An Roinn Talmhaíochta,
Bia agus Mara
Department of Agriculture,
Food and the Marine

13F507 - Development of a water use and waste management framework for the dairy processing industry.

Final Report

This project was funded under the Department of Agriculture, Food and the Marine Competitive Funding Programme.

SUMMARY

The primary goal of the study was to efficiently and effectively treat wastewater of dairy processing plants using a range of innovative biological and disinfection technologies. In parallel, the efficient use of water (and resulting energy costs) within the plants and rainwater harvesting was also explored. Life cycle assessments (LCAs) were performed in order to evaluate the environmental impacts associated with manufacturing of dairy products in Ireland.

In this project, lab-scale, on site pilot-scale and desktop research have been conducted. The results of lab-scale and pilot scale IASBR systems indicate that this technology has great potential for utilisation within the dairy sector for treating dairy wastewater. The novel microbial fuel cell (MFCs) technologies developed show great commercial potential for wastewater treatment. Both IASBR and MFCs technologies treat dairy wastewater with high efficiency, low operational and capital costs. The low-pressure UV technology was proved to efficiently disinfect treated effluent and harvested rainwater, with a lower energy consumption compared to the conventional UV technology. The LCA research quantified the environmental impacts of Irish dairy products and compared the environmental impacts of Irish dairy products with other countries.

The knowledge generated in this project has contributed to PhD and Master research theses and has been published in peer-reviewed research papers. It has been disseminated to the policy makers, dairy industry, farmers, and engineering companies through national and international conferences, workshops, onsite demonstrations, and social media. The technologies demonstrated have shown great commercial potential for dairy wastewater treatment. The results obtained advise Irish dairy industry how to reduce the carbon footprints of dairy products so as to compete with other countries. Some of the research papers published have been highly cited indicating that the project has been attracted good attentions from the research community and the industry.

KEYWORDS

dairy processing, wastewater treatment, life cycle assessment.

ACRONYM	DairyWater
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Section 1 - Research Approach & Results

Start Date

01 December 2013

End Date

28 February 2019

Research Programme

Food Institutional Research Measure

TRL Scale

TRL 6: Technology demonstrated in relevant environment.

NRPE Priority area

Sustainable Food Production and Processing

Total DAFM Award

€999,595.50

Total Project Expenditure

€907,728.44

Rationale for undertaking the Research

The abolishment of milk quotas in 2015 was expected to result in a 50% increase in milk production in Ireland by 2020, which would lead to the increase in greenhouse gas emissions in the dairy industry. Customers and the market require this industry committed to environmental protection and competitive by improving resource efficiency (water and energy). This increase in the volume of milk being processed along with stringent measures on emissions from the industry and growing commercial drive for operational efficiencies is driving the need for innovative technological and operational solutions within the dairy processing industry. In this context DairyWater, a new multi-stakeholder research project, is developing innovative solutions for the efficient management of water consumption, wastewater treatment and rainwater harvesting within the country's dairy processing industry. This project has the potential to position Ireland at the forefront of European, or indeed international, research in this sector as it strives to make the Irish dairy processing industry more efficient and environmentally sustainable by reducing carbon footprints, and water use. This will, in turn, lead to greater potential for exports, increased international competitiveness for Irish products and stimulate job creation, due to the improved green image of the Irish dairy products and reduced cost in treating wastewater.

Methodology

The project was conducted through laboratory-scale, on site meso-scale and desktop research to improve resource efficiency (water and energy utilisation), and to quantify environmental impacts of the dairy processing industry.

Task 2: The intermittently aerated sequencing batch reactor (IASBR) technology was constructed in both bench scale and pilot scale for treating dairy wastewater. Its performance in wastewater treatment, in particular in nitrogen and phosphorus removals, was assessed. Its system stability was tested on site.

Task 3 is bench-scale research. Nano-Zeolite material was synthesized and assessed for removal of pollutants from diary wastewater. A novel microbial fuel cells (MFCs) technology was developed and employed to remove pollutants from wastewater and simultaneously produce electricity. The fabricated nanoparticles were used to improve the performance of MFCs.

Task 4: Low-pressure UV (LPUV) disinfection system was investigated in lab-scale and site-scale research, and the performance of LPUV and pulsed ultraviolet disinfection (PUV) system on inactivation of pathogenic bacterial strains was compared.

Task 5: Genomic DNA was extracted from the biomass samples collected from lab-scale and pilot-scale IASBR reactors. 16S rRNA, bioinformatics and statistical analyses was applied to investigate the bacteria community structure and functional gene diversity in the IASBR systems.

Task 6 was conducted as desktop research. A comprehensive life cycle assessments (LCAs) was performed in order to quantify the environmental impacts associated with the manufacturing of dairy products in Ireland, in accordance with the life cycle assessment guidelines of the International Organisation for Standardisation. Particular attention was paid to the LCA methodology for the dairy industry published by the International Dairy Federation.

Task 7: An excel-based toolkit was developed to help calculate and evaluate how rainwater could be used at a facility level and inform economic analysis of the system, and to calculate the energy costs of the IASBR system.

Project Results

The results from the bench- and pilot-scale research of the IASBR technology indicate that the technology has great potential for utilisation within the dairy sector. The IASBR wastewater treatment system reached stable operation quickly even though high variations of incoming wastewater quality and achieved removal efficiencies of above 90% for ammonium-N, phosphate, and total suspended solids. The quality of treated effluent met the EPA discharge limits and it can be discharged into surrounding water bodies. The biological system potentially offers the industry a more sustainable, cheaper, and more environmentally friendly alternative to currently used chemical treatment solutions and secondary biological process followed by chemical treatment.
The novel MFCs technologies developed successfully removed 88.1% of COD and 92.8% of TN from the dairy wastewater, while producing 4.7 ± 0.2 W/m3 of electricity. This technology has many advantages in wastewater treatment sector, such as low operational and capital costs, low sludge yields, low energy input and no chemical addition. The nanoparticles developed, nanocrystalline zeolites, as filtration and absorption materials for diary wastewater treatment had high efficiencies, but the removal of nanoparticles from the treated wastewater is a challenge. While the fabricated nanoparticles can be used to improve the performance of microbial fuel cells (MFCs) technologies.
The survey of Irish dairy processing plants show that rainwater harvesting is not considered of significant interest at this stage given current water prices. For wastewater reclamation, wastewater related regulations and potential microbiological regulations would be likely to be a challenge.
Low-pressure UV (LPUV) offers a more complete solution to disinfection of dairy processing wastewater when compared to pulsed UV (PUV). Organic SS had a negative impact on both PUV and LPUV systems' efficiency, and the PUV technology was not as effective as LPUV in targeting both general microbial contaminants in water and dairy-specific contaminants. Removal rates for PUV technology were lower and energy consumption was significantly higher. LPUV is recommended for the wastewater treatment sector.

The results of molecular ecology analysis indicate that aeration rates, low temperature and nutrient influent strength were the key drivers of change of the microbial communities in IASBR systems during the treatment of synthetic and industrial wastewater. At the aeration rate of 0.6L/min in which optimal ammonia and orthophosphate treatment performance was achieved, there was an enrichment of the family Comamonadaceae. According to the LCA for the dairy products in Ireland, the most significant contributor to the greenhouse gas emissions is raw milk production, at 84%, and processing of raw milk into milk powder accounts for 14%. The main contributor to the greenhouse gas emissions in the processing phase is direct energy use within the plant, accounting for between 91% and 98%. Energy usage and water consumption in the processing phase are of the same magnitude as that of the production phase. For milk powder and butter production, emissions associated with wastewater treatment contribute approximately 10% and 40% to the total freshwater eutrophication potential and marine eutrophication potential, respectively, for both milk powder and butter production.

Section 2 - Research Outputs

Summary of Project Findings

This project shows that IASBR technology is feasible in treating dairy wastewater, and it will benefit the engineering consultancy in the water area to design a new process for a more sustainable and cheaper alternative wastewater treatment process. The operation cost for the plants used in the industry was €1.81/m3 wastewater, while the cost for the IASBR system was €1.78/m3, and the cost of the IASBR system can be much lower after optimisation of the operation. This technology was demonstrated to the industry in the open day. Further on, the IASBR technology was developed into IASBR-anammox technology for a wider use in wastewater treatment. In addition, mathematical modelling was carried out to study the mechanisms of partial nitrification and P removal by phosphorus accumulating organisms (PAOs). The knowledge of key microbial groups associated with IASBR systems is crucial for process optimisation and stable bioreactor operation. The MFCs technology developed in this project has many advantages, such as low operational and capital costs, low sludge yields, low energy input and no chemical dose. Irish Water thinks of this technology positively. This technology is now being further funded by Enterprise Ireland's commercialisation fund. The rainwater harvesting toolkit developed in this project will help the industry and practitioners in designing rainwater harvesting systems. The characteristics of dairy wastewater and the performance of UV systems on the killing of various pathogenic microorganisms were studied in detail. The results provide the practitioners and researchers better understanding of UV technology applications in disinfection. The LCA results obtained show raw milk production has the greatest contribution to environmental impacts of dairy products, and the use of greening energy can mitigate environmental impacts of dairy products. The LCA research methodology developed can be used by the industry in the assessment of environmental impacts across the agri-food sector.

Summary of Staff Outputs

Research Output	Male	Female	Total Number
PhD Students	3	2	5
MSc Students	0	1	1
Post Doctorates	1	0	1

Summary of Academic Outputs

Research Outputs	Total Number	Details
Publications in Peer Reviewed Scientific Journals	17	Peer-reviewed journal publications are listed as follows. It is worth noting that the DairyWater research team have been invited by Journal of Dairy Research, a leading journal in the dairy area, to publish a collection of articles, which clearly implies that the DairyWater project has attracted international attentions. 1. Leonard, P., Clifford, E., Finnegan, W., Siggins, A., Zhan, X. 2021. Deployment and optimisation of a pilot-scale IASBR system for treatment of dairy processing wastewater. Energies, 14(21), 7365, 10.3390/en14217365. 2. Finnegan, W., Goggins, J., Chyzheuskaya, A., Zhan, X. M. 2017. Global warming potential associated with Irish milk powder

production. Frontiers of Environmental Science & Engineering, 11(3), 1-8.
3. Finnegan, W., Goggins, J., Clifford, E., Zhan, X. 2017. Environmental impacts of milk powder and butter manufactured in the Republic of Ireland. Science of The Total Environment, 579, 159-168.
4. Finnegan, W., Goggins, J., Clifford, E., Zhan, X. M. 2017. Global warming potential associated with dairy products in the Republic of Ireland. Journal of Cleaner Production, 163, 262-273.
5. Finnegan, W., Clifford, E., Goggins, J., O'Leary, N., Dobson, A., Rowan, N., Xiao, L. W., Miao, S., Fitzhenry, K., Leonard, P., Tarpey, E., Gil-Pulido, B., Gao, F., Zhan, X. M. 2018. DairyWater: striving for sustainability within the dairy processing industry in the Republic of Ireland. Journal of Dairy Research, 85(3), 366-374.
6. Finnegan, W., Goggins, J., Zhan, X. 2018. Assessing the environmental impact of the dairy processing industry in the Republic of Ireland. Journal of Dairy Research, 85(3), 396-399.
7. Finnegan, W., Yan, M., Holden, N. M., Goggins, J. 2018. A review of environmental life cycle assessment studies examining cheese production. International Journal of Life Cycle Assessment, 23(9), 1773-1787.
8. Fitzhenry, K., Rowan, N., Finnegan, W., Zhan, X., Clifford, E. 2018. Microbiological characterisation and impact of suspended solids on pathogen removal from wastewaters in dairy processing factories. Journal of Dairy Research, 85(3), 391-395.
9. Gil-Pulido, B., Tarpey, E., Almeida, E. L., Finnegan, W., Zhan, X.,Dobson, A. D. W., O'Leary, N. 2018. Evaluation of dairy processing wastewater biotreatment in an IASBR system: Aeration rate impacts on performance and microbial ecology. Biotechnology Reports, 19, e00263.
10. Gil-Pulido, B., Tarpey, E., Finnegan, W., Zhan, X., Dobson, A. D.,O'Leary, N. 2018. Dominance of the genus Polaromonas in the microbial ecology of an Intermittently Aerated Sequencing Batch Reactor (IASBR) treating dairy processing wastewater under varying aeration rates. Journal of Dairy Research, 85(3), 388-390.
11. Leonard, P., Finnegan, W., Barrett, M., Zhan, X. 2018. Efficient treatment of dairy processing wastewater in a pilot scale Intermittently Aerated Sequencing Batch Reactor (IASBR). Journal of Dairy Research, 85(3), 384-387.
12. Leonard, P., Tarpey, E., Finnegan, W., Zhan, X. 2018. Efficient treatment of dairy processing wastewater in a laboratory scale Intermittently Aerated Sequencing Batch Reactor (IASBR). Journal of Dairy Research, 85(3), 379-383.

		13. Fitzhenry, K., Rowan, N., del Rio, A. V., Cremillieux, A., Clifford, E.2019. Inactivation efficiency of Bacillus endospores via modified flow-through PUV treatment with comparison to conventional LPUV treatment. Journal of Water Process Engineering, 27, 67-76. 14. 14. O'Donoghue, C., Chyzheuskaya, A., Grealis, E., Kilcline, K., Finnegan, W., Goggins, J., Hynes, S., Ryan, M. 2019. Measuring GHG emissions across the agri-food sector value chain: the development of a bioeconomy input-output model. J International Journal on Food System Dynamics, 10(1), 55-85. 15. Qiu, S. K., Hu, Y. S., Liu, R., Sheng, X. L., Chen, L. J., Wu, G. X., Hu,H. Y., Zhan, X. M. 2019. Startup of partial nitritation-anammox process using intermittently aerated sequencing batch reactor: Performance and microbial community dynamics. Science of the Total Environment, 647, 1188-1198. 16. Li, D. Z., Shi, Y. H., Gao, F., Yang, L. M., Kehoe, D. K., Romeral, L., Gun'ko, Y. K., Lyons, M. G., Wang, J. J., Mullarkey, D., Shvets, I. V., Xiao, L. W. 2020. Characterising and control of ammonia emission in microbial fuel cells. Chemical Engineering Journal, 389, 124462. 17. Qiu, S., Li, Z., Hu, Y., Shi, L., Liu, R., Shi, L., Chen, L., Zhan, X. 2021. What's the best way to achieve successful mainstream partial nitritation-anammox application? Critical Reviews in Environmental Science and Technology, 51(10), 1045-1077.
PhD Theses	3	3 theses have been completed and 2 are still going on due to the employment of the two PhD students: • Beatriz Gil Pulido, Microbial ecology of Intermittently Aerated Sequencing Batch Reactors (IASBRs) for the treatment of dairy processing wastewaters • Fitzhenry, Kelly, Evaluation of modified flow-through pulsed UV technology for bacterial inactivation with comparison to a standard continuous-flow low pressure UV system • Songkai Qiu, Nitrogen removal using partial nitritation-anammox process. • It is expected that Fei Gao will submit his PhD thesis in September 2023. • It is expected that Peter Leonard will submit his PhD thesis soon but since he is working in a University of Galway's start-up right now, it is difficult to know the exact time when he can submit PhD thesis.
Masters Thesis	1	Emma Tarpey, An investigation into the use of IASBRs for treatment of dairy processing wastewater

Intellectual Property

To protect/exploit the MFCs technologies developed in this project, the research partner, Prof. Liwen Xiao from Trinity College Dublin, has been funded with an Enterprise Ireland's commercialisation fund, and is considering to set up a startup. The policy of each partner Institution will ensure that whatever opportunities that exist for the protection of knowhow arising during the course of the project will be taken.

Summary of other Project Outputs

Project Outputs	Details	Total No.
New Technology	The MFC technology was developed in this project with high removal efficiencies of COD (88.1%) and TN (92.8%) from the dairy wastewater, while producing 4.7 ± 0.2 W/m3 of electricity.	1
New Processes	This project has tested the IASBR process in bench and site pilot scale in dairy wastewater treatment. It also developed an IASBR-anammox process.	2

Potential Impact related to Policy, Practice and Other Impacts

Impact	Details
Industry	1. Technologies developed, IASBR, MFC, and LPUC can be used by the industry. 2. The LCA results help the industry to improve their manufacturing process so as to reduce the environmental impacts and improve the resource efficiency.
Environmental Sustainability	1. Technologies developed, IASBR, MFC, and LPUC provide more sustainable solutions alternative to current practices. 2. The LCA results help the industry to improve their manufacturing process so as to reduce the environmental impacts and improve the resource efficiency.
Socio-Economic	The LCA methodology developed in this project can be used for LCA analysis for the agrifood sector.

Dissemination Activities

Activity	Details
Workshops at which results were presented	The first DairyWater Workshop took place on 9th March 2016 in NUI Galway. The main themes of the workshop were microbiology of dairy wastewater treatment systems, phosphorous removal from dairy wastewater and life cycle assessment of the dairy sector. The keynote speakers are as follows: • Dr. Mingjia Yan (UCD), life cycle assessment of the Irish dairy sector • Mr. Rory Farrell (Lakeland Dairies), Water and wastewater challenges in the Irish dairy processing industry • Dr. Mark Fenelon (Teagasc), Current status and challenges within the Irish dairy processing industry • An international expert on wastewater treatment systems (phosphorus removal/recovery)
Workshops at which results were presented	The second workshop on Wastewater treatment and reuse for the Irish dairy processing industry, took place on the Friday, 4th May 2018, in Ballaghaderreen, Co. Roscommon. Environmental experts, from both the Irish dairy processing industry and Irish research institutes, presented on a number of current challenges that are facing the Irish dairy processing industry, particularly related to wastewater treatment efficiencies and water reuse. Additionally, researchers within the DairyWater project presented their research activities to date and its potential impact for industry. Later on, a panel consisting of experts from the industry and Enterprise Ireland discussed the current status and challenges of water issues for the Irish dairy water industry. At the end of the workshop, the participants visited the pilot-scale IASBR unit (Task 2) for dairy wastewater treatment and they were impressed with the performance of IASBR and the effluent quality. There were 34 attendees with representation from all major stakeholders including, Aurivo, Arrabawn, Lakeland, Dairygold, Glanbia, Wyeth Nutritionals, Ryan Hanley, EPA, Enterprise Ireland, DPTC, a number of researchers from Irish universities.
Media Events	The project was presented in the Westmeath Independent, Agriland, NUIG's university news. The project newsletters were produced and circulated to the industry and the research community.

Knowledge Transfer Activities

Identify knowledge outputs generated during this project.	1. Pilot-scale IASBR system with high efficiencies of above 90% for ammonium-N, phosphate, and total suspended solids removal, indicating that the technology has a great potential for utilisation within the dairy sector. 2. The relationship between the microbial community structure and IASBR operational parameters was studied. 3. The novel microbial full cells (MFCs) technologies developed had high removal efficiencies of COD (88.1%) and TN (92.8%) from the dairy wastewater, while producing 4.7 ± 0.2 W/m3 of electricity. 4. Low pressure UV was more efficient than pulsed UV in disinfecting treated wastewater. 5. Evaporation and drying have the most significant environmental impact in milk power manufacturing, and refrigeration uses 39% of the total electrical energy in butter manufacturing. 6. The most significant contributor to greenhouse gas emissions is raw milk production, at 84%, and the processing of raw milk into milk powder accounts for 14% of the total greenhouse gas emissions. 7. Fresh cheese has less environmental impacts than semi-hard cheeses, particularly when examining direct energy consumption.
Identify any knowledge transfer activities executed within the project.	1. DairyWater website (www.dairywater.ie) was established and used as a platform for communication during the project. 2. 17 peer-reviewed research papers have been published; some of themwere published as open access publication. 3. A special collection of research papers from DairyWater project was published in Journal of Dairy Research. 4. Results were presented in more than 10 national and international conferences. 5. Results were invited to present in international research institutes in China. 6. Two workshops were held in addition with an open day, providing a platform for the communication of the industry, academia and the policy makers. The open day demonstrated the IASBR technology to the industry. 7. 5 PhD theses and 1 research master thesis. 8. Results were demonstrated in social media, like Twitter, Facebook, Google Scholar, Research Gate, etc. 9. The project was presented in local media like West Meath Independent, Agriland; etc.
List any impacts resulting from the knowledge transferred during the project.	1. The website, workshops and the open day benefit the farmers, local industry, policy makers, and general public in understanding the technology development of wastewater treatment, water reuse and waste management for the dairy processing industry. 2. The results presented in invited seminars, research papers and conferences help transfer knowledge to wider academic and industry communities to understand the dairy processing industry in Ireland. 3. Irish Water has a very positive view of the MFC technology, which has just obtained Enterprise Ireland’s commercialisation fund.

4. The knowledge generated in this project can be leveraged to extend related research into other food processing sectors (meat industry, drinks) and to secure EU fundings.
5. The LCA research methodology developed in this task has been adopted in the assessment of the environmental impacts of other activities in the agrifood sector.

Section 3 - Leveraging, Future Strategies & Reference

Leveraging Metrics

Type of Funding	Funding €	Summary
Additional Staff	€64,000.00	A PhD student, Songkai Qiu, attended the Task 2 research.

Future Strategies

The research consortium is seeking funding and industry support to test the technologies developed in this project on a larger scale with the purpose of commercialisation. The research partners will synchronise their long-term knowledge development plans with long-tern trends in industry and research, translate the know-how obtained in the DairyWater project into new consultancy or training activities, and advance their knowledge and research capability in relevant areas. For example, the MFC technology has got Enterprise Ireland Commercialisation Grant and the partner is considering a start-up to commercialise this technology.
The research capabilities developed in this project will help the research partners to apply for funds under a number of research themes, including the development of future safe and secure food supply (sustainable water use and waste management in the food and drink industry); and efficient use of resources (water use). These research funding will be from Horizon Europe, and national funding agencies.
Development of closed loop waste treatment systems and development of low water footprint industry and urban cities shall require the future collaboration of all partners.

Project Publications

Peer-reviewed journal publications are listed as follows. It is worth noting that the DairyWater research team have been invited by Journal of Dairy Research, a leading journal in the dairy area, to publish a collection of articles, which clearly implies that the DairyWater project has attracted international attentions.

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