Environmental assessment of biological treatment of washing waters from cheese production

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Abstract
Life cycle assessment (LCA) is a tool for evaluating environmental burdens related to a product, process or activity throughout its entire life cycle. In wastewater treatment, LCA can provide, for example, guidance for improving the environmental performance of existing treatment plants. In this study, we applied LCA to assess the environmental impacts of treating washing waters from cheese production by nitrification/denitrification and simultaneous phosphorus precipitation. Wasted sludge was applied as organic fertilizer to farmland to recycle nutrients. LCA results revealed that emissions from biological treatment to air and water, electricity consumption, and consumption of ferric chloride contributed most to the environmental burdens at the level of the treatment plant. Sensitivity analysis of the LCA results regarding the choice of precipitating agent showed that the use of ferrous sulphate instead of ferric chloride reduces the environmental impacts in all impact categories.
Keywords
Industrial wastewater; Life Cycle Assessment (LCA); phosphorus precipitation; organic fertilizer; wastewater treatment

INTRODUCTION

Life cycle assessment (LCA) is a methodology for evaluating environmental impacts associated with a product, process or activity covering all stages of its life cycle from cradle to grave. With respect to wastewater treatment, LCA allows identifying processes at the treatment plant level or beyond that contribute most to the environmental burdens of wastewater treatment. LCA results can provide guidance for improving the environmental performance of existing treatment plants. During the design of a treatment plant, LCA can be used to compare the environmental performance of different plant configurations.

In this study, we used the LCA methodology to evaluate the environmental impacts of treating washing waters from cheese production by nitrification/denitrification with simultaneous phosphorus precipitation. Washing waters from cheese production originate from cleaning pipelines, tanks and equipment, and can contain different fractions of cheese whey. For this study, we assumed that the lactose and protein rich cheese whey is valorised, for example, by drying it and using it as feedstock for animal feeding. The remaining washing waters are, nonetheless, characterized by high organic loads of readily biodegradable organics (Carvalho *et al.* 2013) and need to be treated prior to discharge to receiving waters. Waste activated sludge from biological treatment of the washing is applied to farmland in order to recycle nutrients.

MATERIALS AND METHODS

Goal and scope

The aim of this study was to assess the environmental impacts of treating washing waters from cheese production by nitrification/denitrification and simultaneous phosphorus precipitation. The studied system included application of waste activated sludge as organic fertilizer on farmland, replacing the use of mineral fertilizers. Cheese production and pretreatment of washing waters (sieving and degreasing) is excluded from the study. The functional unit of the system is the treatment of 1 m^3 washing waters from cheese production.

System description

The treatment system under study is designed for treating 250 m^3/d washing waters from cheese production and is depicted in Figure 1. The characterization of the washing waters in the influent of the treatment plant and imposed effluent limits are given in Table 1. The washing waters are treated by nitrification/denitrification and simultaneous phosphorus precipitation using ferric chloride as precipitating agent. The aeration basin is intermittently aerated with two surface aerators. Sludge is recycled from the clarifier to the aeration basin. The effluent from the clarifier is discharged to receiving waters. Waste activated sludge is thickened, conditioned with a polymer solution, and dewatered in a belt filter press. The dewatered sludge is stored, transported for 50 km and spread on farmland as organic fertilizer. The air from the sludge thickener, the dewatering hall and the sludge storage silo is treated with an activated carbon filter.

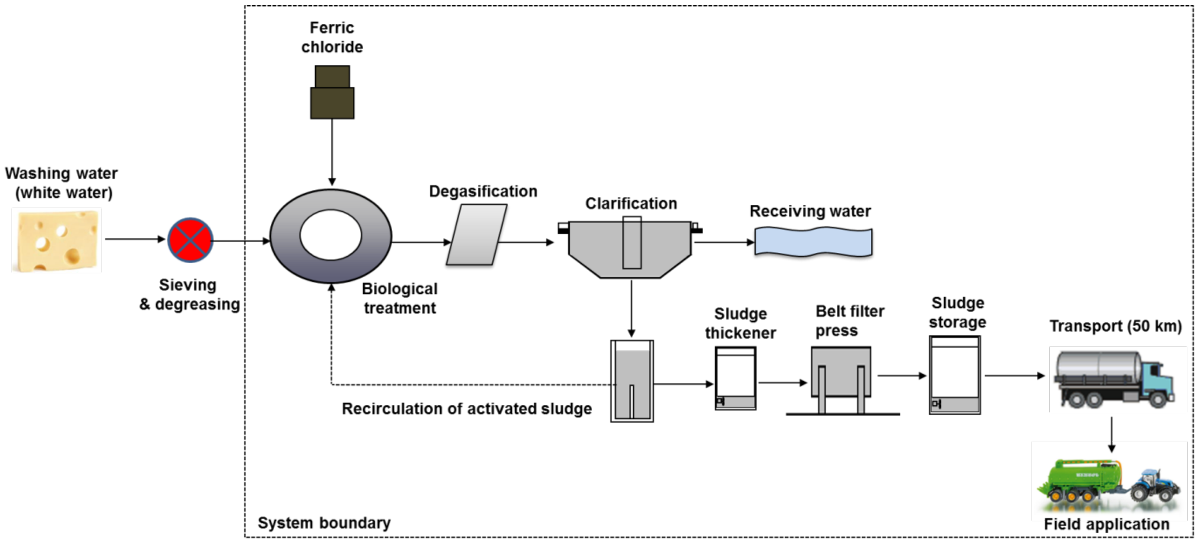

Figure 1. Schematic of the treatment process for washing waters from cheese production.

Field application of biological sludge replaces mineral fertilizer application at equivalent nutrient and fertilizer values. The nitrogen mineral fertilizer equivalent (MFE) of waste activated sludge was determined using the plant available nitrogen (PAN) calculation method (Water Environment Federation 2005). MFE values for phosphorus and potassium were fixed at 0.95 and 1.0, respectively, as both phosphorus and potassium are primarily available in mineral form. N_2O emissions from biological treatment as well as emissions to water from the discharged effluent were accounted for. Direct emissions to air, water and soil from mineral and organic fertilizer application were calculated using different emission models. Overall, ammonia (NH_3), nitrous oxide (N_2O), and nitrogen oxide (NO_x) emissions to air, nitrate (NO_3^-) and phosphorus emissions to water, and heavy metal emissions to soil were considered. Heavy metal contents of mineral fertilizers were taken from Dittrich and Klose (2008) and Nemecek and Schnetzer (2012). Heavy metal contents of the waste activated sludge were assumed to be similar to those of activated sludge from municipal wastewater treatment plants and were taken from Oliva *et al.* (2009). A detailed description of the applied emission models and the PAN calculation is given in Brockmann *et al.* (2013).

Impact assessment

Environmental impacts of treating washing waters from cheese production were assessed at midpoint with the ReCiPe Method (version 1.07) (Goedkoop *et al.* 2013) using the ecoinvent v2.2 database and SimaPro 7.3.3 software.

Table 1. Wastewater characterization of the washing waters from cheese production and imposed effluent limits**.**

Parameter	Unit	Influent	Effluent
Q_{in}	m^3/d	250	250
COD	g COD/m^3	2,000	125
BOD_5	g BOD_5/m^3	1,500	25
TSS	g TSS/m^3	500	35
TKN	g N/m^3	100	(2)
NO_3-N	g N/m^3	40	(13)
N_{tot}	g N/m^3	140	15
P_{tot}	g P/m^3	50	2
Grease	g/m^3	300	-

RESULTS AND DISCUSSION

Figure 2 shows the results of the environmental impact assessment of treating 1 m^3 washing waters from cheese production. Emissions from the biological treatment step had large impacts on climate change (N_2O), freshwater eutrophication (phosphorus), and marine eutrophication (NO_3^- and NH_4^+). Electricity consumption (French electricity mix) at the wastewater treatment plant significantly affected 11 of 18 impact categories (76-320% of the total impact). The consumption of consumables at the treatment plant, in particular ferric chloride (84% of the impact of consumables), had a large influence on 12 impact categories (27-196% of the total impact). In addition to the processes at the treatment plant, direct field emissions from organic fertilizer application and the amount of replaced mineral fertilizers had large impacts on the environment. Field emissions from sludge spreading had negative environmental effects on human toxicity (heavy metals), particulate matter formation and terrestrial acidification (NH_3 and NO_x), freshwater eutrophication (phosphorus), marine eutrophication (NH_4^+ and NO_3^-), and terrestrial ecotoxicity (heavy metals). In contrast, substitution of mineral fertilizers by produced sludge resulted in large environmental benefits. Recycling nutrients from washing waters from cheese production significantly reduced the environmental burdens of the treatment. Levers for improving the environmental performance of the wastewater treatment plant are 1) emissions from biological treatment to air and water, 2) electricity consumption, and 3) consumption of ferric chloride.

Impact of choice of precipitating agent

Due to the large environmental impact of ferric chloride consumption, the sensitivity of the LCA results with regard to the choice of precipitating agent was evaluated. Besides ferric chloride ($FeCl_3$), ferrous sulphate ($FeSO_4$) and aluminium sulphate ($Al_2(SO_4)_3$) were chosen as precipitating agents. Aluminium chloride ($AlCl_3$) was not considered as precipitating agent, because it is not inventoried in the ecoinvent v2.2 database. Using ferrous sulphate instead of ferric chloride for simultaneous phosphorus precipitation reduced the environmental impacts for all impact categories by 2-145% (median 22%). The use of aluminium sulphate (instead of ferric chloride) resulted in reduced environmental impact for 14 of the 18 regarded impact categories. But the environmental impacts increased for four categories (photochemical oxidant formation, particulate matter formation, terrestrial acidification, and water depletion). Thus, from an environmental perspective, the use of ferrous sulphate instead of ferric chloride should be favoured.

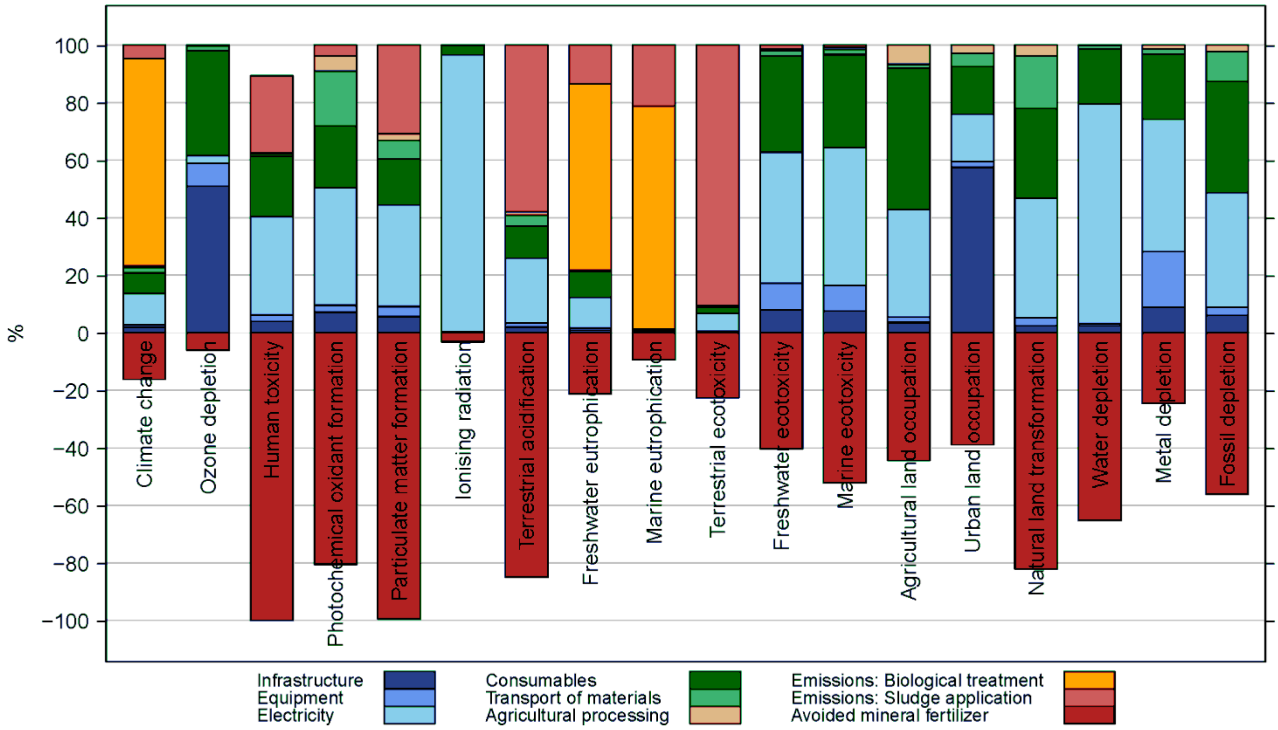

Figure 2. Impact assessment for treating 1 m^3 washing waters from cheese production. ReCiPe Midpoint (version 1.07) was used for characterization at midpoint.

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Edited by

Roberto Canziani, Francesco Fatone and Evangelia Katsou