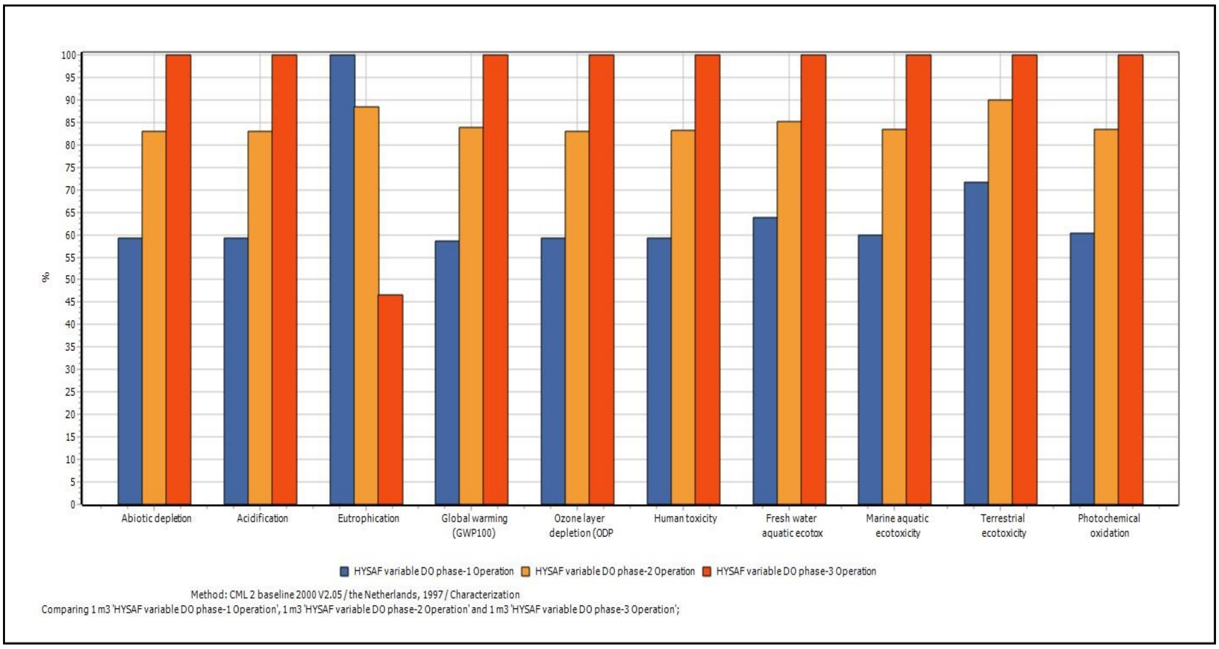

Fig 2: Impact of variable DO phes on various impact categories

Fig. 2 shows the qualitative comparison of impacts due to variable DO phases on various impact categories. It is important to mention here that in the variable DO phase 3, treatment performance was recorded quietly satisfactory as per local discharge standards. In particular, an increase of ~22% in all impact categories was observed, when DO increase from phase 1 to phase 2 as well as phase 2 to phase 3. Eutrophication is one of the priority criteria for considering a treatment system to be environmentally sustainable [23]. DO phase 3 contributed to lowest impact on the environment in terms of eutrophication potential. These results suggest that maintaining a high bulk DO in the reactor will affect the environment significantly, however from a treatment potential point of view, the requisite quality effluent can be achieved at high DO levels.

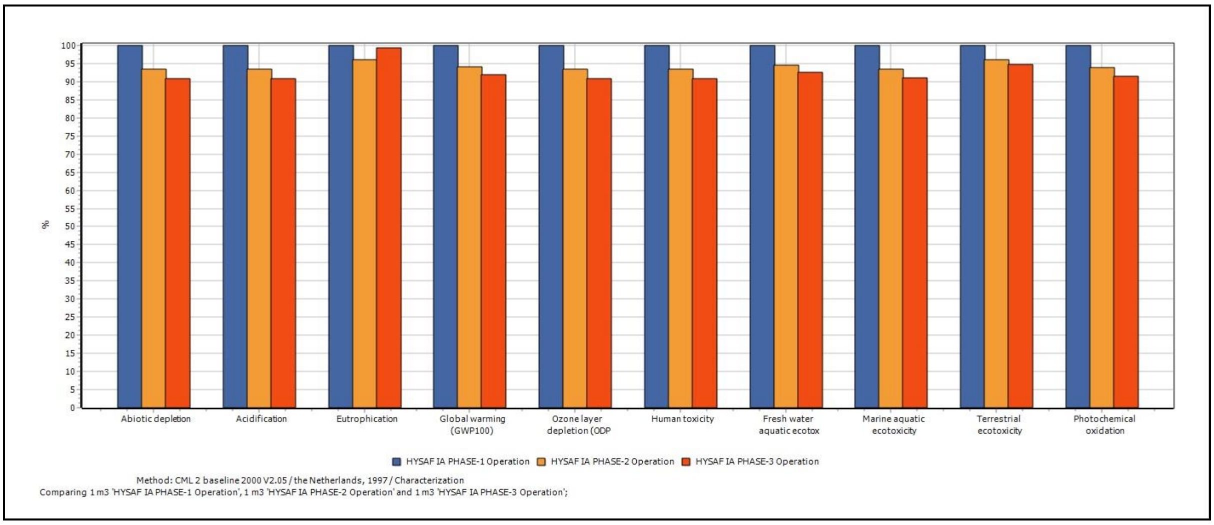

Fig 3: Impact of intermittent aeration phases on various impact categories

Considering intermittent aeration phases (Fig. 3), a slightly decreasing trend was observed in all impact categories, except the eutrophication, with increasing the aeration off-time of blower. It indicates clearly that electricity consumption is playing the main role in this operational phase. With respect to eutrophication potential, all intermittent phases were almost same as the difference in concentrations of nutrient parameters was recorded insignificant. This can be attributed to the balance between the nitrification and denitrification activities in the reactor. As shown in Fig. 4, with respect to each other, a decrease of ~5% was found in all impact categories by reducing the blower run time during the operation.

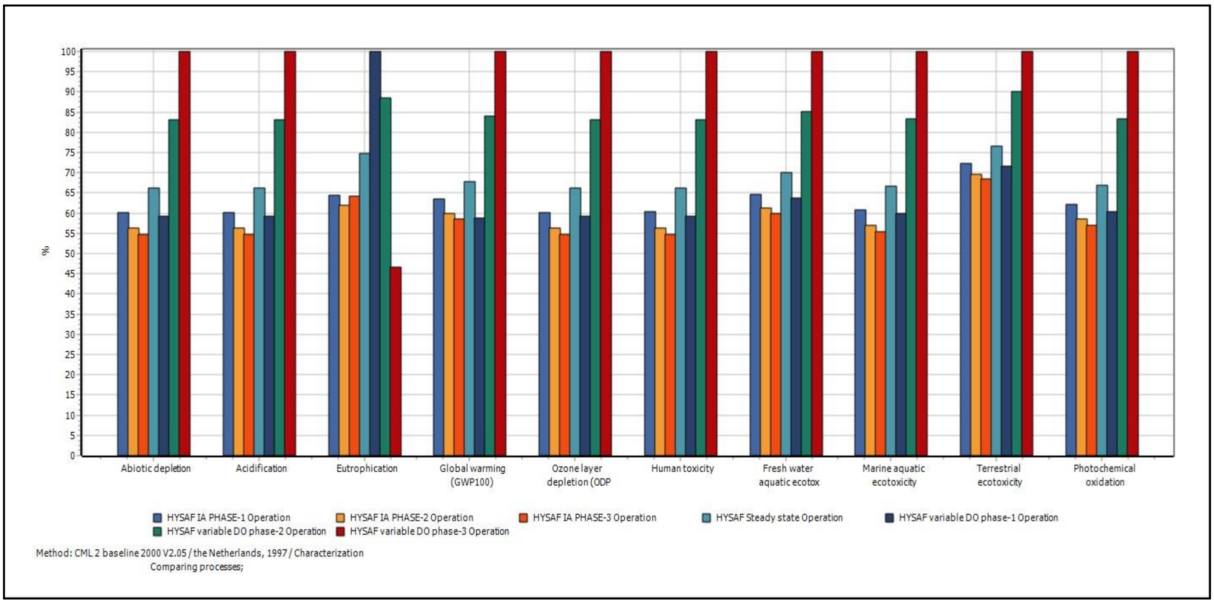

Fig 4: Comparison of LCA results of all operational phases of IFAS reactor

A comparative account of all operational phases is also shown in Fig. 4. The results clearly indicated that among all operational phases, variable DO phase 3 was the least favourable from an environmental impact point of view. High DO phase contribute mainly to all impact categories only due to high consumption of electricity [24]. However, the eutrophication potential of this phase was low as compared to other phases. On the other side, DO phase 1 contributed most to the eutrophication of water bodies.

It is important to mention here that although the DO levels were almost same in the steady state and DO phase 2 but the observed difference in impact was due to the difference in treatment capacity under experimental conditions. Furthermore, these results suggest that although increasing the hydraulic load, decrease the treatment capacity, but consequently decreases the environmental impact on surrounding.

CONCLUSIONS

- This paper consists on performing the qualitative environmental assessment, by means of the Life Cycle Assessment (LCA) technique of an IFAS reactor treating municipal wastewater during its different operational phases in order to know how much this system provokes the environment. A well-known LCA software (SimaPro 8.0.5.13) has been used using CML 2 baseline 2000 method.
- From the comparison between the LCA results of the variable DO phases, it can be inferred that although high DO levels improve treatment performance, but on account of its impact on the environment also increases due to its higher electricity consumption. One possible conclusion of this LCA study would be that there is a need to further develop the energy efficiency of the IFAS reactor.
- LCA results of intermittent aeration phases revealed that decreasing the blower run time will reduce the burden in the environment on all impact categories except the eutrophication. A balance of nitrification and denitrification was found to be effective at all IA phases.

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