contribution to the field, he has received the ExxonMobil Chemical European Science and Engineering Award 2005, the Christian Friedrich Schönbein Medal 2009, European Ceramic Society Young Scientist Award 2015, Medal of the Royal Spanish Engineering Academy 2016 and Air Liquide Scientific Prize 2018. He is the founder of KERIONICS, the Spin-off which develops ceramic membrane systems for the generation of O_2.

José M. Catalá-Civera (M'04–SM'15) was born in Valencia, Spain, in 1969. He received the Dipl.Ing. and Ph.D. degrees from the Universitat Politècnica de València, Valencia, in 1993 and 2000, respectively. Since 1996, he has been with the Communications Department, Universitat Politècnica de València, where he received the Readership in 2000 becoming a Full Professor in 2011. Prof. Catalá-Civera is currently co-Head of the Microwave Division at the Research Institute ITACA, Universitat Politècnica de València, and since 2016 he is Director of the Institute. His current research interests include the design and application of microwave theory and applications, the use of microwaves for electromagnetic heating, microwave cavities and resonators, measurement of dielectric and magnetic properties of materials, and development of microwave sensors for nondestructive testing. He has published over 100 peer-reviewed articles in refereed journals and conference proceedings and received research funding from various sources including awards from the European Union programs (EU), National Institute of Standards and Technology (NIST) and industry contracts. He is also a holder of 24 national and international patents. Prof. Catalá-Civera is reviewer of several international journals, IEEE Senior Member and participates in several international professional and scientific associations. He was General Chair of 2019 International Conference on Microwave and High Frequency Heating organized by the Association of Microwave Power in Europe for Research and Education (AMPERE), a European-based organization devoted to the promotion of RF and microwave energy.

Microwave Pre-Treatment of Recalcitrant Dairy Waste for Anaerobic Digestion

Catherine McIntyre

Ashleigh Environmental, Dungarvan, Co. Waterford, Ireland.
Contact Email: catherine@ashleighenv.com

1 Introduction

Ireland has a strong dairy industry, expanding in recent years after the abolition of the EU milk quota in 2015 [1]. The subsequent increase in dairy production along with growing interest in the circular economy as a means to mitigate climate change and biodiversity loss have led to an urgency in efforts to reduce the environmental impact of the industry. For every liter of milk produced, 3 L of dairy wastewater are generated which must be treated before discharge to water bodies. Dairy processing wastewater comes from tank washings, waste products at various stages of production, and spoiled milk. The wastewater contains considerable concentrations of fats, oils, and greases (FOGs), non-soluble in the wastewater. FOGs are composed of highly recalcitrant compounds which are difficult to treat and are inhibitory to the microbial community in the biofilms of anaerobic digesters. While the aqueous phase of dairy wastewater may be treated by aerobic means and anaerobic digestion (AD) to generate biomethane, the FOG fraction must be removed.

FOGs are separated from the dairy wastewater stream by a process called dissolved air flotation (DAF). Briefly, compressed air is pumped into the bottom of the DAF tank. Air bubbles expand as they rise, floating the immiscible FOGs to the surface. Beams skim the surface of the DAF tank, sweeping the FOG sludge into a collection tank, while the remaining water is pumped to further treatment. Flocculant and polymeric coagulant may be added to the DAF to improve the efficiency of the process by causing the FOG particles to clump together and form larger particles, which are easier to skim off. In general, the collected sludge is disposed of via land spreading, however, DAF sludge has low nutrient value to the soils to which it is added. The soil essentially acts as a sink for this waste product.

The inhibitory effect of DAF sludge to AD biofilms is due in large part to the long chain fatty acid (LCFA) content in the FOGs [2], and also to the polymer added in the DAF process [3]. This effect is greatest in high-rate, low-temperature (~20°C) AD reactors. LCFAs are fatty acids with 14+ carbon atoms. The most abundant LCFAs in dairy fats are the unsaturated oleic acid (C18:1), and the saturated stearic acid (C18:0), palmitic acid (C16:0) and myristic acid (C14:0) (Figure 1). These compounds are very stable and insoluble in water. These properties make them difficult to break down and their thermal degradation requires high energy inputs. It is not certain whether the inhibitory effect on AD is due to a direct chemical toxic effect or an indirect physical effect [4], such as accumulation on the surface of the microbes and prevention of chemical exchange between the cell interior and exterior. Microbes appear capable of tolerating a low concentration of these compounds and will eventually digest them over time [4], but higher concentrations quickly cause detrimental effects with costly consequences.

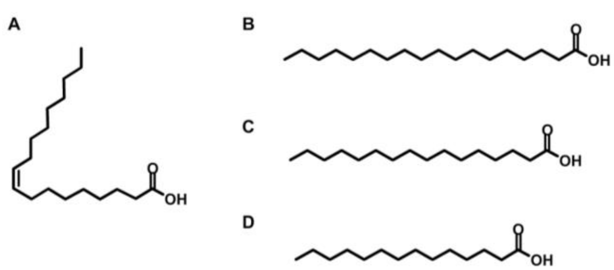

Figure 1: The LCFAs found in dairy fat. (A) Oleic acid (C18), (B) Stearic acid (C18), (C) Palmitic acid (C16), Myristic acid (C14)

The effect of added polymer can vary due to the nature of the polymer and concentration, but it also has an inhibitory effect on the AD microbial community as both polymer and its corresponding hydrolysed monomers [5]. If not broken down, polymers can build up and flocculate, causing flotation of the biofilm to the surface of the reactor and termination of the AD process. The inoculum must then be removed and replaced at great expense.

LCFAs are highly energy-dense compounds. It is estimated that the DAF sludge removed from the dairy wastewater stream represents up to 50% of the chemical oxygen demand (COD), or energy potential, of the wastewater. Yet this fraction is contained in just 10% of the wastewater volume emitted from dairy processing. Recovering all of the energy potential of this fraction would mean up to 50% enhancement of biogas production if this energy-dense sludge could be processed via AD.

The Sustainable Bio-Renewable Energy from Wastewater (S-BREW) project is a collaboration between Ashleigh Environmental and National University of Ireland, Galway (NUIG), which aims to address the challenge of treating dairy FOG waste for AD using Ashleigh Environmental's proprietary microwave technology: Biowave™. The Biowave™ system applies microwave energy to the feedstock, heating it rapidly and accelerating chemical reaction rates. The aim of the treatment is to reduce the LCFA concentration in the DAF sludge to a level that can be tolerated by the AD microbial community, as well as to break down the flocculation polymer. The resulting product will make a feedstock that is suitable for AD, and as such will facilitate access to the valuable energy potential of this waste stream. Solubilisation of solid material in the microwave is also beneficial to the rate of digestion, improving the biogas yield – particularly in low temperature applications. There are additional benefits in diversion of a waste stream from land spreading with inherent transport CO_2 emissions and financial savings to be made.

2 Novel approach to feedstock pre-treatment

While lab-scale experiments to demonstrate the application of microwave energy to treatment of FOG waste have been published in the literature [6], [7], the S-BREW project is unique in several ways. Firstly, the Biowave™ pilot system is at an industrial scale, well beyond the scope of laboratory-based microwaves. The magnetron operates at 915 MHz, offering more energy efficiency and greater penetration than the more common 2450 MHz experiments. The microwave reactor operates on a continuous flow basis, as opposed to the more frequently used batch mode in small vessels of lab scale microwaves. To our knowledge, this is the first time that DAF waste sludge from dairy processing has been trialled in microwave treatment at this scale. The feedstock is complex and variable and investigation of the effect of microwave pre-treatment on the diverse conditions is essential to understanding the application of this process in real world conditions.

2.1 Samples

The aim of our initial investigations was to determine the effect of microwave treatment at a range of temperatures and on a variety of DAF sludge samples from different dairies in Ireland. It was important to investigate sludges from dairies that produce different products (e.g., milk, butter, milk powders, cheese) and also the variation in wastewater treatment approaches in the DAF process. Polymer use varies across treatment plants, with different dosing rates and polarity of polymer used and some producers don’t use polymer at all.

2.2 Microwave system

The pilot scale system is a 915 MHz continuous flow microwave-assisted reactor with 36 kW of power generation. DAF sludge is pumped from a 1 m^3 container and flows continuously through the reactor. Trials to date have investigated the effect of increasing temperature on LCFA breakdown in microwave treated DAF sludge. Further trials have investigated the effect of oxidation, with H_2O_2 added to the sample prior to the microwave reactor.

2.3 Analytical approach

Microwaved samples are analysed by standard methods for pH, total solids (TS), volatile solids (VS), total COD (TCOD) and soluble COD (SCOD). These physico-chemical properties provide context for any effects observed in the treated samples. For example, solubilisation of solid content should result in improved biomethane production. Determination of LCFA concentrations is the most important measure of the effectiveness of the treatment on the DAF sludges as these are the compounds that cause the inhibitory effect. Analysis of volatile fatty acid (VFA) content may indicate if LCFAs are broken down to shorter chain fatty acids with additional benefits for AD as VFAs are a readily available carbon substrate. Biomethane potential (BMP) trials are performed on microwave treated products which exhibit good LCFA reduction. These BMP experiments will demonstrate the suitability of the pre-treated feedstock for AD, if the inhibitory effect has been overcome, and any increase in potential for biomethane production as a result of microwave treatment. Continuous sampling and analysis also indicate the rate of reduction of COD in the AD batch experiments.

3 Results

3.1 LCFA reduction

Results are preliminary at this stage. However, they indicate that LCFA concentrations are reduced by microwave treatment and that the reduction increases with increasing temperature (Figure 2). The greatest reduction in concentration is seen at >95°C for a DAF sludge from a butter plant.

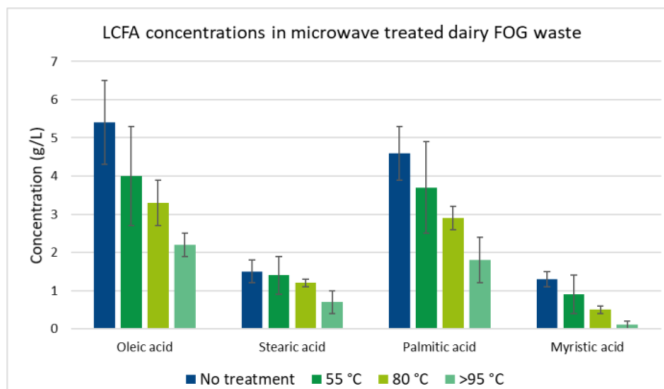

Figure 2: LCFA concentrations in microwave treated dairy sludge from a processer producing butter and cream. Results are from the untreated sample and microwave heated to 55, 80 and >95 °C. Reductions at >95 °C are 59, 53, 60 and 85 % for oleic acid, stearic acid, palmitic acid and myristic acid, respectively.

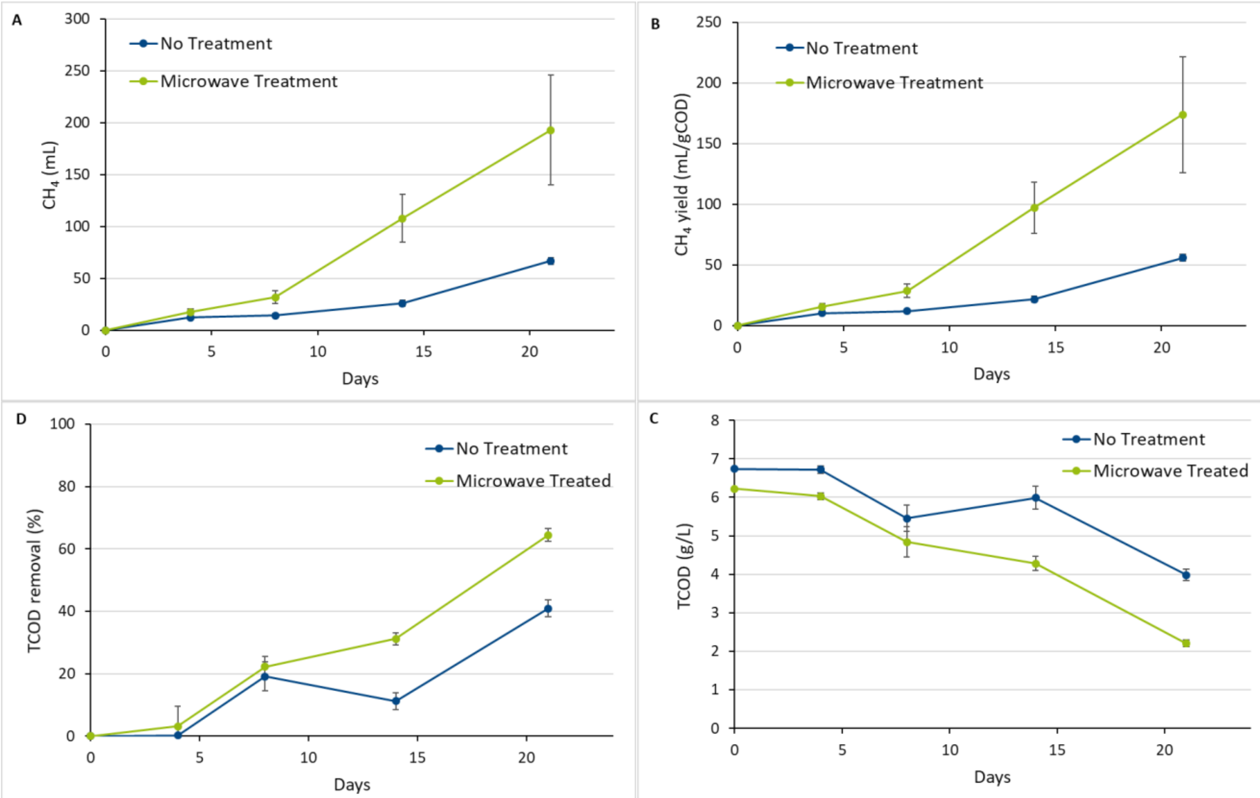

Figure 3: Results from batch degradation experiments at 20°C using an untreated DAF sludge from a milk processing plant as feedstock, and the same sludge microwave treated to >95°C. Cumulative biomethane production over 21 days from AD inoculum fed with NT sludge and microwave treated sludge in absolute volume (A) and volume per gCOD added (B). Reduction in COD in each batch experiment over the course of the 21 days expressed in g/L (C) and % TCOD removal (D).

3.2 Biomethane potential

Similar results were seen in the LCFA concentrations in a sample from a milk processing plant with reductions of up to 30% in samples treated at >95°C in the microwave system. This feedstock was then applied to an anaerobic batch degradation experiment to determine the BMP of the reactors when fed with an untreated sample and one treated at >95°C. The microwave treatment appears to have improved the methane yield of the digester with microwaved feedstock applied (Figure 3A), even when normalised to gCOD added. At the same time, COD removal efficiency is improved by microwave treatment with no lag seen for the treated sample in the batch degradation experiment.

3.3 Effect of oxidation

The effect of addition of H_2O_2 to the samples just prior to microwave treatment was investigated to determine if LCFA reduction rates could be further improved by oxidation. Again, results are preliminary, and the oxidation rate has yet to be optimized. However, initial tests suggest that there are further gains to be made with addition of H_2O_2. Reductions in LCFAs in the DAF sludge from a milk processor were up to 50% with oxidation at 95°C (Figure 4), whereas 30% reductions had been observed with temperature alone.

3.4 Impact on COD

There was no impact expected on TCOD of samples, but significant increases in SCOD were seen for samples with concomitant significant decreases in LCFA concentrations, such as the treated samples in Figures 2 and 3 above.

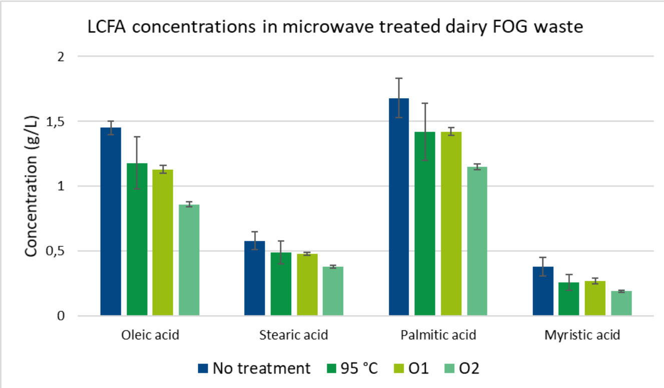

Figure 4: Effect of oxidation with H_2O_2 at two dosing rates at 95°C on DAF sludge from a milk processing plant. LCFA concentrations in the untreated sample, treatment at 95°C without oxidation, treatment at 95°C with 0.05% H_2O_2 per % TS (O1), and 0.17% H_2O_2 per % TS (O_2) are shown. Reductions at oxidation rate O_2 are 41, 35, 32 and 50% for oleic acid, stearic acid, palmitic acid and myristic acid, respectively.

4 Discussion

The initial results seen to date in this project are very encouraging. There is a clear trend in LCFA reduction with increasing temperature across multiple sludge types. Reductions of up to 80% were achieved, however, the largest gains are seen in the shorter C14 fatty acid, which is in lower abundance than the longer chain C18 and C16 fatty acids. Reductions of ~60% were observed for the C18 and C16 in the butter plant DAF sludge. Oxidation with hydrogen peroxide resulted in improved LCFA reduction above what can be achieved with temperature alone. The optimal dosing rate has yet to be determined.

Variation in the results between samples has been observed with greater LCFA reductions seen in the DAF sludge from the butter producer. This may be due to differences in wastewater treatment (e.g., polymer dosing rate) or due to some other factor in the composition of these highly complex samples. This highlights the importance of testing real world samples to capture the variability found across processers.

The improvement in biomethane yield at 20°C seen in the batch degradation experiment indicates that the inhibitory effect of the LCFAs, and presumably polymer, is reduced by the microwave process. Increased SCOD in the treated feedstock almost certainly contributes to this effect as well, as soluble material is more easily digested. This data indicates that an improved biogas yield can be obtained by diverting this waste stream from disposal and pre-treating it for AD. Further experiments will indicate the longevity of this effect and contribute to the calculation of the energy balance of the process and indicate transport cost, energy and CO_2 savings that can be achieved.

5 Conclusions

The preliminary results of these trials indicate that the Biowave™ microwave pre-treatment of dairy FOG waste offers a viable solution to the breakdown of LCFAs and generation of a feedstock suitable for AD. There are multiple advantages to be gained from the process, once optimised. Instead of land spreading the DAF sludge, pre-treatment offers the opportunity to access the energy potential of the FOG material. The reduction of LCFA concentration in the treated feedstocks and enhanced biomethane production in AD experiments point to improved bioenergy yield. Reduction of CO_2 emissions from both transport and disposal makes for an important contribution to the circular economy. Financial savings in energy and disposal costs will be available to dairy processers that invest in this cutting-edge technology.

For further readings

1. A. Healy, "Dairy farmers celebrate as milk quotas abolished after 31 years," *The Irish Times*. https://www.irishtimes.com/news/ireland/irish-news/dairy-farmers-celebrate-as-milk-quotas-abolished-after-31-years-1.2160563
2. A. Rinzema, M. Boone, K. van Knippenberg, and G. Lettinga, "Bactericidal effect of long chain fatty acids in anaerobic digestion," *Water Environ. Res.*, 1994, **66(1)**, 40–49, https://doi.org/10.2175/WER.66.1.7.
3. D. Wang et al., "Understanding the impact of cationic polyacrylamide on anaerobic digestion of waste activated sludge," *Water Res.*, 2018, **130**, 281–290 https://doi.org/10.1016/j.watres.2017.12.007.
4. M. A. Pereira, O. C. Pires, M. Mota, and M. M. Alves, "Anaerobic degradation of oleic acid by suspended and granular sludge: identification of palmitic acid as a key intermediate.," *Water Sci. Technol. J. Int. Assoc. Water Pollut. Res.*, 2020, **45(10)**, 139–144, https://doi.org/10.2166/wst.2002.0311
5. E. Campos, M. Almirall, J. Mtnez-Almela, J. Palatsi, and X. Flotats, "Feasibility study of the anaerobic digestion of dewatered pig slurry by means of polyacrylamide,"

Bioresour. Technol., 2008, **99(2)**, 387–395, https://doi.org/10.1016/j.biortech.2006.12.008
6. A. Srinivasan, M. Saha, K. Caufield, O. Abida, P. H. Liao, and K. V. Lo, "Microwave-Enhanced Advanced Oxidation Treatment of Lipids and Food Wastes," *Water. Air. Soil Pollut.*, 2018, **229(7)**, 1–11, https://doi.org/10.1007/s11270-018-3894-y
7. S. Ries, A. Srinivasan, O. Abida, K. Caufield, P. H. Liao, and K. V. Lo, "Microwave enhanced advanced oxidation treatment offat, oil and grease (FOG) withorganic co-substrates," *Environ. Technol.*, 2020, 1–21, May 2020, https://doi.org/10.1080/09593330.2020.1767700

About the author

Catherine McIntyre graduated with a degree in chemistry from National University of Ireland, Galway in 2014. She then did a PhD in biogeochemistry with the Organic Geochemistry Unit at the University of Bristol (2014 – 2018). Catherine has wide research experience in environmental microbiology topics of anaerobic digestion and chemistry of soil and freshwater. She is currently the senior environmental microbiologist at Ashleigh Environmental. Prior to becoming a scientist, she also had a career in animation.

Ricky's Afterthought:

The Spread of Covid-19 in buildings#

A.C. (Ricky) Metaxas

Life Fellow St John's College Cambridge UK
Email: acm33@cam.ac.uk

#Original source:
https://www.cam.ac.uk/research/news/many-ventilation-systems-may-increase-risk-of-covid-19-exposure-study-suggests

With Covid-19 still affecting most of the European countries and indeed the whole world with lockdowns or severe restrictions on peoples' movement, I thought appropriate to reproduce the following Open Access article [1], regarding the effects of Ventilation on the indoor spread of Covid-19 by Prof. Paul Linden of the Department of Applied Mathematics and Theoretical Physics at the University of Cambridge.

Ventilation systems in many modern office buildings, which are designed to keep temperatures comfortable and increase energy efficiency, may increase the risk of exposure to the coronavirus, particularly during the coming winter, according to research published in the Journal of Fluid Mechanics.

"As winter approaches in the northern hemisphere and people start spending more time inside, understanding the role of ventilation is critical to estimating the risk of contracting the virus and helping slow its spread" -*Paul Linden*

A team from the University of Cambridge found that widely-used 'mixing ventilation' systems, which are designed to keep conditions uniform in all parts of the room, disperse airborne contaminants evenly throughout the space. These contaminants may include droplets and aerosols, potentially containing viruses.

The research has highlighted the importance of good ventilation and mask-wearing in keeping the contaminant concentration to a minimum level and mitigating the risk of transmission of SARS-CoV-2, the virus that causes COVID-19.

The evidence increasingly indicates that the virus is spread primarily through larger droplets and smaller aerosols, which are expelled when we cough, sneeze, laugh, talk or breathe. In addition, the data available so far indicates that indoor transmission is far more common than outdoor transmission, which is likely due to increased exposure times and decreased dispersion rates for droplets and aerosols.

"As winter approaches in the northern hemisphere and people start spending more time inside, understanding the role of ventilation is critical to estimating the risk of contracting the virus and helping slow its spread," said Professor Paul Linden