Intensification of gas-liquid mass transfer using porous impellers for application to an *E.coli* batch fermentation process

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PIN Meeting, 16th Nov 2006

Outline

- Background
  - Conventional bioreactor technologies
  - Fundamentals of oxygen transfer to micro-organisms
- Experimental work: Intensification of oxygen transfer using porous impellers
  - Mass transfer performance in air-liquid systems
    - Bubble size distribution
  - *E.coli* fermentation experiments
- Conclusions and on-going work

Conventional fermentation reactor technology

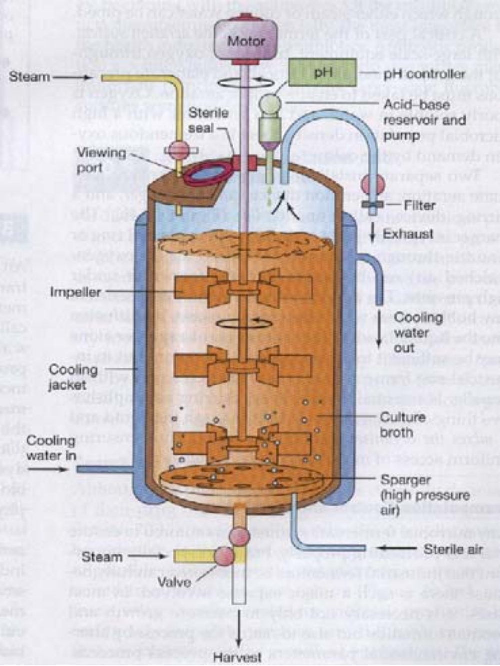
Mechanically stirred tank reactors with Rushton turbine agitators

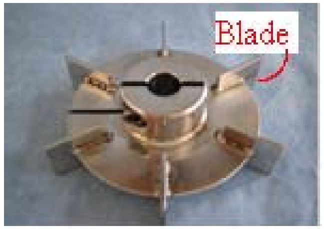
- Highly flexible
- Gives adequate oxygen transfer to cells in water-like medium

BUT

Poor mass transfer performance in applications involving:

- High cell density cultures which require large oxygen transfer rates to support respiring cells
- Highly viscous broths where turbulence and hence high mass transfer rates are difficult to achieve





6-blade Rushton Turbine impeller

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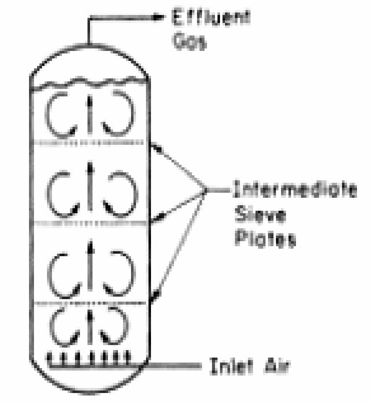
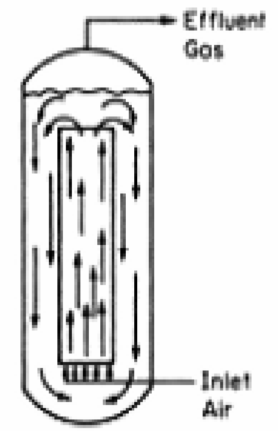
Conventional fermentation reactor technology

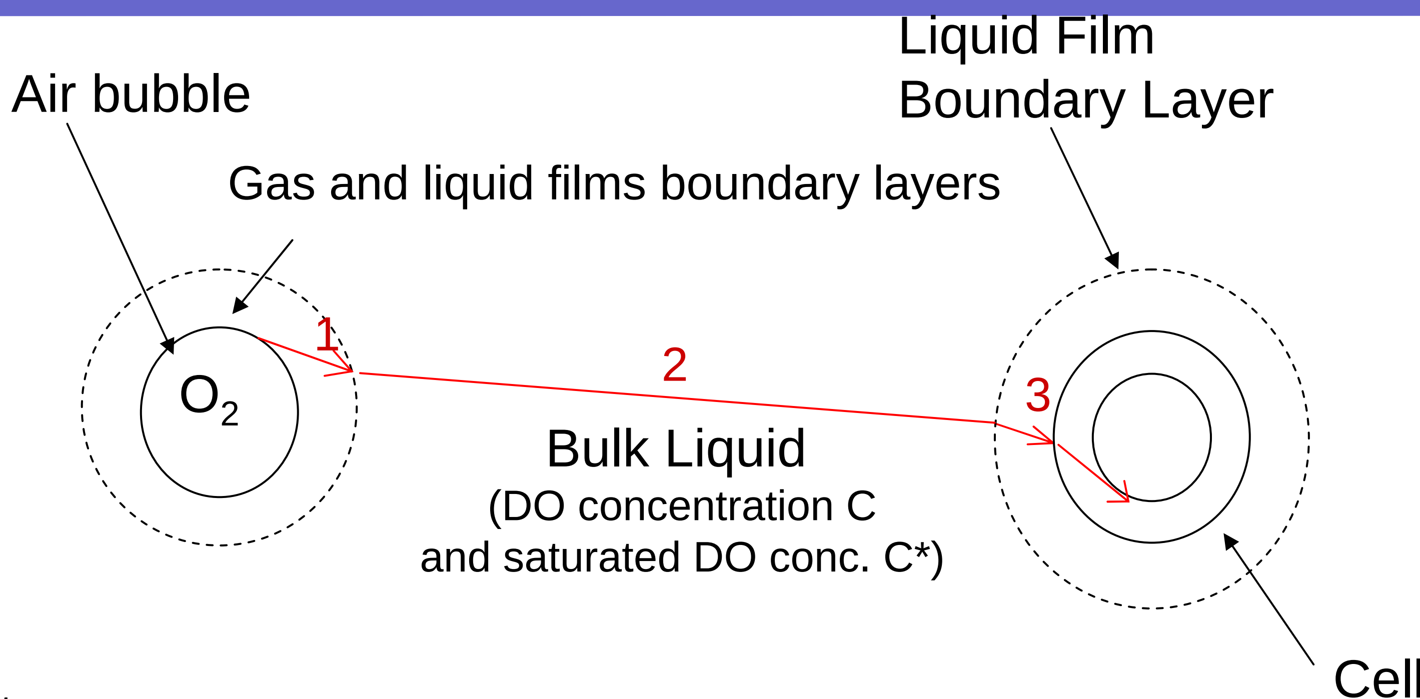
- Bubble column reactors
  - Mixing is by aeration- lower oxygen transfer rates than STRs
  - Low shear environment
  - Used for shear sensitive systems e.g mammalian and plant cells



- Air lift reactors
  - Improved version of bubble column
  - Draft tube gives better circulation of fluid and mixing than bubble column
  - Can give high mass transfer at relatively low power consumption



Oxygen transfer to microbial cells



3 step process:

1. Mass transfer from air bubble to bulk liquid
2. Transfer across bulk liquid
3. Transfer across liquid film boundary and cell wall to cell

Gas-liquid mass transfer rate:

$$\frac{dC}{dt} = K_L a (C^* - C)$$

How can gas-liquid mass transfer be enhanced?

Mass transfer of oxygen into liquid medium can be enhanced by:

- high turbulence for a thin liquid film boundary layer at the gas-liquid interface (i.e increasing K_L)
- small bubble size giving increased surface area to volume ratio (i.e increasing ‘a’)
- increased concentration of oxygen (e.g using pure oxygen instead of air)

Highly porous mesh impellers

Declon Mesh (i2)

Compact fibre mesh (i3)

Knitted stainless steel wire mesh (i4)

- Filaments in mesh structures act as slicing devices to produce small bubbles

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Objective

- Mass transfer studies
  - Tests with porous mesh impellers to intensify oxygen transfer especially in viscous liquid medium
  - Comparison of performance with that achieved using Rushton turbine impellers
- Preliminary fermentation studies
  - Apply porous impeller systems to *E.coli* fermentation process and evaluate effect on cell growth

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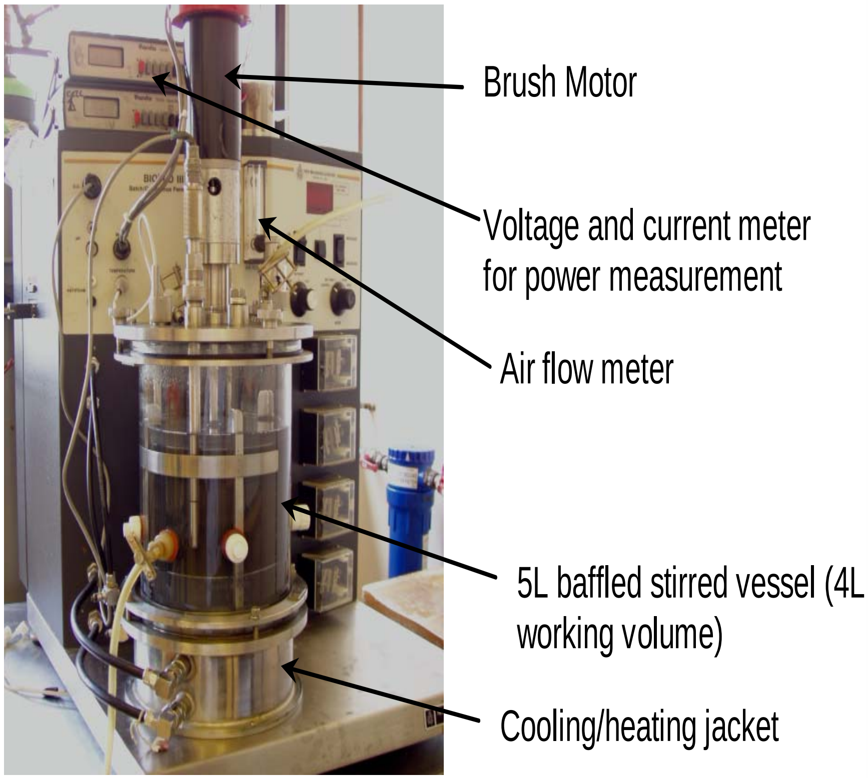
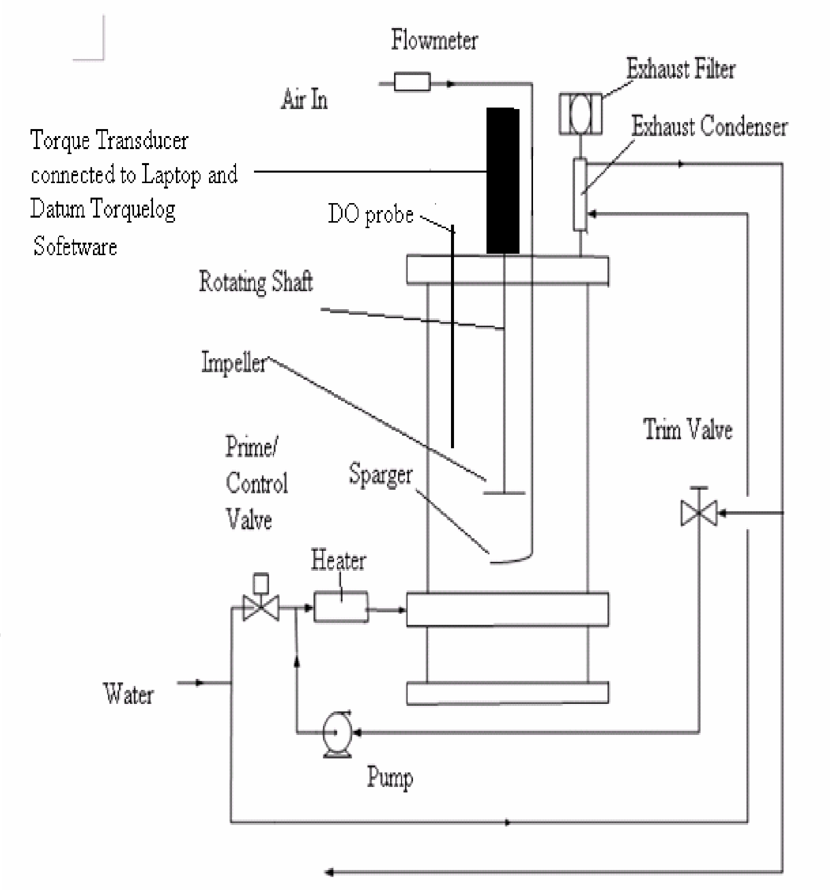
Mass transfer experiments: Apparatus



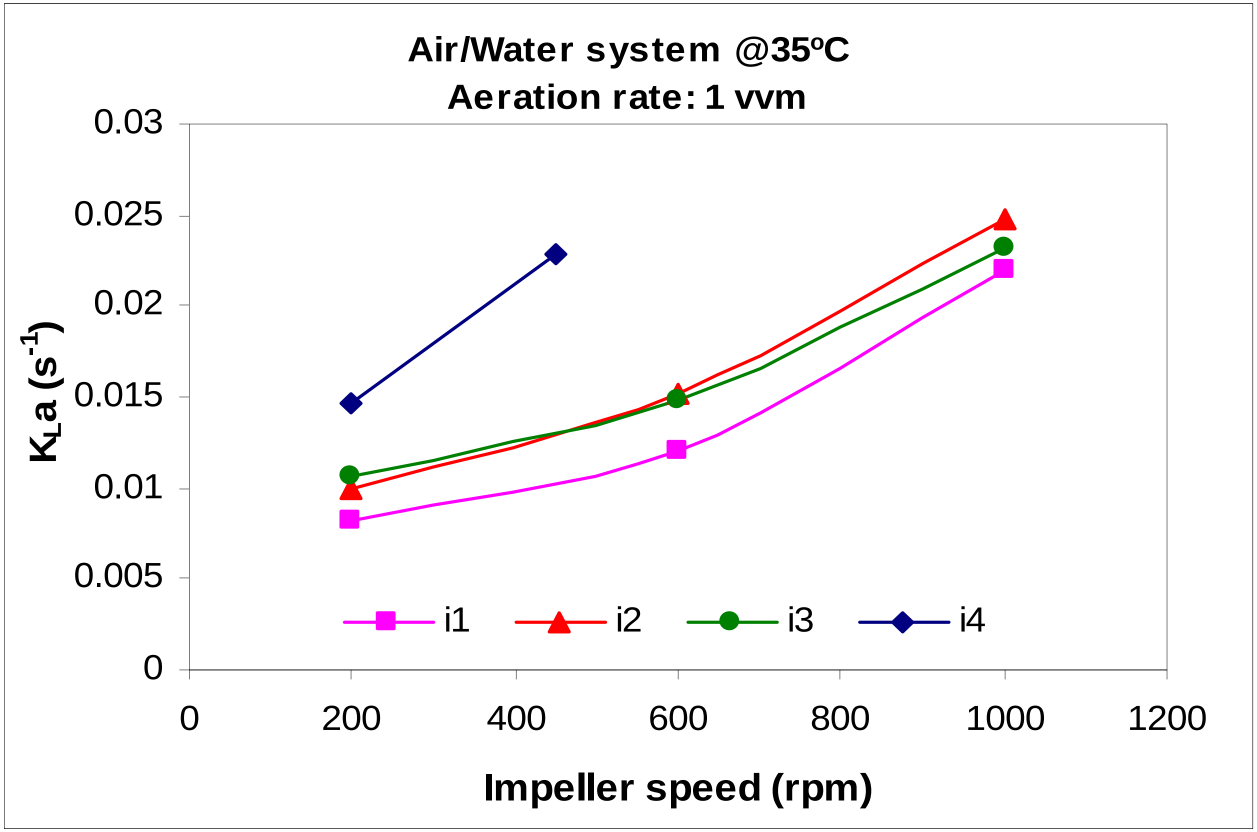
BioFlo III module



Mass transfer experiments: operating conditions

- Range of conditions studied:
  - Impeller types: i1, i2, i3, i4
  - Aeration rates:0.3-1.25 vvm
  - Agitator speeds: 200-1000 rpm
  - Liquid systems: pure water, 75:25, 50:50, 25:75 (%v/v water:glycerol mix)
- K_La determined by unsteady state gassing out method using a polarographic DO probe to measure DO concentration in liquid medium with time
- Power measured using voltmeter and ammeter- later verified with a more accurate torque meter

Impeller mass transfer performance in air/water system



- Higher K_La for porous impellers than Rushton turbine at all agitation rates
- Knitted wire mesh gives best mass transfer performance

i1: Double Rushton turbine (60 cm diameter, 6 blades)
i2: Declon mesh (120 mm diam, 100 mm length)
i3: Compact fibre mesh (115 mm diam, 100 mm length)
i4: Knitted wire mesh (105 mm diam, 40 mm length)

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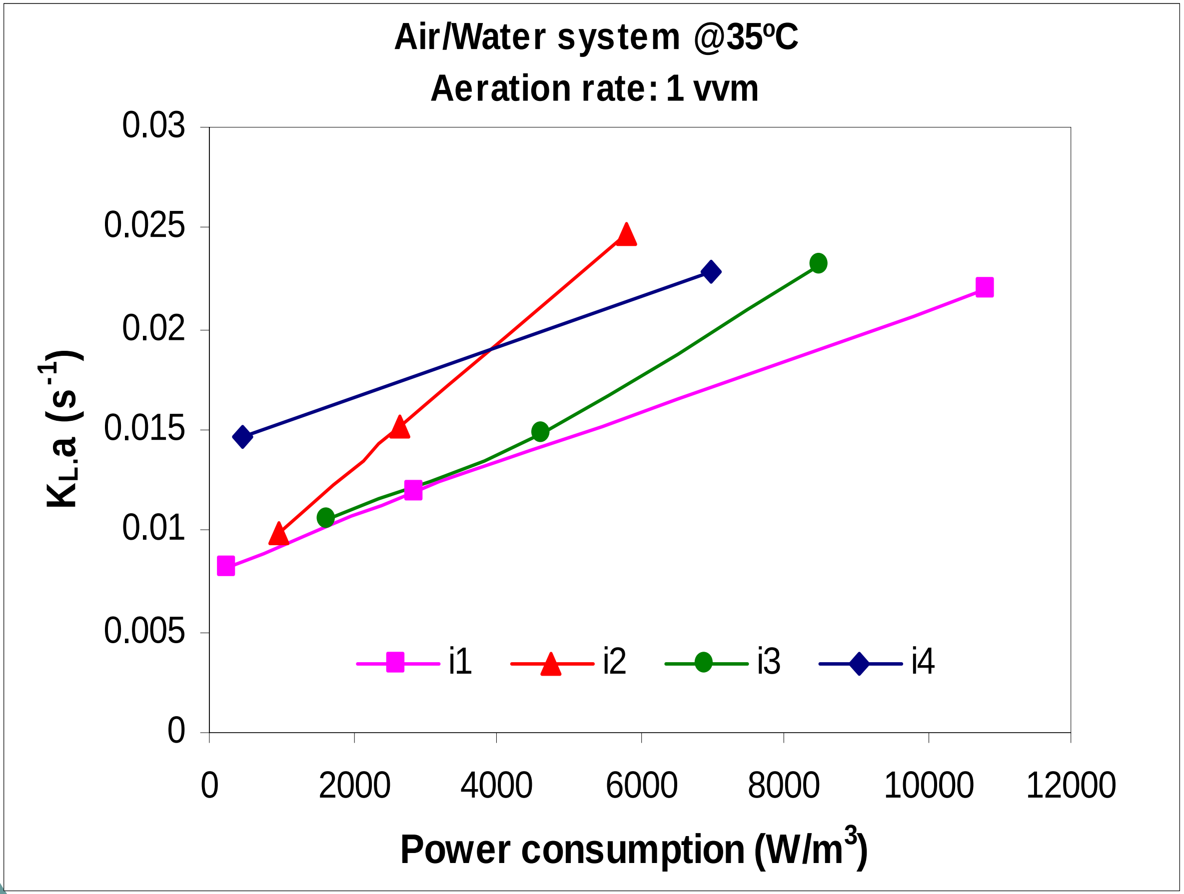
Mass transfer performance and power input in air/water system



- At any given power input, the porous impellers gives higher K_La than the Rushton turbine, demonstrating a process intensification characteristic
- Power input used efficiently to increase mass transfer in porous structures, rather than being dissipated in vortex formation in Rushton turbine

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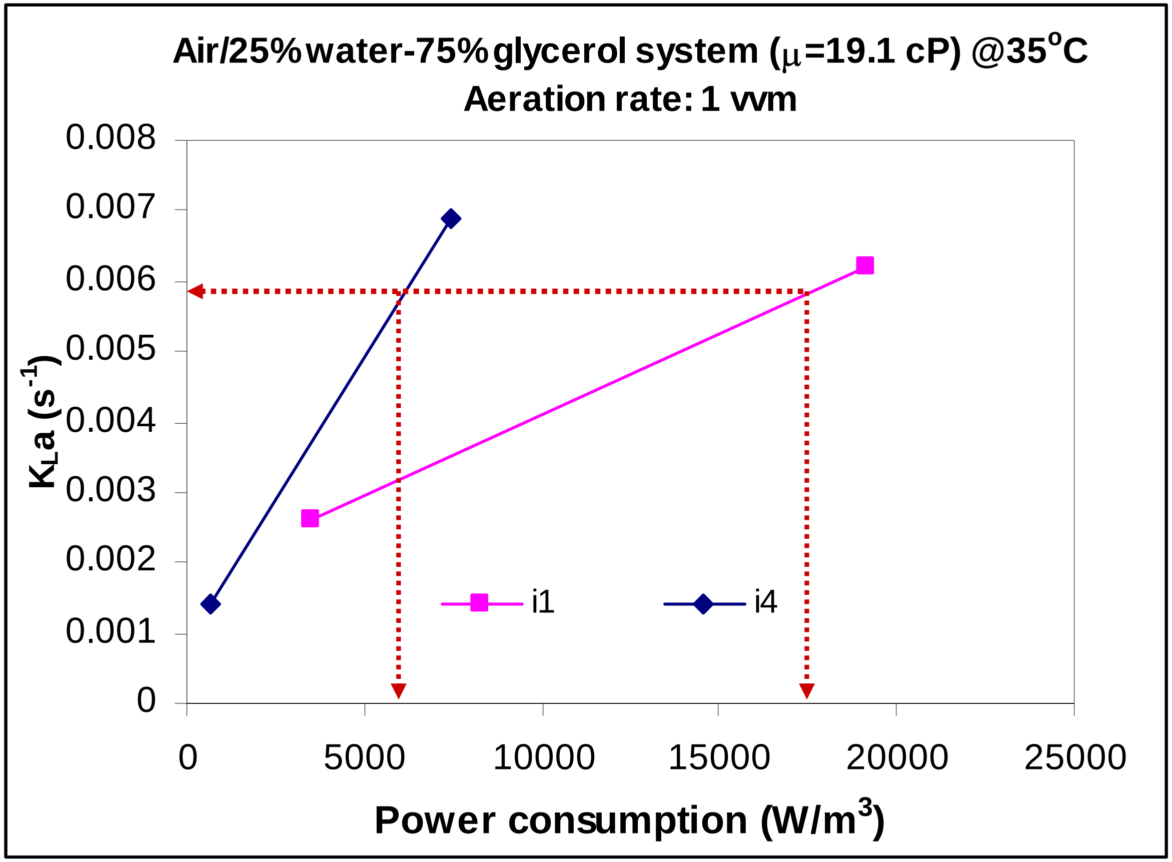
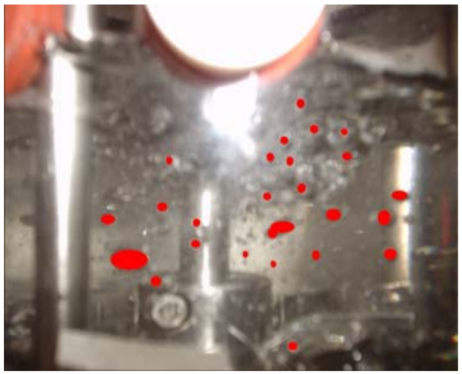
Mass transfer performance and power input in air/viscous liquid system



Rushton turbine (i1) draws significantly more power (about 3 times more for higher K_La) at the higher viscosities to achieve similar mass transfer performance levels when compared to the knitted wire mesh impeller (i4)

Measurement of bubble size distribution

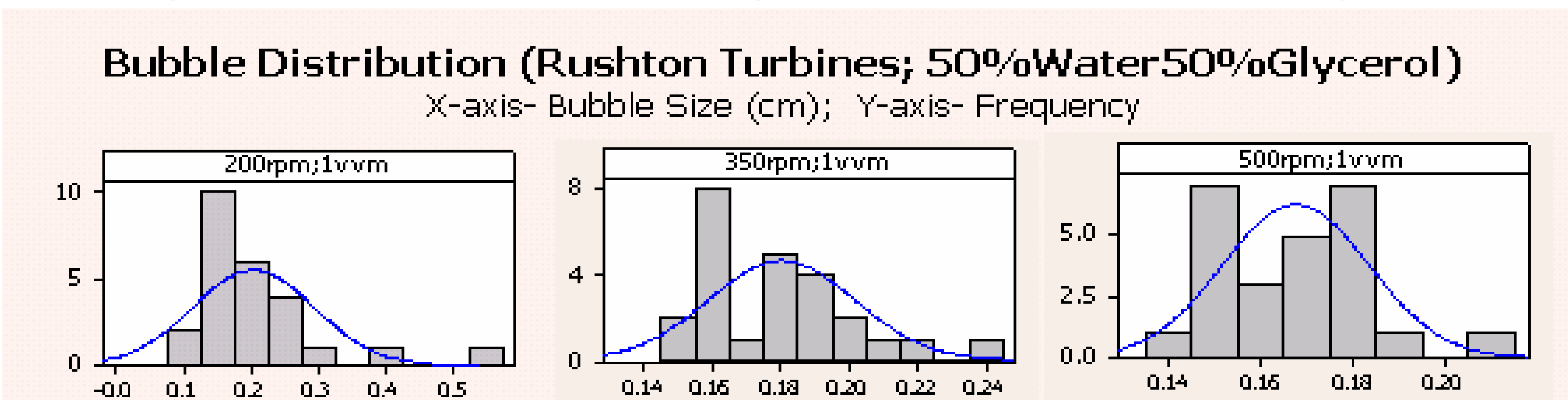
Rushton turbines; Air-50%Water50%Glycerol system



200rpm; 1vvm

350rpm; 1vvm

500rpm; 1vvm



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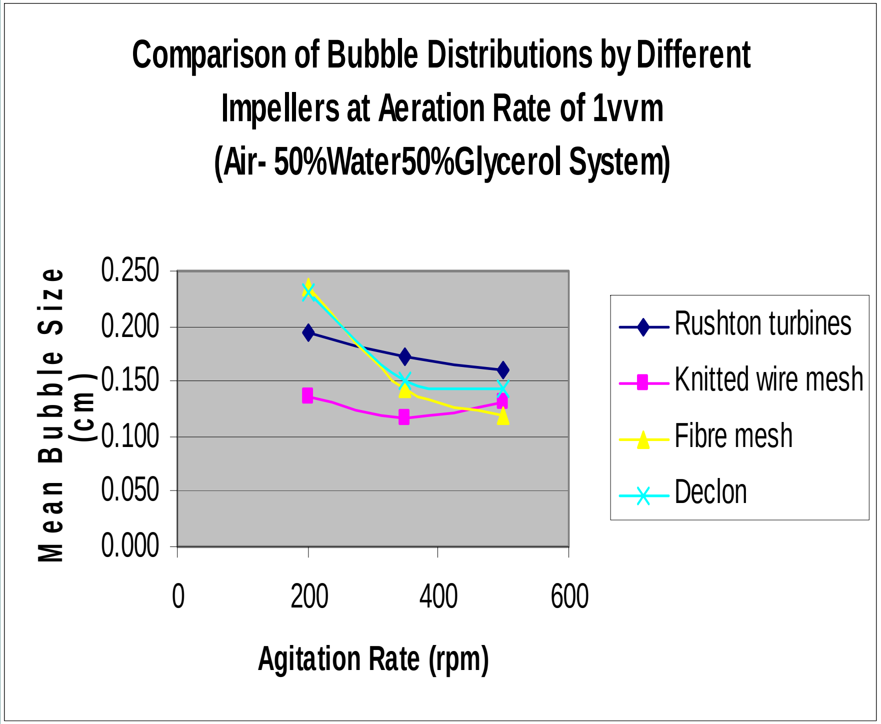
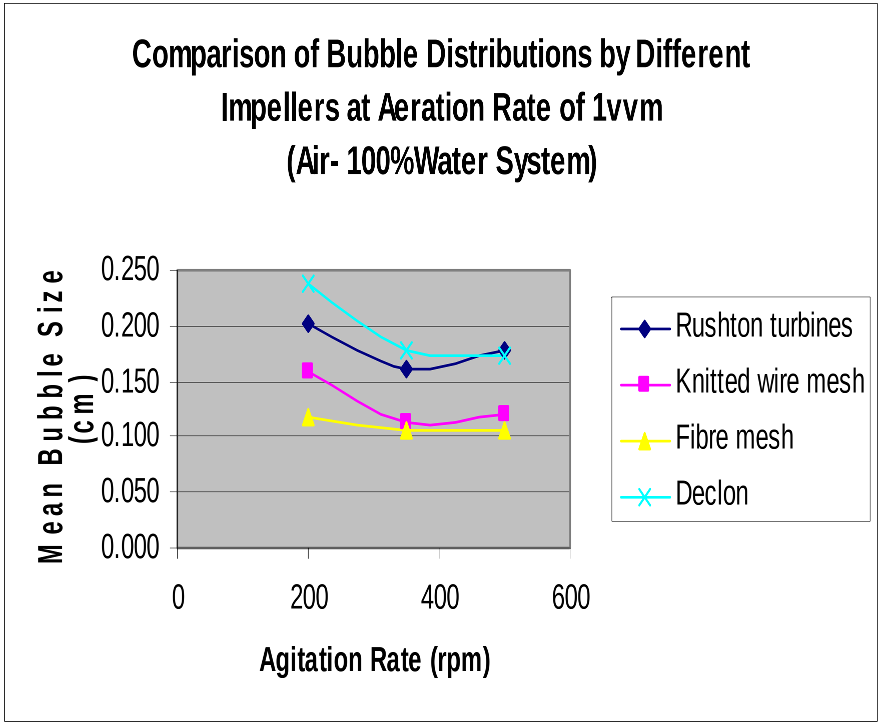
Effect of impeller type on mean bubble size





Smallest bubbles generated with:

- *Knitted Wire Mesh impeller* in Air-50%Water/50%glycerol system
- *Fibre Mesh impeller* in Air-100%Water system.

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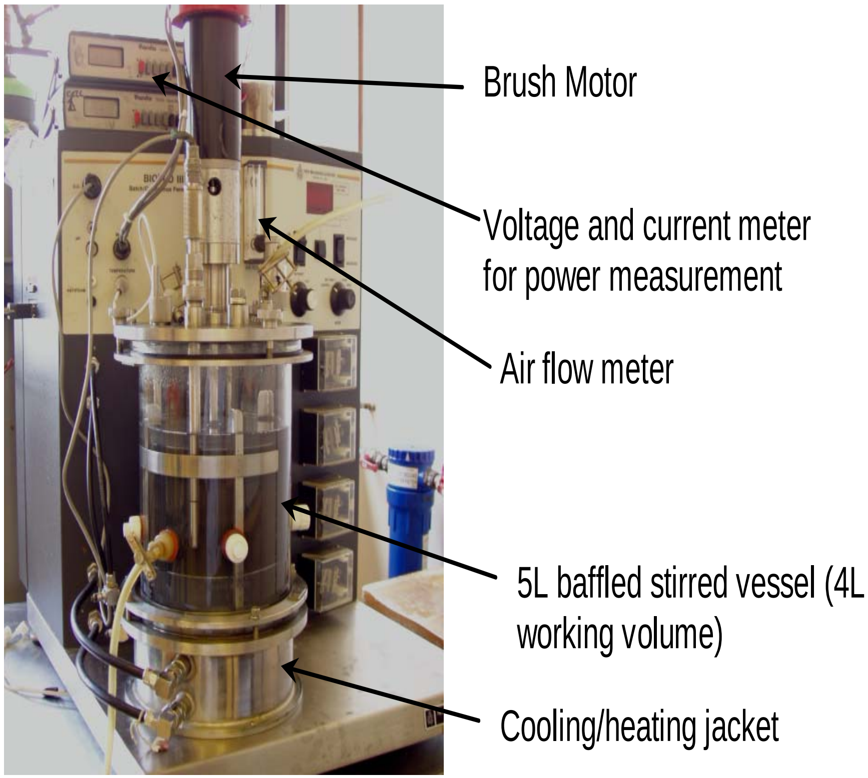
E.Coli fermentation: apparatus and conditions



BioFlo III module

- Range of conditions studied:
  - Impeller types: Rushton turbine and Knitted Wire Mesh
  - Aeration rates:1vvm and 1.25 vvm
  - Agitator speeds: 200, 300, 400 rpm
  - Operating temperature: 35^{o}C
- Fermentation broth constituents:
  - Distilled water; 20 g/l glucose; 5 g/l yeast extract; 3 g/L KH2PO4 3.0; 6 g/l Na_2HPO_4; 0.5 g/l NaCl; 2.0 g/l Casein Hydrolysate and 10 g/l $(NH_4)_2SO_4$
- Measured variables:
  - Oxygen uptake rate ($X \cdot q_{O_2}$) and K_La measured by dynamic method of gassing out
  - Cell concentration estimated at various time intervals by optical density measurements using a UV-Vis Spectrophotometer (570 nm wavelength)

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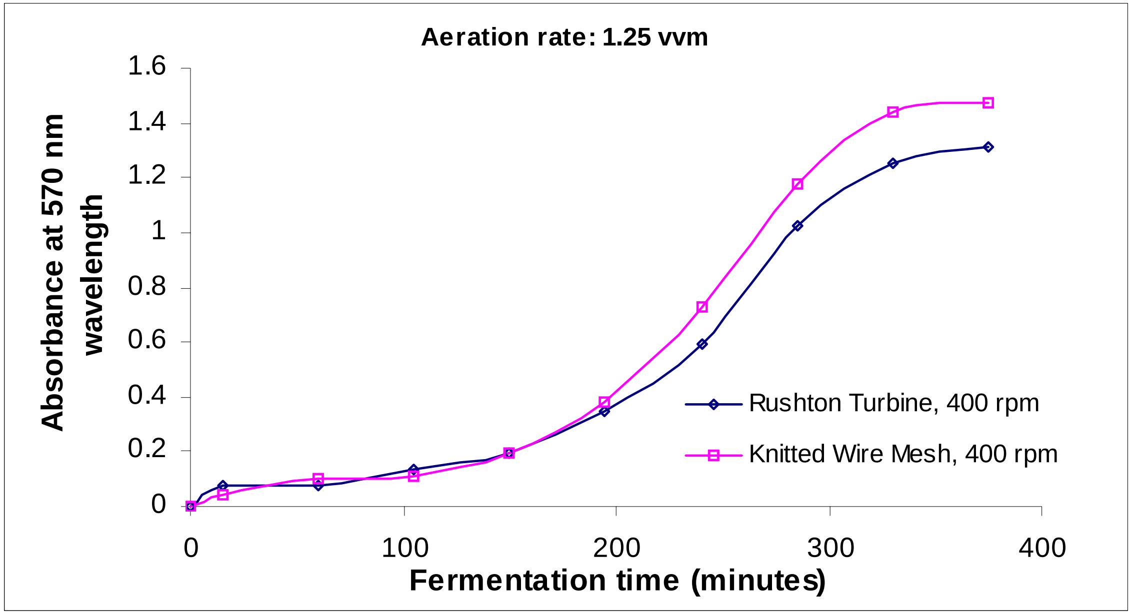
Application of porous impellers to E.coli fermentation



Impeller type	Agitation rate (rpm)	OUR (%/s)	K_La (s^{-1})
Rushton Turbine	200	0.0226	0.00171
	400	0.0351	0.00848
Knitted wire mesh	200	0.0254	0.0053
	400	0.063	0.0236

Summary of results

- Enhanced volumetric mass transfer coefficients K_La obtained with porous impellers in comparison with the Rushton turbine in all liquid systems investigated
  - Smaller bubbles are generally observed with the porous impellers
- The porous impellers give higher mass transfer to power consumption ratio than Rushton turbine impellers, indicating their potential for process intensification.
- Knitted wire mesh gives higher growth rate in E.coli fermentation due to its higher mass transfer capability

Future work

- Study effect of mechanical shear on cells using porous impellers
  - Viable cell count

- Design and fabrication of a centrifugal field bioreactor packed with porous structures, which is expected to have the following processing advantages:
  - Further enhancement of gas/liquid, liquid/liquid, liquid/solid mass transfer in centrifugal field
  - High density cell culture for high productivity in fermentation applications
  - Integrated reaction/separation system using immobilised cells

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Acknowledgements

- Yoke Ling Lee
- Ellen Toogood
- Puneet Puri
- Teresa Ndlovu
- Craig Cartwright (PhD student)

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