Optimization model for the extraction of lipids from urban sewage sludge

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Introduction

With the rapid growth of population and urbanization, the development of alternative and sustainable treatment of sewage sludge has become an important environmental issue worldwide, especially if recovery of resources was coupled to the treatment. For this reason, lipid extraction has been investigated to enhance the treatment of waste sewage sludge with a concomitant production of biodiesel (di Bitonto *et al* 2021, 2020; Pastore *et al* 2015).

The process of recovery of lipid from sludge by using hexane as an extracting solvent, by working on sedimented sewage sludge was already investigated (Olkiewicz *et al* 2016). In this case, the cost of reagents and the energy required for the extraction process are the main limitations for a profitable application.

This work aims to present an innovative industrial configuration for lipid extraction from sewage sludge.

A preliminary centrifugation of sewage sludge was introduced before the extraction process, significantly reducing the manufacturing costs and the total energy demand. This new layout of operations was compared with the conventional scenario (extraction on sedimented sewage sludge), by considering for the first time, the removal and recovery of that part of solvent remained entrapped into the exhausted sludge after the extraction process. Model simulation and economic evaluation of this process was carried out on plants of different capacities, for evaluating the efficiency of the proposed technology in relation to the amount of sludge treated.

Process simulation

The economic evaluation of the extraction processes was carried out with the data generated by process simulator, Aspen Plus® V.9. Primary Sludge (PS) collected from the Wastewater Treatment Plant (WWPT) of Putignano, located in South of Italy, were considered in the simulation model with a typical composition reported in Table 1.

Table 1. Chemical composition of Primary Sludge uptaken from The WWTP of Putignano (South of Italy).

Primary sludge composition	
Total solids (TS)	***(%wt)***
Starting (sedimented) sludge	3
After centrifugation	10
TS composition	***mg/g$_{TS}$***
Saponifiable lipids	180
Waxes	20
Proteins	250
Cellulose	350
Ashes	200

To simplify the simulation mode, palmitic acid and cetyl palmitate were used to simulate, respectively, the percentage of free fatty acids (FFAs) and waxes present as main compounds experimentally detected. Other compounds have been defined as hypothetical solids, according to the previously studies present in literature. The Peng-Robinson equation of state was used to investigate the physical properties of vapor-liquid systems.

Two different approaches for the lipid extraction from PS were evaluated on plant of different capacities 500.000, 200.000 and 50.000 Population Equivalent (PE), corresponding respectively to 100, 40 and 10 ton h^{-1} of sedimented sewage sludge. Flow diagrams are shown in Figure 1.

In route 1, lipid extraction was conducted in a batch mixer reactor (M1) at ambient temperature. Preliminary acidification of sedimented PS (TS: 3%) with hydrochloric acid (HCl) was carried out with lipid composition that consists of 18% of FFAs (convertible into biodiesel) and 2% of Waxes, as denoted in Table 1.

A volume ratio PS to hexane 1:1 was used, obtaining an extraction efficiency of 80% in a single stage, according to our experimental studies (Pastore *et al* 2015). Then, the biphasic system was sent to the separator (S1) allowing the organic phase containing lipid to be separated from exhausted sludge, which contained a residual amount of hexane (8%wt). For this reason, both phases were heated in two vertical evaporators (EV1, EV2). The solvent initially used was totally recovered and eventually reused for subsequent extraction cycles.

In route 2, a preliminary centrifugation of PS (C1) was introduced, obtaining dewatered sludge (TS = 10%wt, Figure 1).

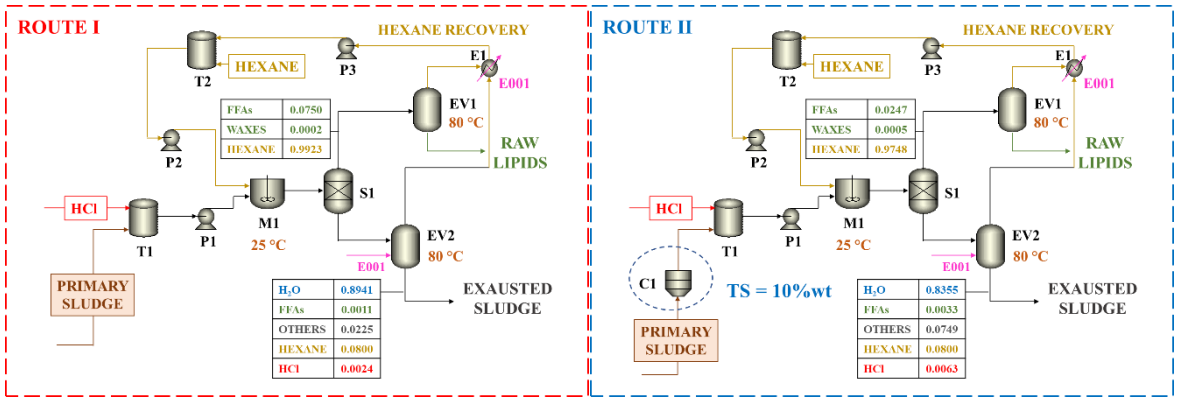

Figure 1. Flow diagrams for the extraction of raw lipids from Primary Sludge obtained by Aspen Plus® V.9. Mass fraction of different components were reported.

Analysis of results

The results of the economical evaluation for the investigated processes are summarized in Table 2. Break-even price (BEP) of lipids extracted for each scenario was assessed with respect to the total plant capacity and the manufacturing costs per unit of product. In all cases, the preliminary centrifugation of sewage sludge (route II), allows to obtain better economic results reducing the raw lipids price beyond the total manufacturing costs.

Table 2. Economic evaluation of Break-Even Price (BEP) for lipids extracted from Primary Sludge.

WWTPs	**500.000 PE**		**200.000 PE**		**50.000 PE**	
	Routes		***Routes***		***Routes***	
	I	***II***	***I***	***II***	***I***	***II***
Total manufacturing costs ($/year)	6544724	3487533	3514520	2155966	1813267	1378335
Raw lipids extracted (ton/year)	3784	3784	1515	1515	378	378
Break-Even Price BEP (ton/year)	**1729**	**922**	**2320**	**1423**	**4792**	**3642**

In particular, a BEP value of 922 $ / ton was obtained compared to 1729 $ / ton obtained for the conventional process (500.000 PE), highlighting the complete feasibility of the proposed process on an industrial scale.
On the other hand, BEP increase drastically approaching to value of 4792 and 3642 ton/year for low-capacity plants (50.000 PE).

Conclusions

In this work an alternative route for the extraction of lipids from sewage sludge was proposed with respect to the conventional process. An economic evaluation of the model demonstrated not only the effectiveness of the entire process, but also its applicability on an industrial scale.

Acknowledges

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