The University Of Sheffield.

Chemical & Biological Engineering

PERLEMAX

c1net BIV and POC:
(1) Intensifying Fermenters : The microbubble way!
(2) Evaluation of fluidic oscillation for a loop reactor

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C1net gas fermentation

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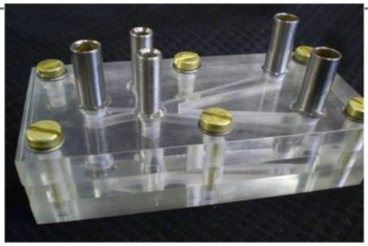
Fluidic oscillator makes microbubbles!



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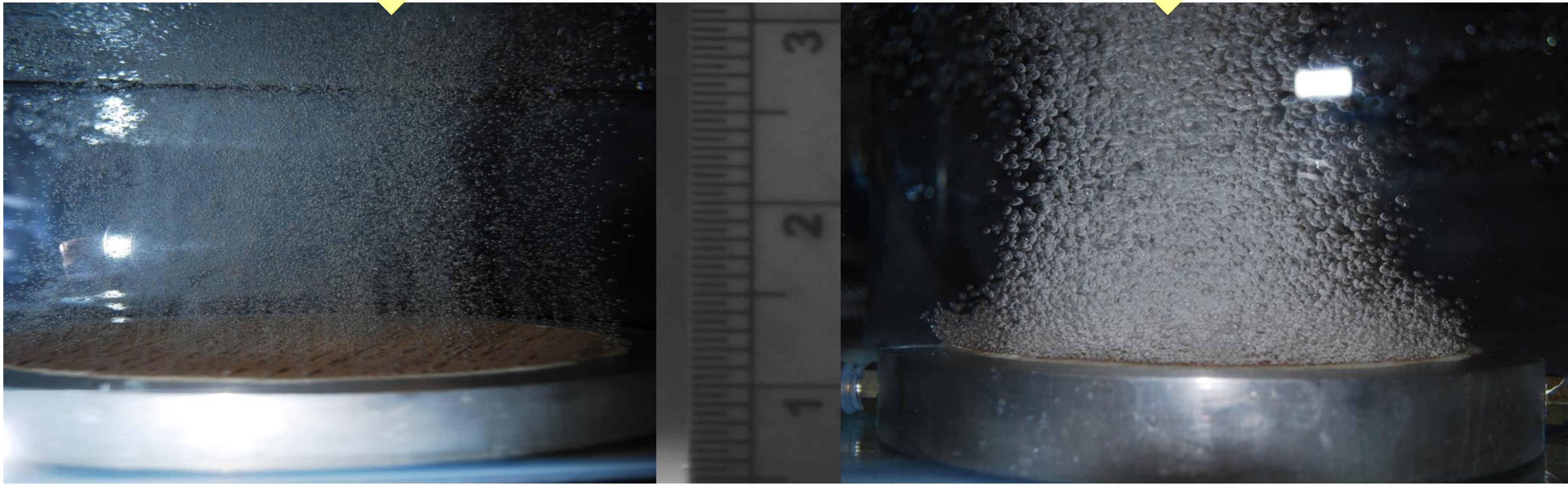
Same Diffuser



- 20 micron sized bubbles from 20 micron sized pores
- Rise / injection rates of 10^{-4} to 10^{-1} m/s *without coalescence*: uniform spacing/size

C1net gas fermentation

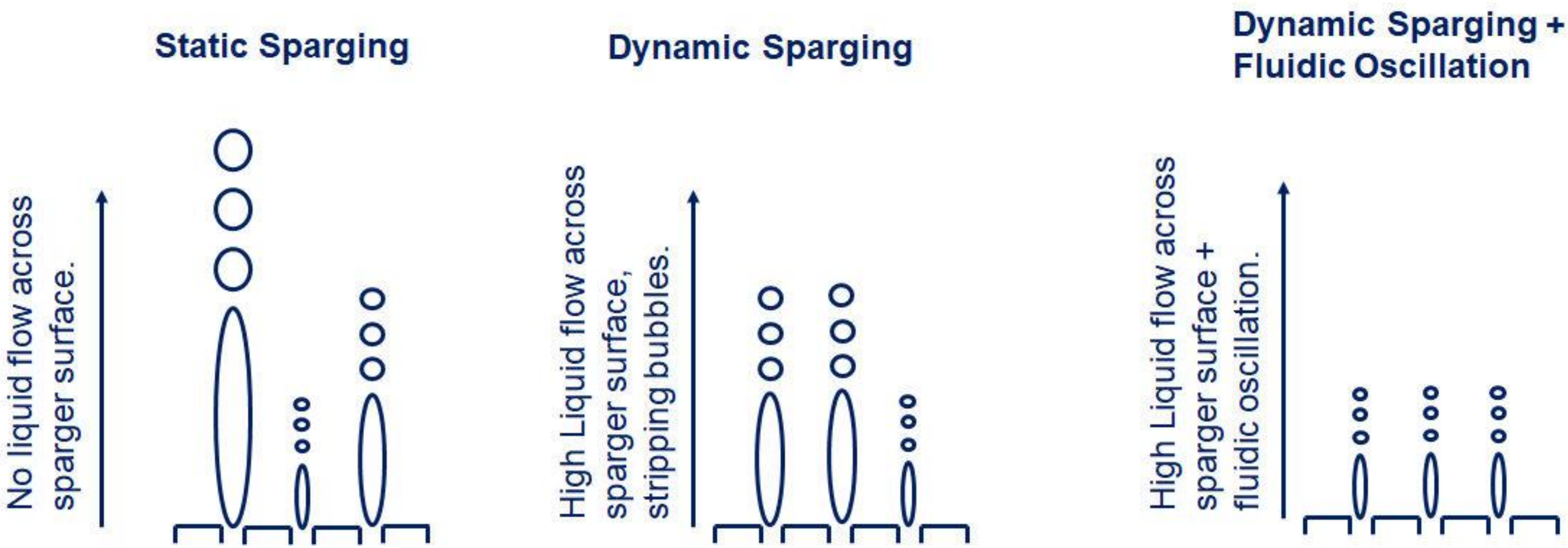
Goals

(1) POC Develop a *novel loop reactor* for gas fermentation that incorporates both fluidic oscillator generated microbubbles and can be conventionally sterilized. Microbubbles are a “retrofit”. The flow loop, however, makes “dynamic sparging” possible.

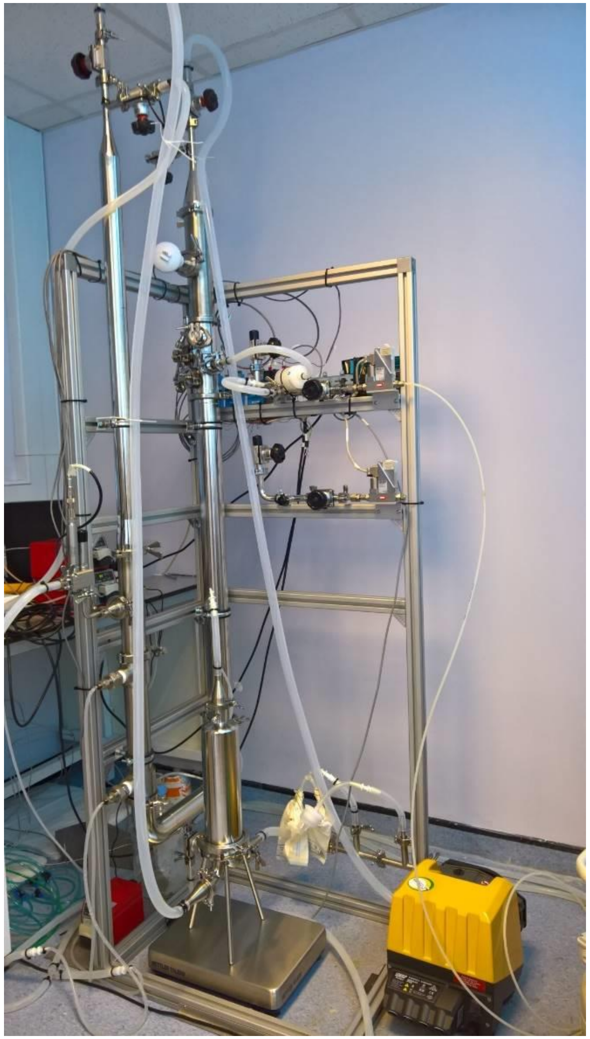
(2) BIV Develop of purpose built microbubble fermenter (DZ Fermenter) that could be used for gas fermentation with bespoke design of the sparger-oscillator fluidic circuit. Microbubbles are integrated.

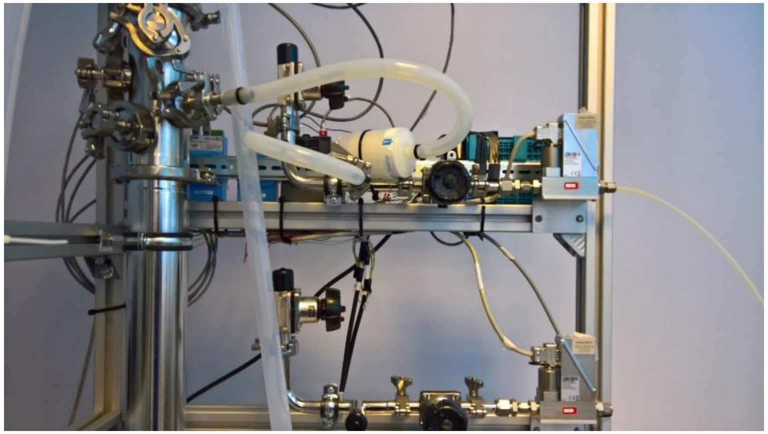
Gives the potential for new downstream processing opportunities including – flotation separation and *in situ* product removal

Sparging modes – testable by loop reactor



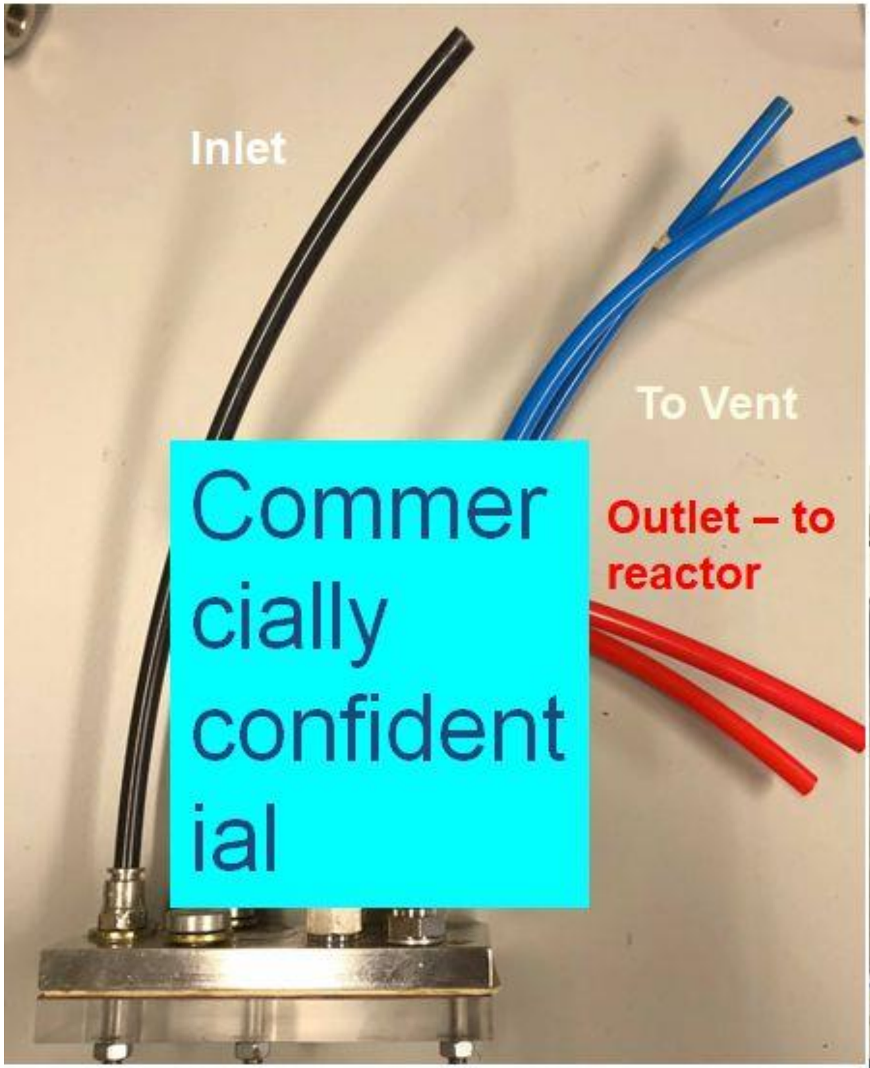
Loop reactor





Preliminary work showed that with standard “candles” for diffusers used with conventional gas fermenters, oscillation showed no improvement over dynamic sparging alone.

DZ Fermenter: oscillator integrated design



Shown without control systems or heating

Key Features

- Specifically Designed Desai-Zimmerman Fluidic Oscillator for this fermenter.
- Spargers designed for oscillatory flow (proprietary Perlemax technology – can be in line disinfected with high chemical and temperature resistance and autoclaved as well. They have a low pressure drop (40-100mbar)).

Bubble Size Characterisation

- Via Acoustic Bubble Spectrometry
- Pioneered by Chahine and Prosperetti – based on Lord Rayleigh's observation that bubbles resonate when insonated at specific frequencies
- Sixth power of the radius
- Desai has made significant advances on this method including designing an own system and first one to demonstrate it industrially in a WWTP
- Bubbles can be heard but cannot necessarily be seen
- Desai *et al.*, 2019 – Cloud bubble visualisation

Mass Transfer Rates

- Mass transfer rates were dramatically increased as opposed to the control with mass transfer mediated by the DZFO coupled to the designed sparger approximately 3 orders of magnitude and 10% of the flowrate achieved

- A much higher mass transfer would be achieved if used at the recommended flow rate but required the use of additives as interfacial stability is increased by microbubble smallness and this results in much larger gas-liquid interfacial area than typical reactors. This leads to enhanced capabilities and will be the focus of next stage R&D.

Mixing in Fermenters

- A known drawback in many fermenters

- A high level of mixedness was observed here with almost 100% homogeneity for both DZFO coupled to the sparger and the sparger by itself. This is due to the design of the fermenter and the small sizes of the microbubbles.

  See Al-Mashhadani, Wilkinson and Zimmerman (2015) ChemEngSci.

Strains

- Effect on Methanotrophic consortia (provided by Viridor) - Significant increase in growth observed (80- 400%)
- Strains included *methylococcus* amongst others (so can be targeted later for fish feed and biomass growth)
- Metabolites were removed from the system easily
- The Control experiment was performed in a typical fermenter with pumping to replicate good mixing – the DZ Fermenter is much more inexpensive
- Air/Methane/CO2 mixtures were used as Oxygen was difficult to get permission for
- Therefore relative results are considered as a preliminary finding and a more detailed set of experiments are required to be conducted in order to better quantify this effect

Downstream Separations

The biomass can be separated in the DZ Fermenter and unoptimised removal recoveries of 95% have been achievable in 10 minutes of processing time.

The typical cycle for dissolved air flotation – a much more power consumptive conventional process – is ~24 minutes for the three separate stages of dosing with flocculant and coagulant, flocculation, and flotation separation, with the same levels of recovery.

Future Work

- Specific Strain growth approach with detailed studies
- Studying mechanisms, flux imbalances , and changes to the metabolism due to the change in growth and removal of metabolites
- Focus on the control parameters for downstream processing routes
- Compare loop reactor approach as benchmark for dynamic sparging gas fermentation with the DZ integrated microbubble design approach