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Resource Recovery from Wastewater Treatment

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Editors

Resource Recovery from Wastewater Treatment

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Preface

Today multidisciplinary is a key and a must for solving issues in the water field.

Dialogue is a must to foster multidisciplinary collaboration among different water specialists and better share specific knowledge.

With this final aim, with the support of the International Water Association (IWA) it was organised the ICWRR2024, International Conference on Wider-Uptake of Water Resource Recovery from Wastewater Treatment, from 18 to 21 June 2024.

ICWRR2024 is the final event of the four-year research project EU project: Achieving Wider-Uptake of water-smart solutions–Wider-Uptake (grant no. 869283), which was aimed to facilitate industrial symbiosis in order to increase resource efficiency, limit emissions and develop a sustainable business based on water-smart solutions. The research project was also aimed to develop an open-access roadmap on how to upscale and implement such solutions on a wider scale, in Europe and beyond.

The final aim of ICWRR2024 was to create a forum for promoting the discussion among scientists, professionals and academia in different areas of the broader theme of water resource recovery from water treatment.

The conference was organised in nine parallel sessions, and for each of them, a keynote by a referral researcher was presented. Specifically, the keynotes were held by the following professors, whose contributions were highly inspiring: Damià Barceló, Menachem Elimelech, Xia Huang, Yongmei Li, Eberhard Morgenroth, How Yong NG, Ana Soares, Eveline Volcke, Zhiwei Wang and Zhiguo Yuan.

The wealth of information exchanged during ICWRR was of great benefit to all involved in a wide range of challenging environmental issues, from innovative and nature-based water and wastewater management solutions to circularity assessment tools and environmental policy and legislation.

Those challenges require the building of a regulatory framework as well as control strategies. The application of innovative techniques and new scientific methods is key to reaching sustainable development. It is, therefore, crucial to address the existing pollution problems and protect public health as well as preserve the welfare of the environment while aiming at recovering resources from waste in line with a circular economy model.

The application of cost-effective technologies for waste treatment and resource recovery is much needed in order to make possible the implementation of appropriate regulatory measures that ensure the success of broader circular economy policies.

Engineers and scientists working in the water sector area need to be familiar with a wide range of issues, including the physical processes of mixing and dispersion, biological developments and mathematical modelling. Hence, a continuous exchange of information between water professionals in different parts of the world is essential.

Protection of the environment, one of the pillars of sustainable development, is an absolute priority for the international community. In this context, the ICWRR conference aimed to focus on relevant experiences, up-to-date scientific research and findings carried out all over the world to protect and preserve the environment while recovering resources.

The book contains contributions presented at the International Conference on Wider-Uptake of Water Resource Recovery from Wastewater Treatment which was held at the University of Palermo, Palermo (Italy) from 18 to 21 June 2024.

The research project also had an educational goal which was to train through seminars and advanced courses to young researchers involved in the project. In particular, three editions of the Formative Seminar for Unipa Students (FORSEM) were organised at Palermo University, Palermo (Italy).

During the project, experimental activities were carried out on pilot plants and real wastewater treatment plants with the final aim to widen and strengthen the knowledge on water smart solutions. The book also contains several contributions to the project research.

Overall, the book is organised into eight parts. Each part deals with a specific topic of the International Conference on Wider-Uptake of Water Resource Recovery from Wastewater Treatment. Specifically, the following parts are present: Part I–Resource recovery from wastewater, Part II–Domestic/industrial wastewater treatment, Part III–Greenhouse gases from wastewater treatment, energy optimisation and life cycle assessment, Part IV–Water Reuse and rainwater harvesting, Part V–Mathematical modelling of wastewater treatment plants and resource recovery, Part VI–Metagenomics analysis and environmental microbiology, Part VII–Governance and business models, environmental policy and legislation in the water sector, Part VIII–Plant-water-soil nexus and fertilisers from wastewater.

Each contribution to the conference has been peer-reviewed by at least two members of the scientific committee. Their efforts have contributed to the high quality of the final book contributions, and, therefore, their reviewing activity is acknowledged and appreciated.

Finally, I express my thanks to Mr. Pierpaolo Riva, the publishing editor at Springer, for his suggestions during the finalisation of the book.

I do hope that the reader will find the book a source of inspiration for both research and professional life.

Giorgio Mannina

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Governance and Business Models, Environmental Policy and Legislation in the Water Sector

Plant-Water-Soil Nexus and Fertilizers from Wastewater

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Water Reuse and Risk Analysis: The Case Study of Corleone (Italy) Ultrafiltration Plant

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Abstract. This study summarises the results of two months of monitoring the full-scale ultrafiltration plant in Corleone (Italy). The monitoring has been conducted according to the current regulations on water reuse in Italy (Italian Ministerial Decree 185/2003 and 2020/741/EU). Samples were withdrawn every ten days from three sections: i. treated disinfected wastewater (Section 1); ii. Downstream the sand filtration (Section 2); iii. After the ultrafiltration (Section 3). Data showed the ultrafiltration plant's excellent capability to remove E.coli, total suspended solids (TSS), and turbidity. For the parameters, the permeate quality can be classified as Class A according to 2020/741/EU. Conversely, in terms of BOD_5, the permeate can be categorised as Class B according to 2020/741/EU since the BOB5 value was around 20 mgO2 L-1 on average. Therefore, treated water can be adopted for food crops, processed and non-food crops and all irrigation methods are allowed. The study also has the novelty of providing a first attempt at performing a risk analysis according to 2020/741/EU, which has yet to apply to Sicilian plants.

Keyword: water reuse · ultrafiltration · European Regulation 2020/741 · membrane

1 Introduction

The amount of natural water withdrawn for agriculture, municipal, and domestic uses has substantially increased during the last century. The volume of natural water adopted for human scopes (agriculture, municipal, and domestic) increased from 500 km^3/year in 1900 to 4000 km^3/year in 2018 (FAO, 2022). Around 72% of this natural water is adopted for agricultural purposes (FAO, 2022). The massive adoption of natural water for human scopes and climate change causing reduced water availability make future access to safe drinking water a struggle. Today, 2.2 billion people need access to safely managed drinking water; conversely, 80% of wastewater in the world flows back into the ecosystem without being treated or reused (UN, 2023). For these reasons, the United Nations has proposed Sustainable Development Goal 6 (SDG 6) to ensure the availability of sustainable water and sanitation management for all.

Treated wastewater could represent an alternative water source in regions with water crises due to climate change (Mannina et al., 2022a). The reuse of treated wastewater in agriculture could facilitate the circularity of water, organic matter, and essential

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nutrients such as nitrogen, phosphorus, and potassium (Cosenza et al., 2022). With this regard, the European Union (EU) have proposed the EU 2020/741 regulation to facilitate water reuse for agricultural scopes imposing limits for four parameters (total suspended solids - TSS, turbidity, biological oxygen demand - BOD_5, Escherichia coli - *E. coli*) according to four classes of reclaimed water quality (namely, classes A-D). Therefore, in Italy two regulations are currently valid for treated wastewater reuse: i. the Italian Ministerial Decree 185/2003 imposing limits for industrial and civil reuse; ii. the 2020/741/EU imposing limits for agricultural reuse. In view of producing water that couples the imposed limits, adopting advanced wastewater treatment technologies is mandatory. Among the technologies applied within the wastewater treatment plants, the membrane bioreactor (MBR) allows the achievement of high effluent quality comparable to that required for agricultural scopes. The adoption of MBR could favour the circularity of wastewater, guaranteeing water availability for agriculture and saving the adoption of natural water. However, despite the advantages of reuse, this practice still needs to be widespread due to several existing barriers (technological, economic, social, and legislative). To overcome the existing barriers, several actions promoting water reuse have to be applied (such as good operating practices or increasing social awareness). With this regard, within the H2020 Wider Uptake project, a roadmap for the Corleone case study is building (Mannina et al., 2021). This roadmap indicates several actions to be applied in view of spreading the water reuse in Corleone (Mannina et al., 2022b). One of these actions is to know the current plant performance to be adopted as a benchmark for future improvement. The study aims to present the results of two months of monitoring of the Corleone ultrafiltration plant and assess the risk according to EU 2020/741 regulation.

2 Material and Methods

Corleone's full-scale plant couples the wastewater treatment and tertiary ultrafiltration (UF) systems. The wastewater treatment system treats around 3700 m^3/d using a conventional activated sludge process and aerobic digestion for the sludge line. Around 1/3 of the treated and disinfected wastewater is subjected to further treatment inside the UF system. Figure 1 depicts the layout of the UF system. The UF system has two sand filters, two ultrafiltration membrane units, and a clean-in-place (CIP) tank.

The permeate is collected in a storage tank (Fig. 1). Each membrane unit comprises 36 modules of polyvinylidene fluoride hollow membranes with a porosity of 0.04 μm. The membranes are operated under filtration (22 min) and backwashing (3 min) cycles. Chemical cleaning takes place every 14 days for 3 h. During the chemical cleaning, hot water (around 35 °C) taken from the CIP is dosed with sodium hypochlorite (300 mg/L) and sulphuric acid (0.05%) and pumped from the outer to the inner membranes (Fig. 1). The water adopted for the chemical cleaning is then neutralized and discharged (Fig. 1).

During the two-month experimental campaign, samples were collected every ten days from three sections: i. after disinfection (Section 1); ii. After the sand filters (Section 2); iii. After the ultrafiltration (Section 3) (Fig. 1). For each sample, BOD_5, turbidity, TSS, and *E. coli* were analysed coupled with the parameters imposed by the Italian 185/2003 regulation. Standard methods (APHA, 2012) were used to measure BOD_5 and TSS. *E.*

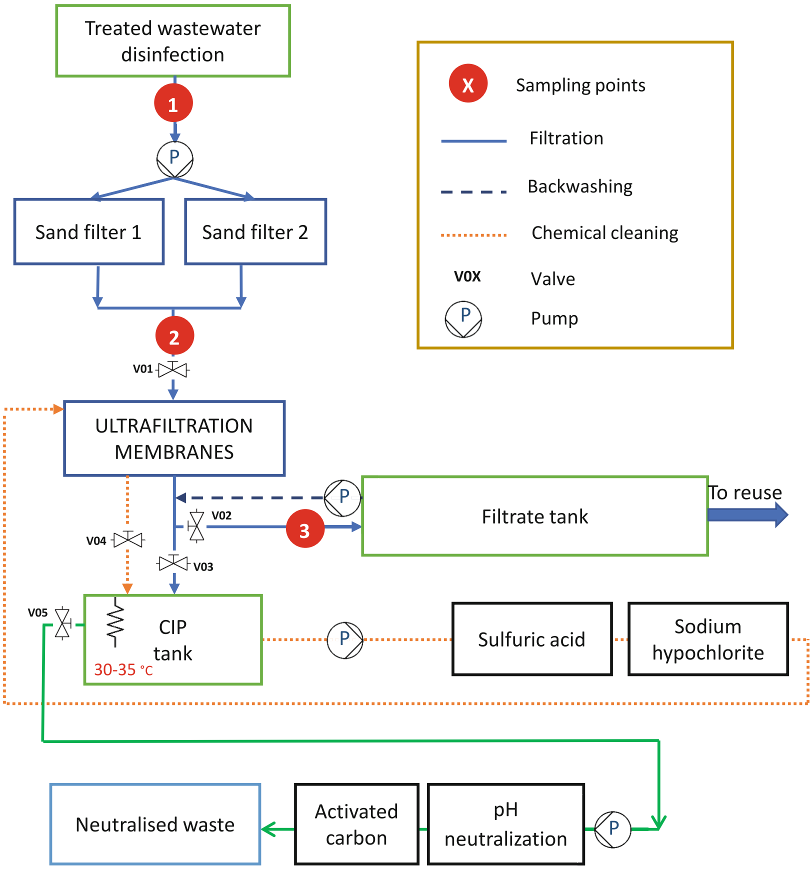

Fig. 1. Layout of Corleone UF full—scale plant and sampling point indication

coli concentration was measured using method F as proposed by IRSA – CNR. Turbidity was measured by using a portable Hanna (USA) HI93703 turbidimeter.

3 Results and Discussion

For the sake of conciseness in this study, only the results of BOD5, turbidity, TSS, and *E. coli* will be shown and discussed. The limits regarding the parameters imposed by the Italian Ministerial Decree 185/2003 are respected. Figure 2 shows the results of BOD5, turbidity, TSS, and E. coli for all sampling days and monitored sections.

Data from Fig. 2a show that despite the high variability of the E.coli concentration measured in Section 1 (ranging between 35 and 90 UFC/100 ml), the permeate (Section 3) *E.coli* concentration always equals zero. This suggests the UF system's excellent capability in removing pathogenic bacteria. Further, the sand filters provided an average removal of *E. coli* of 67%. Regarding BOD_5 removal, no substantial variation was obtained between Section 1 and Section 2 (Fig. 2b). Excepting for the sampling day

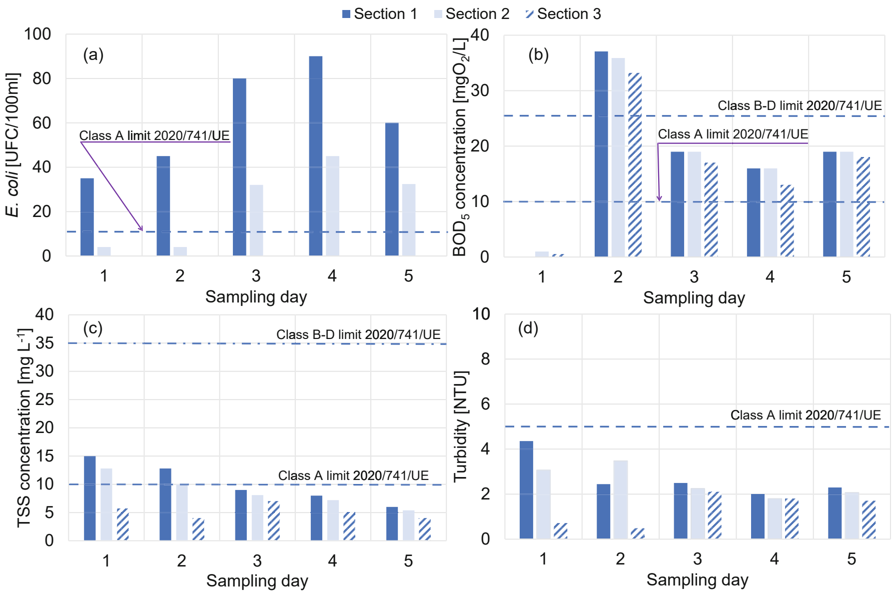

Fig. 2. Measured values of E. coli (a), BOD_5 (b), TSS (c) concentrations, and Turbidity (d) for each sampling day and monitored plant section.

2, the BOD5 concentration of the effluent permeate (Section 3) was always lower than 25 mg/L, which represents the limit imposed by the EU 2020/741 regulation for quality Class B. The high value of the BOD_5 concentration obtained during sampling day 2 is due to the WWTP process dysfunctions. Indeed, the disinfected effluent from the plant exceeded the regulation limit of 25 mgL^{-1} (Italian Legislative Decree 152/2006). In terms of permeate TSS concentration and turbidity, the measured quality was always within the Class A of EU 2020/741 regulation. Specifically, by analysing data of Fig. 2c one can observe that even when the disinfected effluent from the WWTP (Sample 1) had a TSS concentration greater than 15 mg L^{-1}, the permeate was always lower than 10 mg L^{-1} (limit of Class A quality of EU 2020/741 regulation). In particular, the average permeate TSS concentration was 5.14 mg L^{-1}. The sand filters reduced the TSS concentration by around 13%. The remaining removal was due to the UF action. The results in terms of turbidity were obtained for the TSS concentration (Fig. 2d). Data related to the Italian Ministerial Decree 185/2003 (not shown here for conciseness) respected the imposed limit. Therefore, the produced water could be adopted even for Industrial and civil scopes. The qualitative risk assessment is ongoing; results will be presented in the revised manuscript.

4 Conclusions

The Corleone full-scale UF plant was monitored to evaluate the quality of the water produced according to EU Regulation 2020/741 (agriculture reuse) and the Italian Ministerial Decree 185/2003 (civil and industrial reuse). The quality of the water produced respects Class A of EU Regulation 2020/741 for the parameters E.coli, TSS concentration, and turbidity. In contrast, for the parameter BOD_5 concentration, water can be classified as allowing to Class B of EU Regulation 2020/741. The Italian Ministerial Decree 185/2003 imposed all the measured parameters. Therefore, the treated water could be adopted for civil, industrial and agricultural scopes. According to EU Regulation 2020/741, all irrigation methods could adopt the treated water for food, processed, and non-food crops.

Acknowledgements. This work was funded by the project "Achieving wider uptake of water-smart solutions—WIDER UPTAKE" (grant agreement number: 869283) financed by the European Union's Horizon 2020 Research and Innovation Programme, in which the last author of this paper, Giorgio Mannina, is the principal investigator for the University of Palermo. The Unipa project website can be found at: https://wideruptake.unipa.it/.

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Volatile Fatty Acids by Acidogenic Fermentation of Wasted Domestic Sludge from IFAS-MBR: The Effect of Sludge Retention Time

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Abstract. Rapidly emerging as valuable resources, volatile fatty acids (VFA) can be obtained from sewage sludge by acidogenic fermentation of its organic content. Existing work focuses on optimising VFA generation by altering pH and temperature, integrating chemicals, or pre-treating the sludge. Nonetheless, little is known about the impact of sludge properties, namely the sludge retention time (SRT). It is essential to comprehend how the characteristics of sewage sludge affect acidogenic fermentation when constructing fermenters that can be expanded to industrial sizes. Through the effective reuse of waste streams, standardised fermenter designs would not only improve VFA output but also advance into sustainability. The literature lacks thorough investigations or defined criteria necessary to fill this knowledge gap. In this sense, fermentation batch tests were carried out utilising surplus sewage sludge from an Integrated Fixed Film Activated Sludge Membrane Bioreactor (IFAS-MBR) pilot plant to provide insights into the fermenter reactor's design. The preliminary results show that the sludge with the lowest SRT tested proved to be the one with the best quality and quantity of produced VFA. VFA accounted for 63% of the organics produced, expressed as chemical oxygen demand (COD). Moreover, a higher share of acetic acid was made (76%) compared to sludge with highest SRT tested, highlighting the increased efficiency in VFA production when sludge with low SRT is used.

Keywords: Biosolid management · Resource recovery · Volatile Fatty Acids

1 Introduction

Sewage sludge has recently been recognised as a valuable resource for energy and nutrient recovery instead of just a waste produced by the wastewater treatment process, in line with a circular economy approach. Sewage sludge disposal technologies, such as anaerobic digestion, have proved to be an asset for high-value-added chemical compounds such as volatile fatty acids (VFA) (Montiel-Jarillo et al., 2021). VFA are easily

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degradable organic compounds that can be used as platform chemicals by the microorganisms available in the sludge to produce biopolymers such as polyhydroxyalkanoates (PHA) (Mannina et al., 2019). VFA is produced during the digestion process's acidogenic phase (acidogenic fermentation), where complex organic compounds available in sewage sludge are broken down into simpler intermediates. Despite being an auspicious process, several challenges are hampering its scale-up due to the nature of the sewage sludge. Without proper pre-treatment, sewage sludge is characterised by a complex structure not easily degraded by the microorganisms' biological activity. On the one hand, factors such as pH and temperature play a crucial role in the process. In view of that, the literature has focused on optimising these parameters by adjusting the pH and temperature, adding chemicals or thermally pre-treating the sludge, which will inevitability increase the environmental impact of the process, in contrast with the circular economy approach (Mineo et al., 2023).

On the other hand, several sewage sludge features can affect the acidogenic fermentation, such as the sludge retention time (SRT), which remains unexplored (Chen et al., 2021). Filling the knowledge gap regarding these features will lead to in-depth knowledge that will guide towards standardised fermenter designs. By adopting these guidelines, it will be possible to optimise the VFA production and foster sustainability by effectively reusing waste streams given scaling up the process.

In view of the above, this abstract shows the preliminary results obtained by carrying out four acidogenic fermentation batch tests. The tests were conducted using sludge samples with different SRT withdrawn from a Fixed Film Activated Sludge Membrane BioReactor (IFAS-MBR) pilot plant.

2 Materials and Methods

Bench-scale batch fermentation tests have been performed in 1100 mL of magnetic stirred glass bottles (Fig. 1). The bottles were closed with a cover and a liquid sampling port. The bottles are connected to a probe to continuously monitor pH, temperature and oxidation-reduction potential (ORP). Sewage sludge samples were withdrawn from the wastewater treatment pilot plant located at the Water Resource Recovery Facility of Palermo University with an IFAS-MBR configuration (Mannina et al., 2021a, 2021b). The sewage sludge was not pretreated prior to fermentation tests.

The experiments were performed using 4 batch tests, namely T1–T4, run in duplicate with sludge having different features, as reported in Table 1. Soluble and total chemical oxygen demand (sCOD and TCOD, respectively), VFA, ammonium (NH_4^+-N) and phosphate (PO_4^{3-}-P) were analysed during the fermentation. VFA concentration (mg/L) was converted to COD concentration (mg COD/L), as reported by Yuan et al. (2011). VFA production is calculated as the percentage ratio of VFA (expressed as mg COD/L) and sCOD.

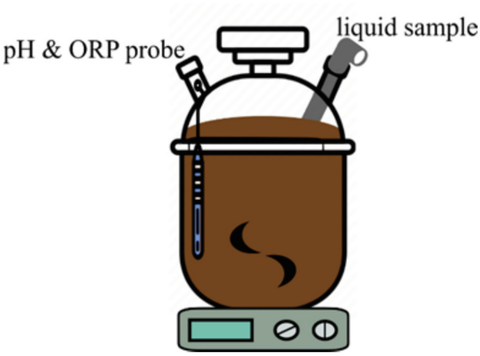

Fig. 1. Batch fermentation test set up.

Table 1. Properties of the sewage sludge used for the batch fermentation tests.

Batch test	Total suspended solids – TSS	Food to microorganism ratio – F/M	SRT	TCOD	sCOD	NH_4^+-N	PO_4^{3-}—P
	(g/L)	(kg BOD/kg TSS . day)	(days)	(mg/L)	(mg/L)	(mg N/L)	(mg P/L)
T1	3.23	0.26	4.3	4570.7	57.6	11.8	3.7
T2	3.38	0.21	6.8	5173.4	63.2	12.3	4.3
T3	3.27	0.23	10.1	6815.6	58.4	10.4	5.6
T4	3.31	0.22	16.9	6630.9	62.7	9.7	2.4

3 Results and Discussion

As reported in Fig. 2, the highest VFA/sCOD ratio (65%) was obtained during T2, with an sCOD peak at the fifth day of 497.7 mg COD/L. When a sludge with lower SRT was adopted (T1, 4.3 days), organic matter solubilisation reached the highest concentration (678.9 mg COD/L), corresponding to the highest VFA concentration of 427.7 mg COD/L.

Moreover, an SRT positive effect was also registered for the VFA distribution shown in Fig. 3. In T1, acetic acid accounted for 75.5% of the VFA produced, which is the highest value registered throughout the fermentation tests. Only 24.5% of propionic acid was made in T1, while valeric and butyric acid were produced starting from T2. The results highlight the positive effect of adopting a sludge with low SRT in the acidogenic fermentation. More VFA are made with a faster kinetics, especially if the sludge's SRT is lower than 5 days. Moreover, acetic acid was the main product followed by small shares of propionic acid, which will allow to obtain a fermentation liquid suitable for PHA copolymer production (Szacherska et al., 2021).

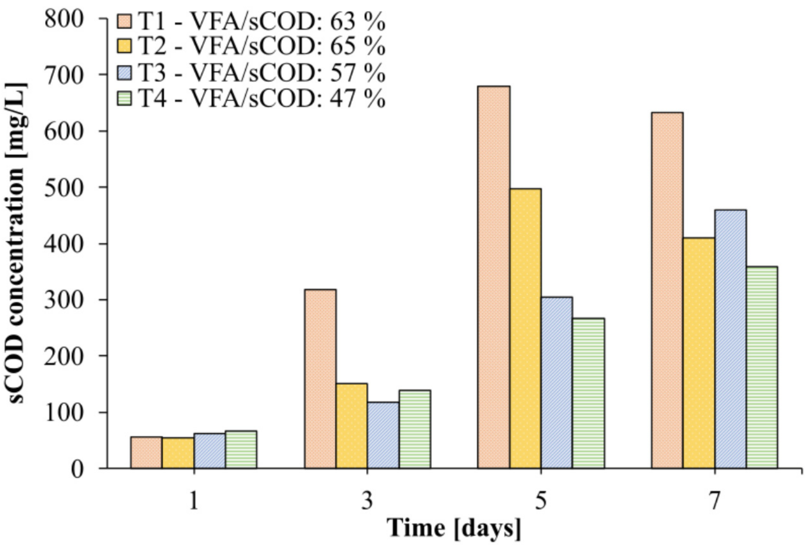

Fig. 2. sCOD and VFA/sCOD ratio for the batch fermentation tests.

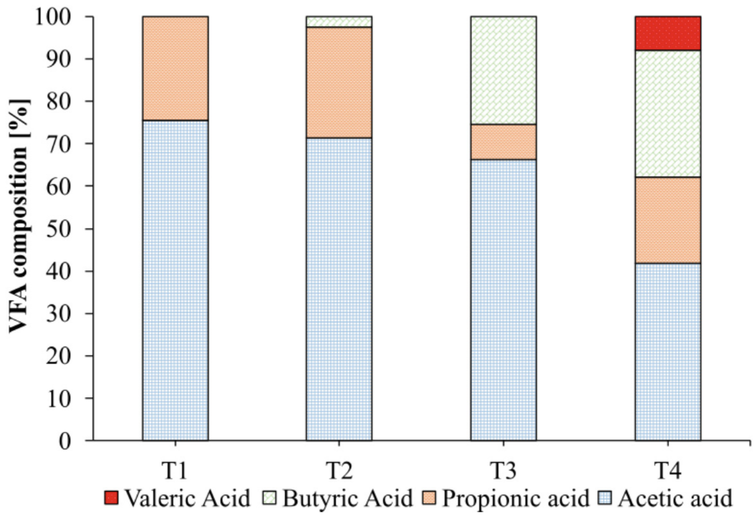

Fig. 3. VFA's composition.

4 Conclusions

The results presented in this abstract shed light on the role of SRT as a feedstock parameter that should be taken into account for optimizing the VFA production, both in terms of quantity and of quality. Low SRT sewage sludge (4.3 days) achieved the highest VFA concentration in the fermentation effluent (427.7 mg COD/L) which is composed mainly of acetic acid (75.5%) and propionic acid (24.5%). Adopting sludge with similar features