CAMURE-11 11th International Symposium on Catalysis in Multiphase Reactors
ISMR-10 10th International Symposium on Multifunctional Reactors
MILANO, ITALY - 21-24 March, 2021

Valorising Waste Biomass via Hydrodynamic Cavitation and Anaerobic Digestion

Sanjay Nagarajan[1] and Vivek V. Ranade[1,2]*
1 Multiphase Flows, Reactors and Intensification Group, School of Chemistry and Chemical Engineering, David Keir Building, Queen's University Belfast, Belfast, United Kingdom, BT9 5AG;
2 Bernal Institute, University of Limerick, Limerick V94T9PX, Ireland
**Corresponding author E-Mail: Professor Vivek Ranade (V.Ranade@qub.ac.uk) (Vivek.Ranade@ul.ie)*

1. Introduction

Energy and materials are crucial for maintaining decent living standards of global population. It is however essential to ensure sustainability while providing affordable energy and materials. Current global reliance on fossil sources for energy and materials is not sustainable because of its adverse impacts on climate change and public health via undesired emissions (greenhouse gases and other hazardous gaseous, liquid and solids wastes). Several steps are being taken worldwide to mitigate such adverse impacts by promoting decarbonisation and circular economy. Carbon emissions are primarily from the transportation, energy and heat production sector, particularly in EU [1]. It is therefore important to develop renewable fuels with nearly net zero carbon emissions which are suitable for these three sectors. Secondly, it is important to focus on best use of materials for promoting circular economy via waste valorisation to reduce reliance on fossil sources. Both of these objectives can be simultaneously achieved by transforming waste biomass (from agri and forest based industries) into biofuels and other useful materials.

Agri and forest industries generate significant quantities of waste biomass worldwide (~ 4 - 9 billion tons/year [2]). This waste biomass is a tremendous potential source of energy (17 – 82 EJ [2]), fertilisers and materials if appropriate transformation processes are developed. Several routes for valorising waste biomass are available which may be broadly divided into thermo-catalytic and biochemical. The best choice of valorisation pathway depends on biomass characteristics, local conditions (availability, economic, societal acceptance, etc) and technology. Considering that the waste biomass is available in rural areas, decentralised biochemical valorisation routes are generally more attractive. Biochemical valorisation routes are typically anaerobic fermentation processes and can be used to produce alcohols (bioethanol – pure culture fermentation) or biogas (using a microbial consortia). Biogas production via anaerobic digestion (AD) has many significant potential advantages such as robust process capable of handling multiple and wet waste biomass, possibility of recovering fertilisers and soil conditioner which may be recycled to agri – forest industries and cleaner fuel for all the three target sectors: transportation, electricity and domestic/industrial heating. This work reviews waste valorisation via AD (see Fig. 1).

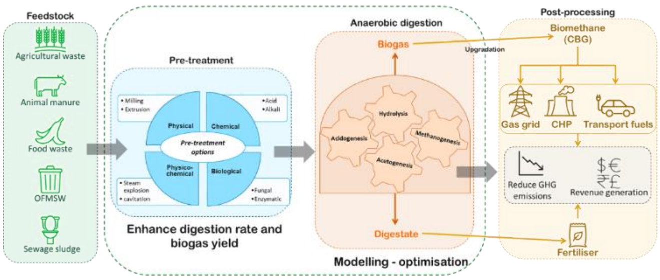

Fig. 1. An overview of AD based valorisation of biomass

AD involves a consortium of anaerobic microorganisms that work in synergy to breakdown biomass to biogas. A number of parameters such as pH, operating temperature, mixing, nutrients, solid loading, retention time, etc can influence the digestion process [3]. The complex structure of lignocellulosic biomass hinders digestion rate. It is therefore essential to develop appropriate pre-treatment of biomass. Several pre-treatments are available, however, based on the critical analysis of cost to benefit ratio, hydrodynamic cavitation (HC) appears to be the most techno-economically attractive method. In this work, we discuss recent developments on HC based pre-treatment for enhancing productivity of AD for valorising waste biomass.

2. Hydrodynamic Cavitation for Intensifying Anaerobic Digestion

HC is the phenomenon of formation, growth, and rapid collapse of vaporous cavities in a flowing fluid due to the reduced local pressure. The collapsing cavities generate extreme local temperature and pressure, breakdown water molecules to form reactive radicals and produce intense shear. While the reactive radical species partially hydrolyse the biomass, the shear generated during collapse breaks down the biomass physically lowering the particle size and modifying the surface morphology. HC can be realised using linear flow (orifice or venturi) or swirl flow devices (rotor-stator or vortex based devices). Amongst the available devices, the vortex based devices offer distinct advantages over other devices such as no moving parts, less device erosion due to the cavities collapsing in the core of the flowing liquid, earlier cavitation inception, lower energy consumption, not prone to clogging and ability to handle fibrous biomass slurries. Vortex based HC has shown to enhance biogas generation (Fig. 2) from a variety of biomasses such as grass silage and sugarcane bagasse with a net positive energy gain [3].

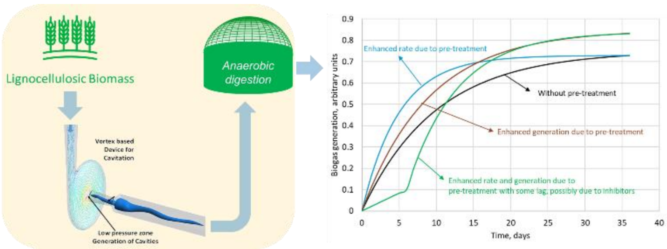

Fig. 2. HC pre-treatment of biomass for enhanced biogas production

While the influence of device design and operating parameters of the vortex based HC device are fairly understood for wastewater treatment systems, its optimisation relative to biomass pre-treatment is largely unexplored. This gap can be closed using appropriate modelling tools. For instance, computational fluid dynamics (CFD) based simulation tools can be used to optimise device designs for enhancing the pre-treatment efficiency. Secondly to optimising device design, models to describe the kinetics of biogas generation are required to understand the digestion process. The currently available models can be classified as (i) simple empirical first order models and (ii) complex comprehensive reaction engineering models (ADM1). While the empirical approach can describe batch biogas production, complex models are required to simulate large scale performance and facilitate scale up. The problem however, with such complex models are the requirement of a large number of input parameters that are often unavailable and assumed. To overcome this issue, intermediate models that are simple to implement like first models requiring minimal input parameters without compromising the accuracy of the complex models are required. Recent development of such models for AD are presented in this work. The need to link the pre-treatment performance to biogas generation via multi-layer models which is hardly addressed in current AD literature is highlighted.

Biomass pre-treatment maximises substrate conversion, enhances biogas production rate and yield. Although an increase in substrate conversion is observed, conversion of biomass in AD is still modest (at the most 70%). Therefore, the resultant digestate is often rich in fibres (predominantly cellulose and lignin). HC based pre-treatment can be used to unlock the valorisation potential of digestate. An AD based bio-refinery approach which uses HC based intensification to valorise biomass and primary digestate looks quite promising [4].

3. Conclusion and Outlook

AD by virtue operates in a circular economy framework and has a potential to make substantial contributions to decarbonisation goals. HC, especially vortex HC based pre-treatment can be harnessed for intensifying and enhancing performance of AD. Computational models discussed in this work allow optimisation of HC devices as well as AD design, operation and scale up. The approach, models and results discussed in this work will be useful to realise effective valorisation of waste biomass and achieve ambitious goals of decarbonisation.

References

[1] International Energy Agency, Data and statistics, 2021.
[2] World Bioenergy Association, Global Bioenergy Statistics, 2019.
[3] P. Bajpai, Process Parameters Affecting Anaerobic Digestion, in: P. Bajpai (Ed.) Anaerobic Technology in Pulp and Paper Industry, Springer Singapore, Singapore, 2017, pp. 13-27.
[3] S. Nagarajan, V.V. Ranade, Ind. Eng. Chem. Res. 58 (2019) 15975-15988.
[4] K.S. Konde, S. Nagarajan, V. Kumar, S.V. Patil, V.V. Ranade, Sustainable Energy & Fuels 5 (2021) 52-78.