Unleashing Process Potential

Through Rapid Heat and Mass Transfer

Dr John Burns

Protensive Ltd, Bioscience Centre, International Centre for Life,

Newcastle upon Tyne, NE1 4EP, U.K.

(www.protensive.co.uk)

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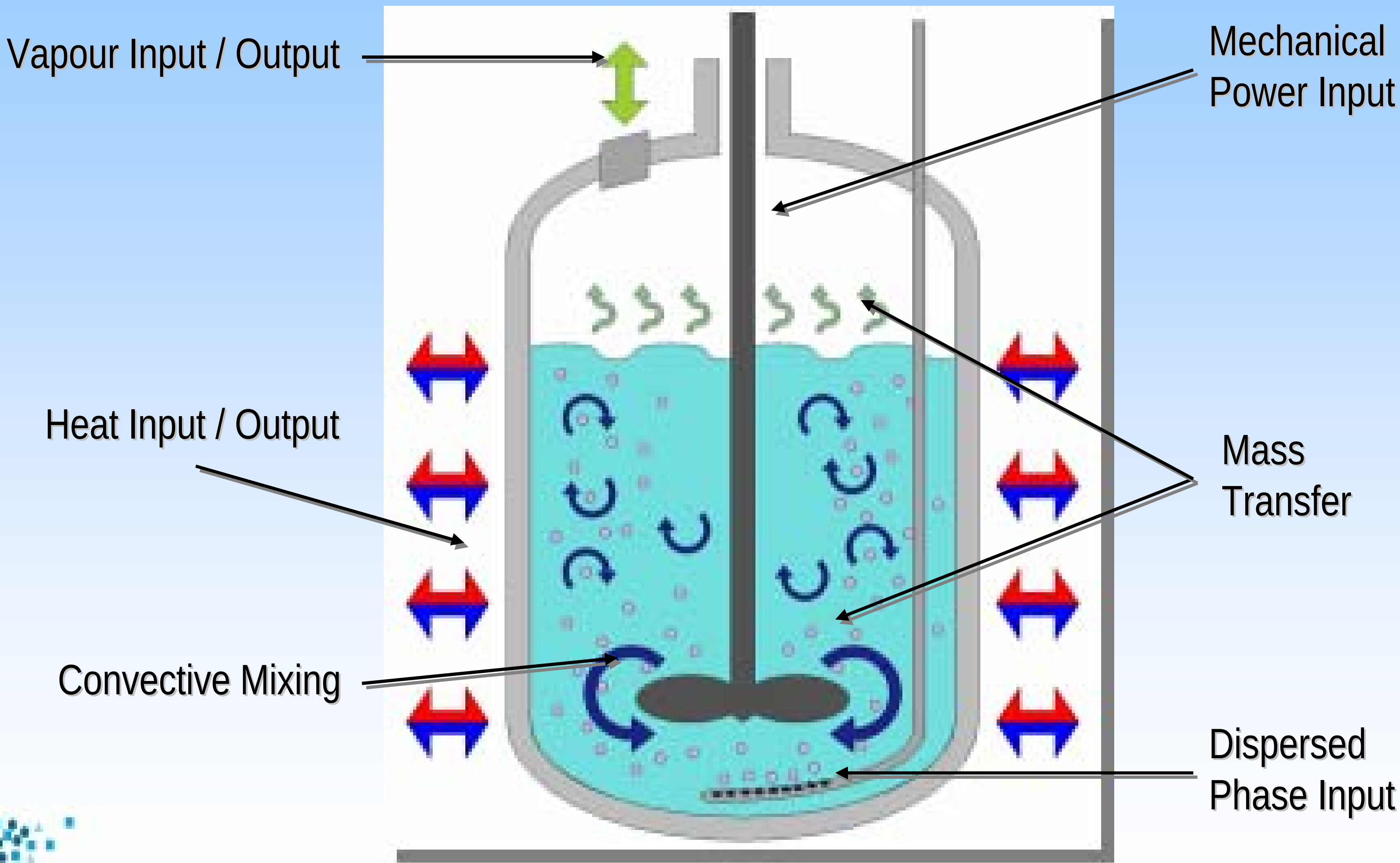
Back to Basics

What are the Limitations of Conventional Processing?

The Batch Reactor



Processing Limitations

Heat Transfer

- Speed at which temperature can be changed.
- Ability to remove or supply heat to exothermic / endothermic processes.

Mass Transfer

- Rate of moving molecules between fluid phases.
- Rate of moving molecules to active catalyst sites.

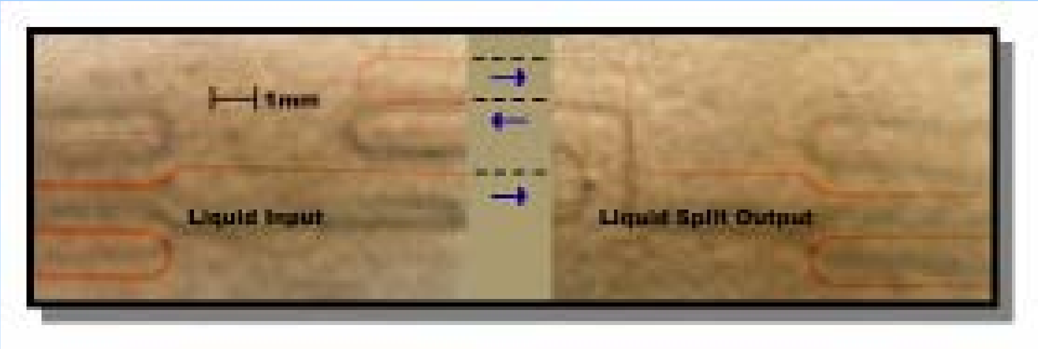
Mixing

- Ability to maintain even concentration distribution.

Scale - Up

- Ability to maintain processing conditions during scale-up.

Pushing Back the Limitations with Intensified Equipment



Microreactor

Spinning Disc Reactor

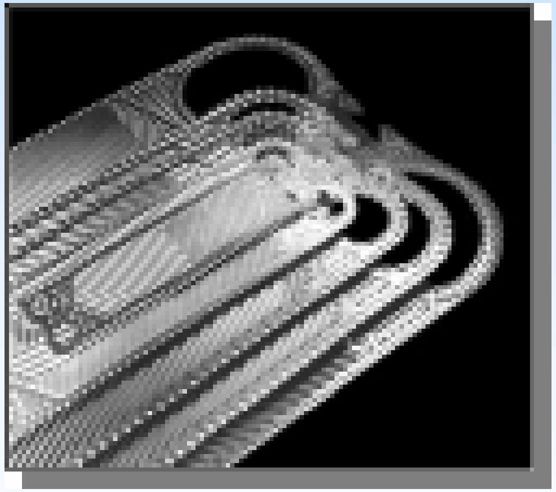


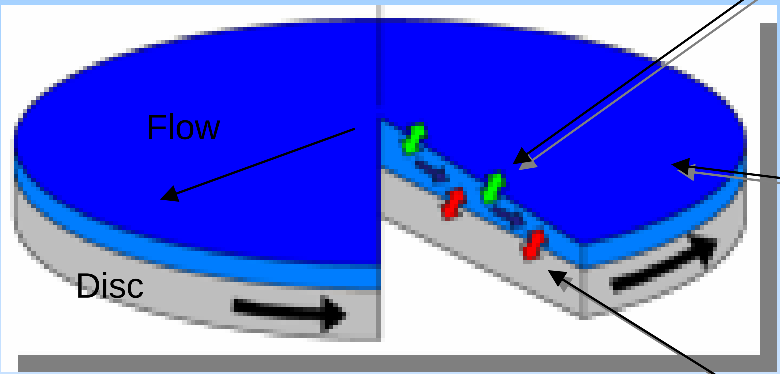
Plate Heat Exchanger

Rotating Packed Bed

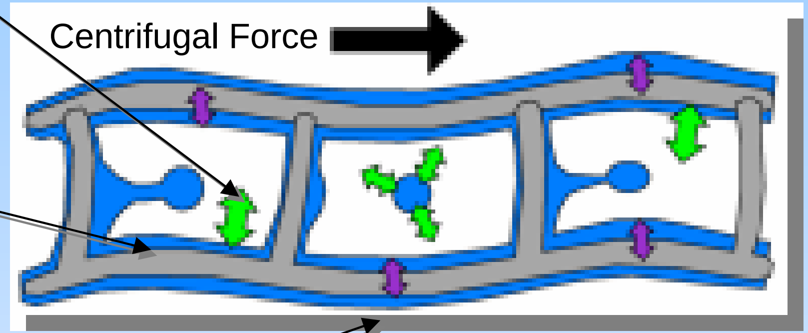
Catalytic Plate Reactor

Common Themes Within These Devices

Gas-Liquid Transfer



Thin Film

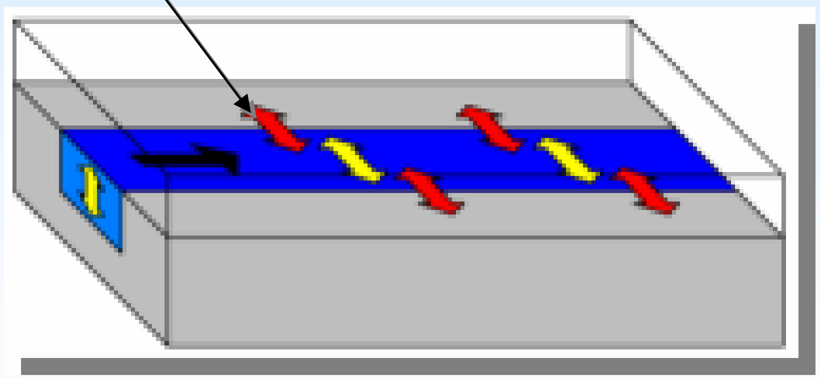


Spinning Disc Reactor

Rotating Packed Beds

Liquid-Solid Transfer

- Short path length from molecules to surface.
- Diffusive transport dominates.
- Scale-up maintaining surface to volume.



Microreactor, Plate Heat Exchanger, Catalytic Plate Reactor

Shift in Processing Methods

Shift from Batch to Continuous

- Reduced reactor inventory and equipment size (lab-scale is closer to full scale).
- Ability to vary conditions quickly => opportunity for rapid grade change.

Shift from Convection to Diffusion

- Liquid Conduction >> Molecular Diffusion => Thermal Stability
- No zones of high and low mixing, “every molecule gets the same processing experience”
- Easier to model from simple physics rather than empirical data.

Engineered Short Path Length

- Small ΔC and ΔT required to drive transport => avoid gradients in conditions.
- Rapid heating and cooling => exploit high temperature without degrading.
- Evaporation rather than bubbling => foaming resistant, bubble free boiling.

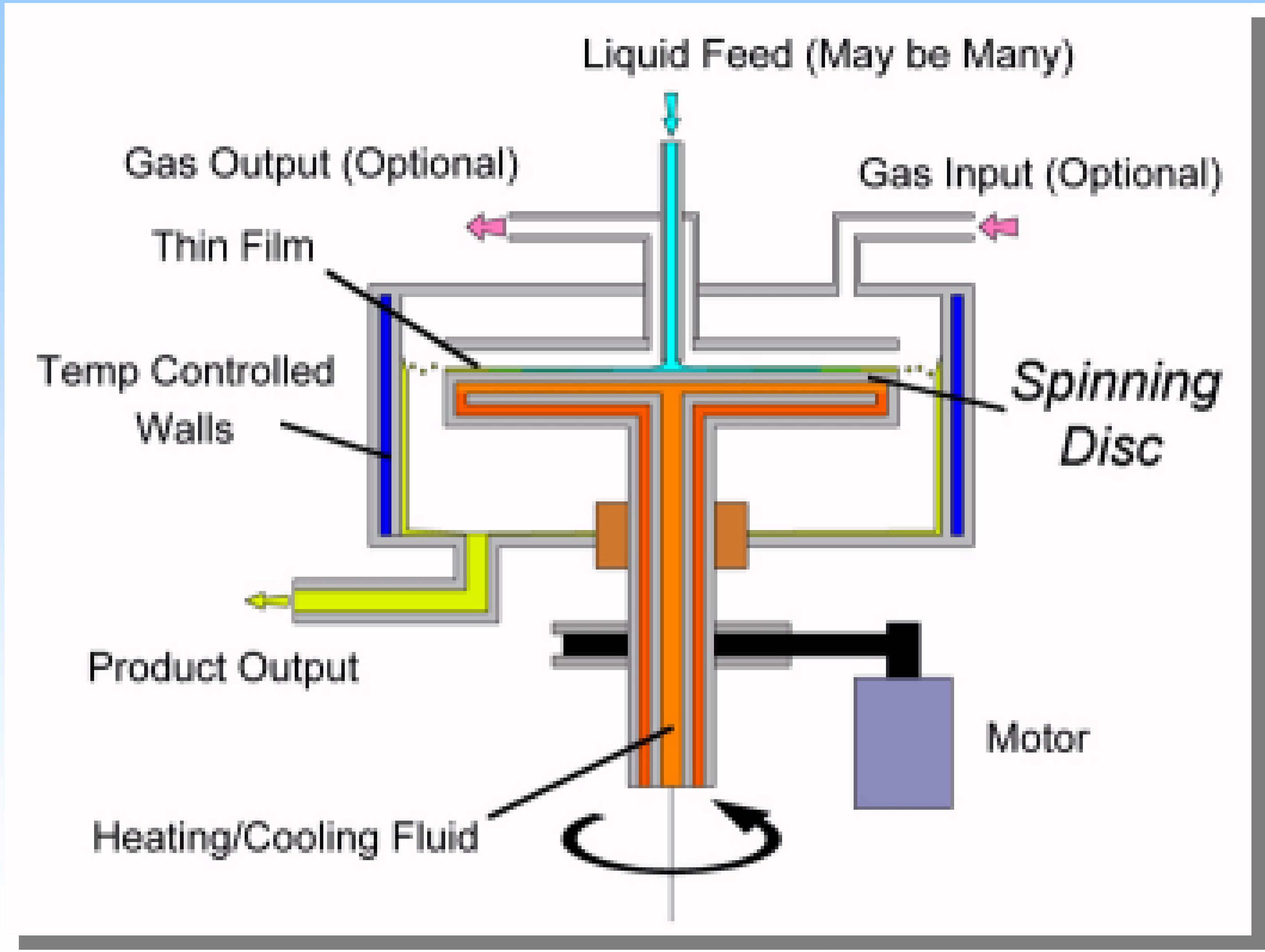
Scale-Up Maintaining Surface to Volume Ratio

- Scale-up maintaining processing environment.

The Spinning Disc Reactor

Examples of Intensified Processing

The Spinning Disc Reactor (SDR)



Commercially Available Spinning Disc Reactors

Fluid Heated / Cooled Reactors

10cm and 20cm disc diameter

Variable speed of up to 3000rpm

Electrically Heated Reactor

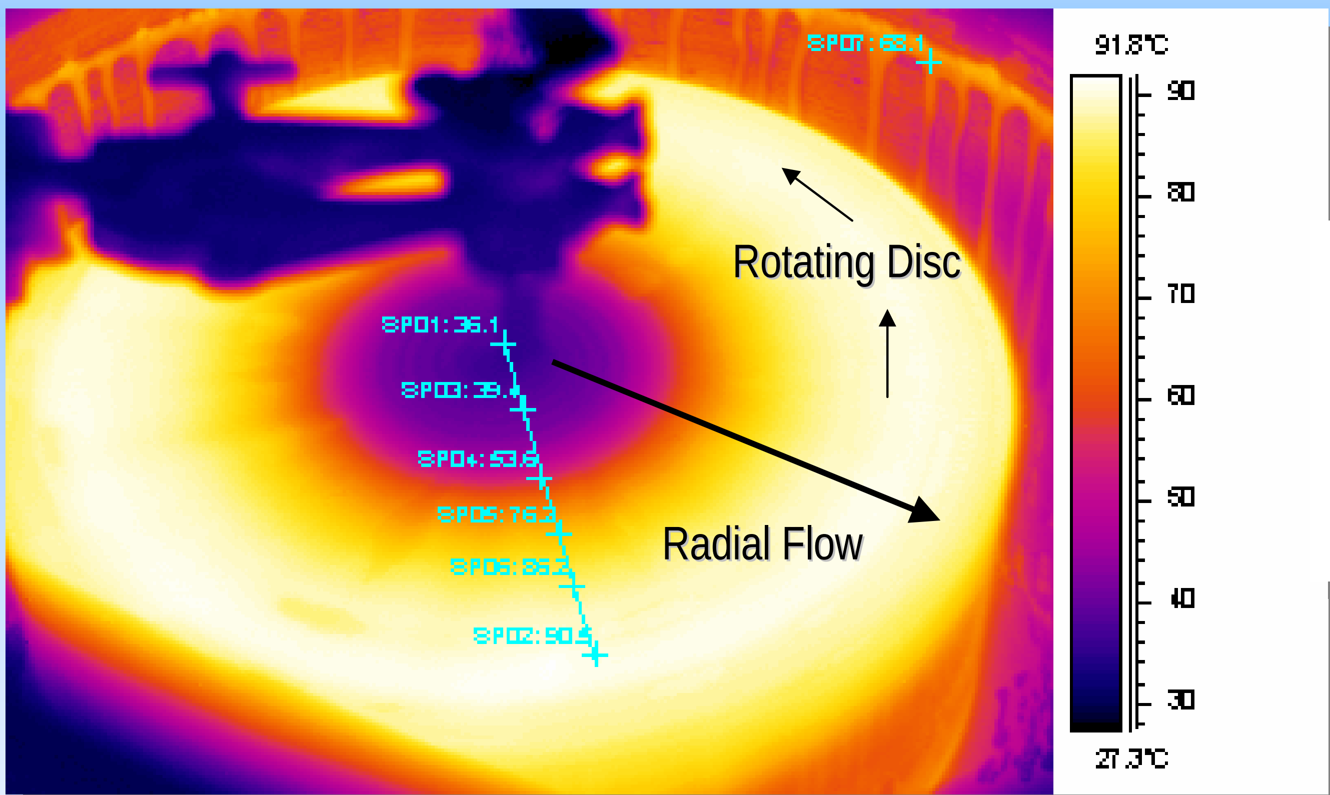
30cm disc diameter with conical walls

Variable speed of up to 1200rpm

Intensified Heat Transfer

Rapid Heating without High ΔT

Rapid Heat Transfer

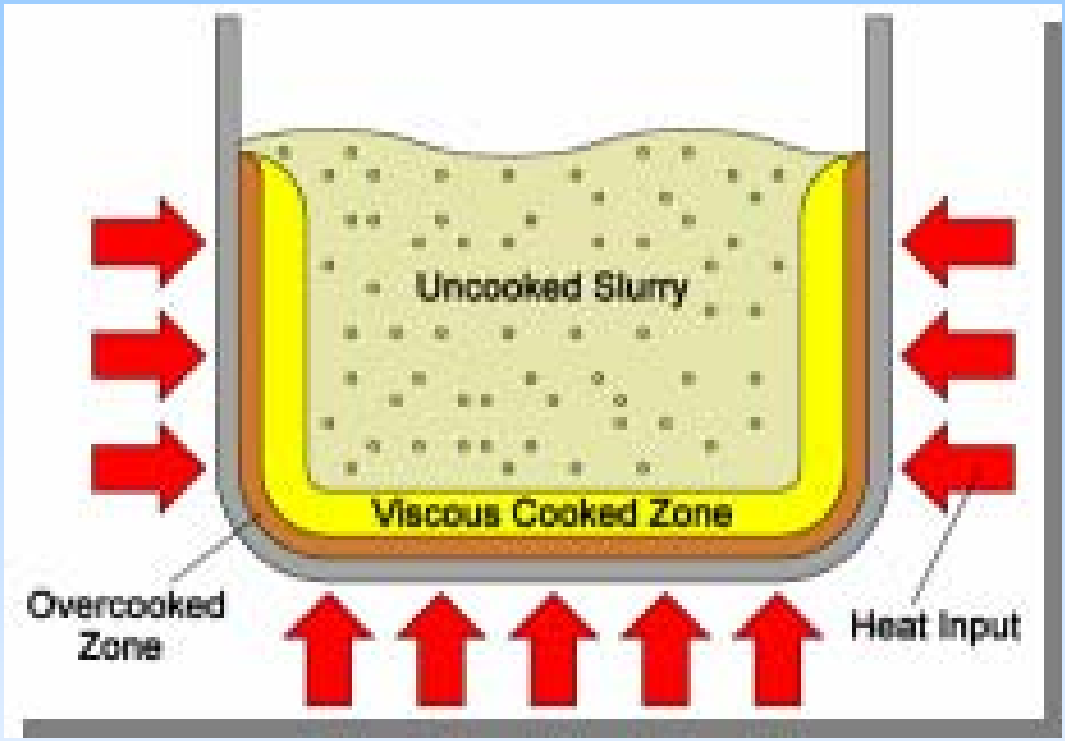


Continuous heating of "Treacle" from 40ºC to 90ºC in seconds using a SDR

Image Courtesy of
Campden & Chorleywood
Food Research Association

- Fluids can attain desired operating temperatures in seconds (1 - 10kW/m^2/K typical performance).
- Temperature can be maintained during exothermic and endothermic processing.
- Heating and cooling rates can be easily maintained as equipment is scaled up.
- Short residence time => low inventory => rapid grade change capabilities.

Rapid Heat Transfer - Food Processing Example



Cooking Starch in a Batch

Specific Example

Making custard from powder and milk

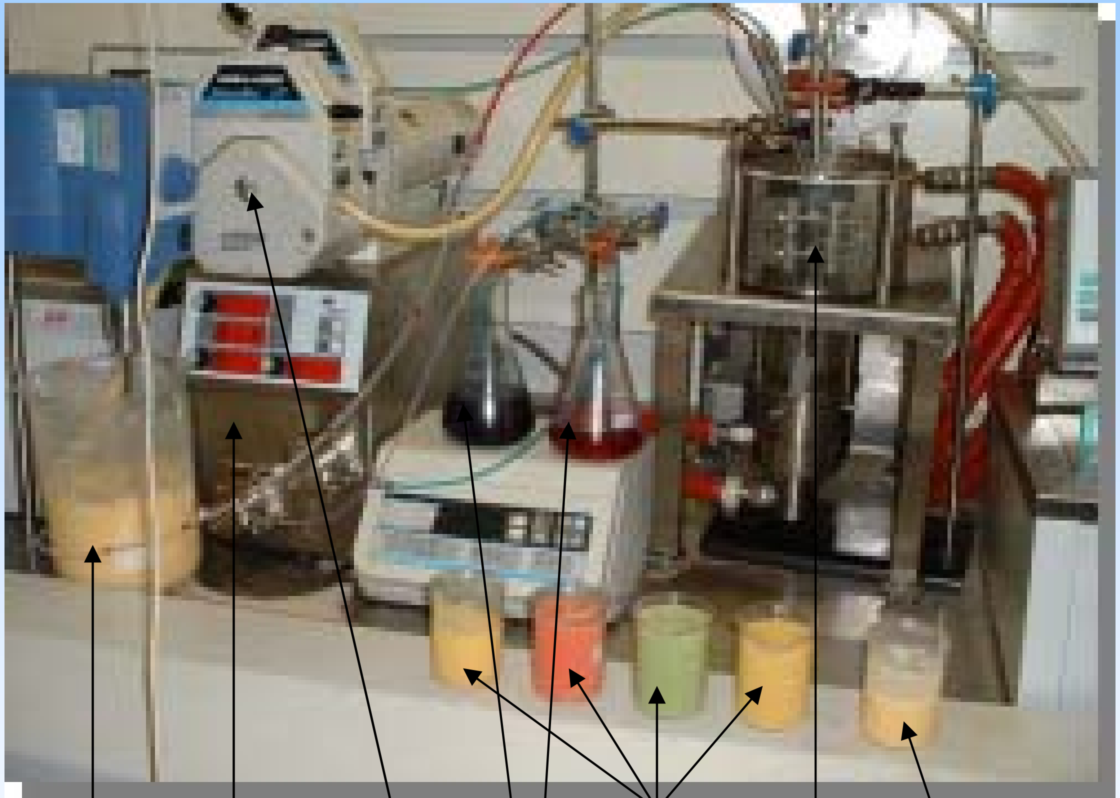
(“Custard” powder = cornflour, salt, flavouring and colouring)

Conventional Processing

- Slurry is heated in a vessel.
- Mixing is by natural convection with some additional stirring.
- Product formed is a viscous liquid.
- Failure to mix sufficiently results at over heating at the surface and burning on the vessel walls.
- This limits processing speed and can influence product quality.

Rapid Heat Transfer - Food Processing Example

Alternative - Process Continuously Using a SDR



Liquids blended and heated on the disc

Rapid Heat Transfer - Food Processing Example

Rapid cooking of custard powder slurry

Rapid Heat Transfer - Food Processing Example

Pre-processing slurry

Disc cleaned immediately with water wash
Surface remains free of fouling

Post-processing viscous product "Custard"

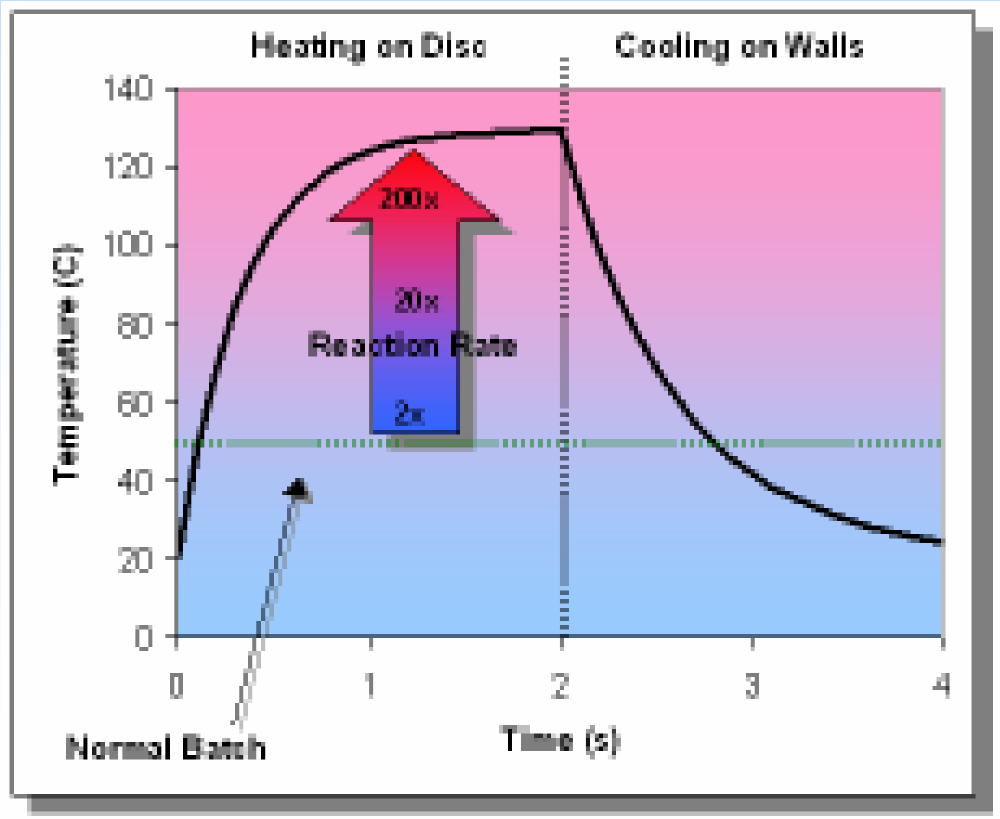
Rapid Heat Transfer - More Conventional Processes

Rapid Heating + Short Residence Time = New Processing Opportunities

- Ability to rapidly heat and cool allows excursions into new reaction regimes can be exploited.
- Short residence time allows risk of degrading of material or over reaction to be minimised.

One reaction normally taking 1/2 hour in a batch at 50°C was completed on an SDR in under 2s residence time at 130°C.

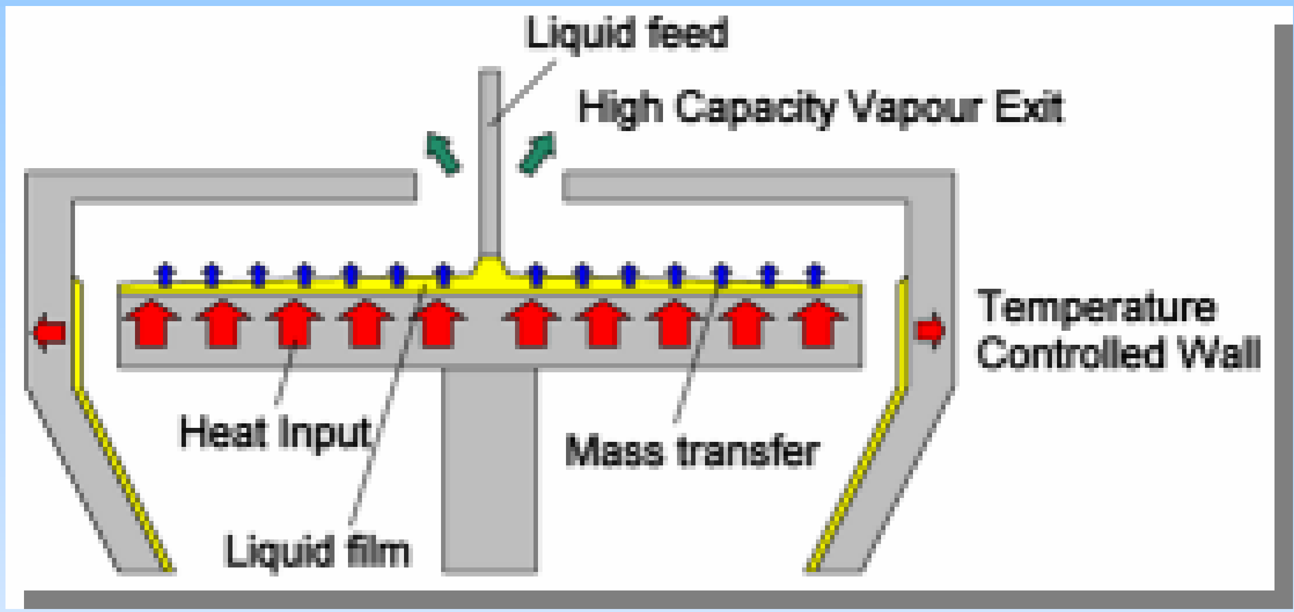
An impossible process to replicate in the conventional process equipment.



Intensified Heat & Mass Transfer

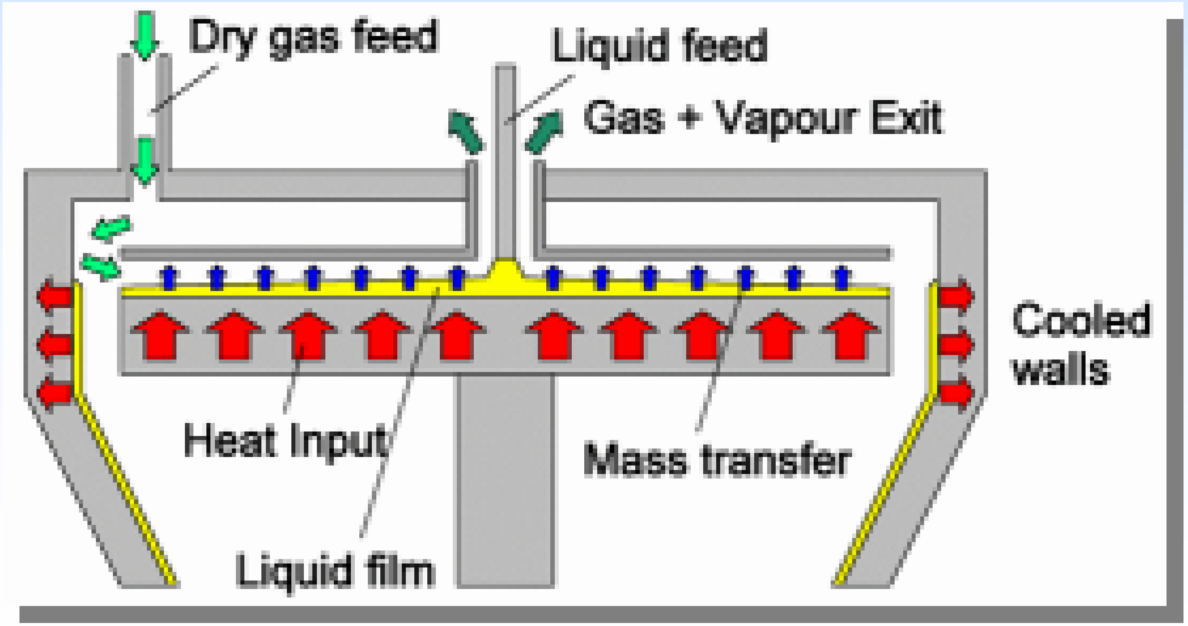
Hit it Hard and Hit it Fast - Reach Equilibrium in Seconds

Rapid Heat & Mass Transfer – Stripping and Concentrating



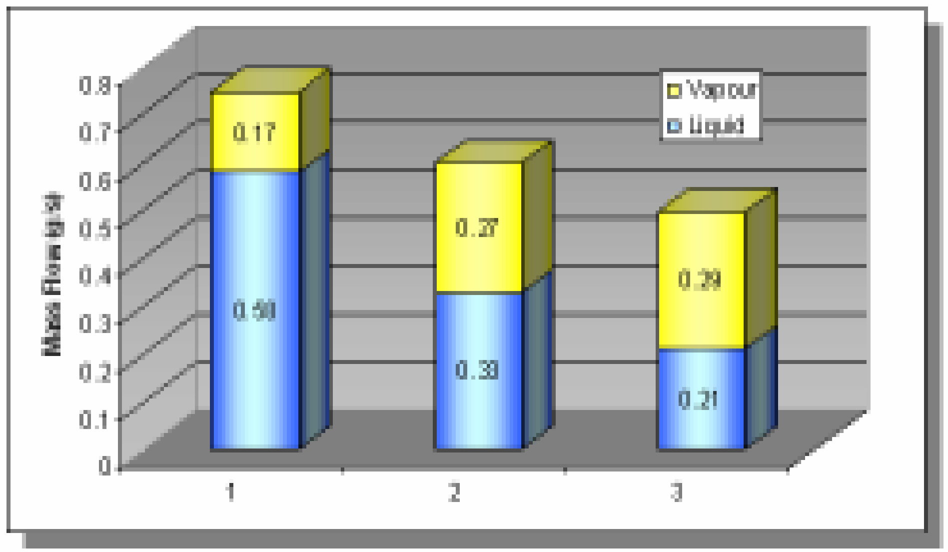
High Capacity Evaporative Stripping

(High Flow or Vacuum Mode)



Counter-Current Operation

Rapid Heat & Mass Transfer – Concentrating of Liquids



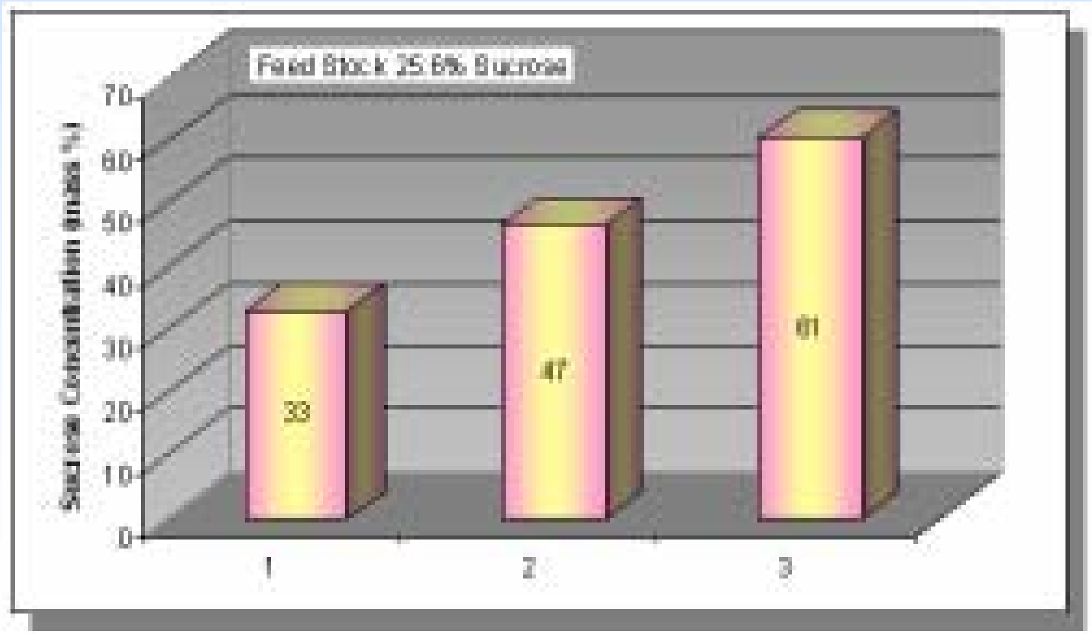
Mass Flow

Concentrating “Sugar”

Water / Sucrose mixture 25.6% sucrose passed over a 10cm SDR at 1200rpm.

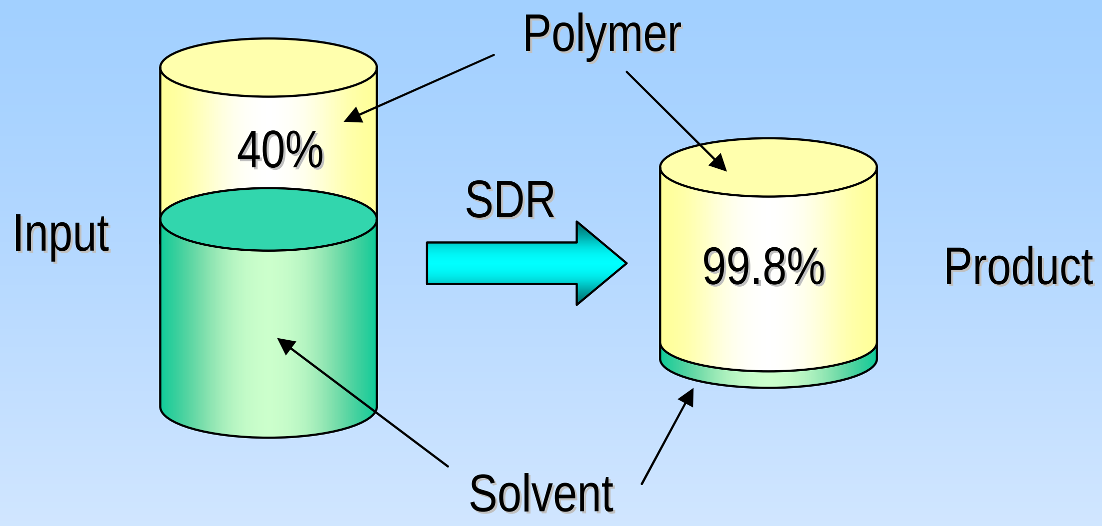
Rapid evaporation resulting in continuous production of viscous product.

Bench top production rate : 21kg / day Concentrated Solution.



Output Concentration (<1s Residence Time)

Rapid Heat & Mass Transfer – Stripping Solvents



Stripping Solvent to Recover Polymer

- Polymer at 40% concentration in a solvent.
- 4g/s of Liquid Processed on a 20cm SDR working at 2500rpm.
- Disc and wall temperature of 200ºC.
- Counter-current stripping with Nitrogen.

20cm SDR
Discharging 2 litre/s Gas!

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Rapid Heat & Mass Transfer – Scaling up Throughput

Typical 30cm SDR
Capacity : 10 to 100 kg/hr

Electrically Heated Disc

Static Shroud Plate

Temperature Controlled Walls

Intensified Mass Transfer and Mixing

Predictable, Scaleable Performance

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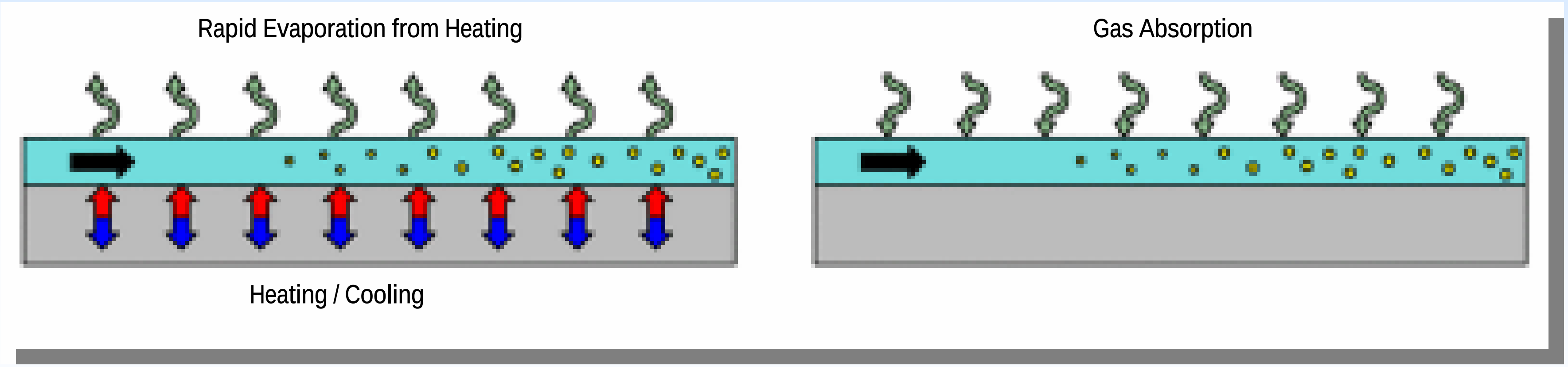
Rapid Mass Transfer & Mixing - Particle Production

Particle Generation - Processing Benefits

- Ability to generate super saturation rapidly and evenly through thin film.
- Ability to vary shear and mixing rates with disc speed to influence particle formation.
- Ability to do the above in a predictable and scaleable manner.



Heat Transfer Driven Supersaturation

Reaction Driven Supersaturation

Rapid Mass Transfer & Mixing - Particle Production by Evaporation

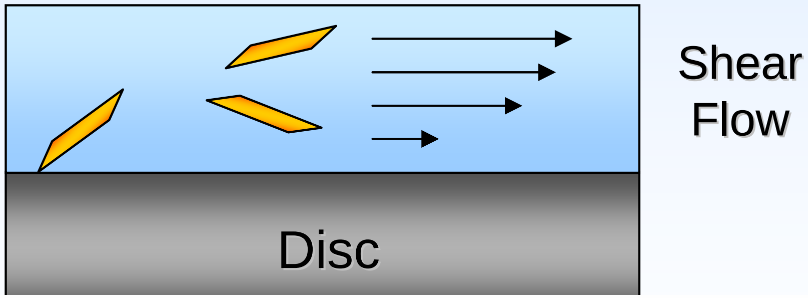
Crystallisation of a Metal Complex Salt (15cm SDR)

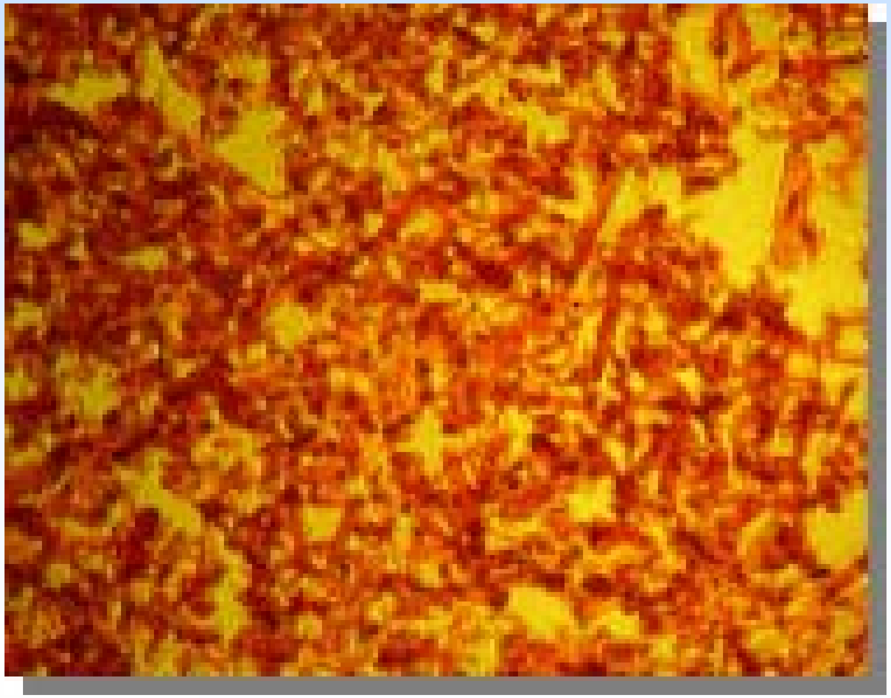
- Feed stock had salt dissolved in an Acetone/Water mixture.
- Mixture heated to 40°C on a disc at 1000rpm.
- Acetone removed through a 15mm vacuum port to generate super saturation.
- Crystal formation – Batch = amorphous, SDR = needles

Control the Dynamics

Novel Product Generation

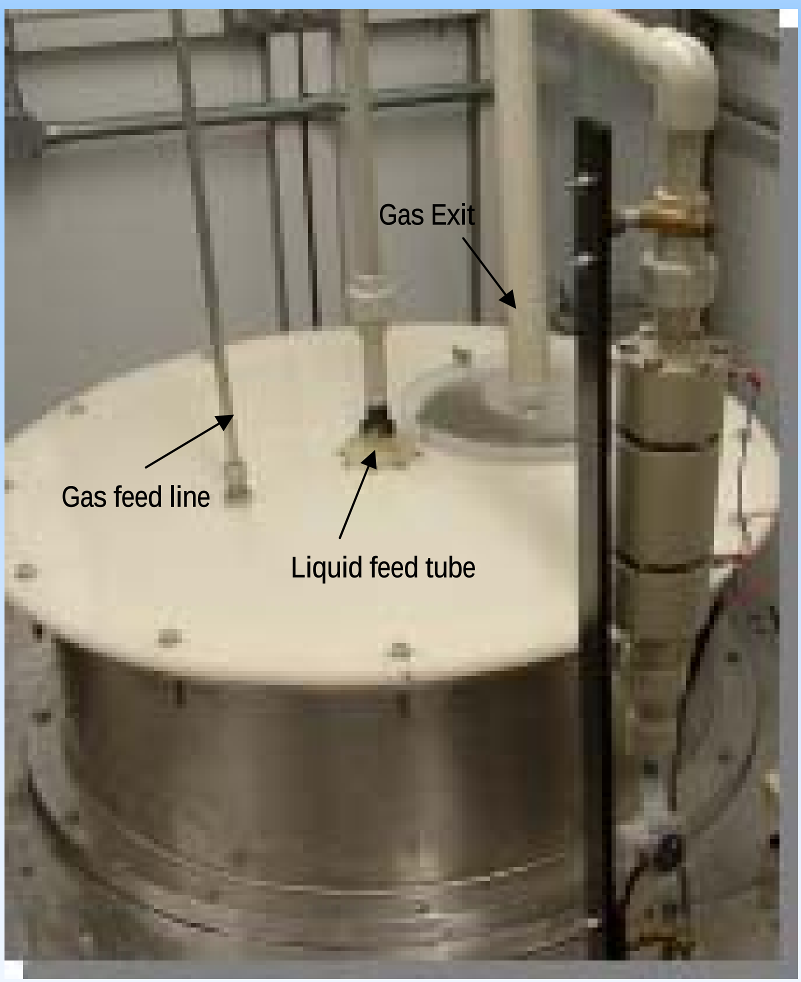
Uniform Needle Formation



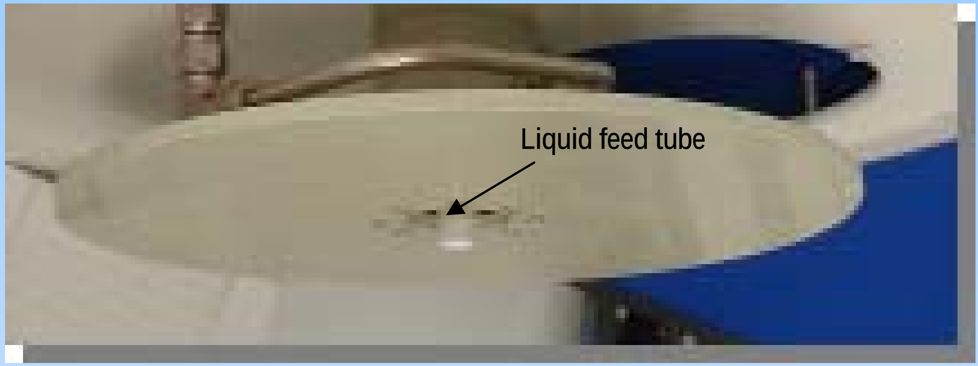


Microscope Image of Crystals

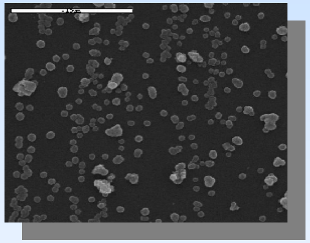
Rapid Mass Transfer - Particle Production from Gas-Liquid Reaction

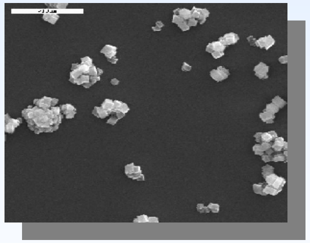


30cm SDR with built-in conductivity monitor for measuring ion depletion during conversion



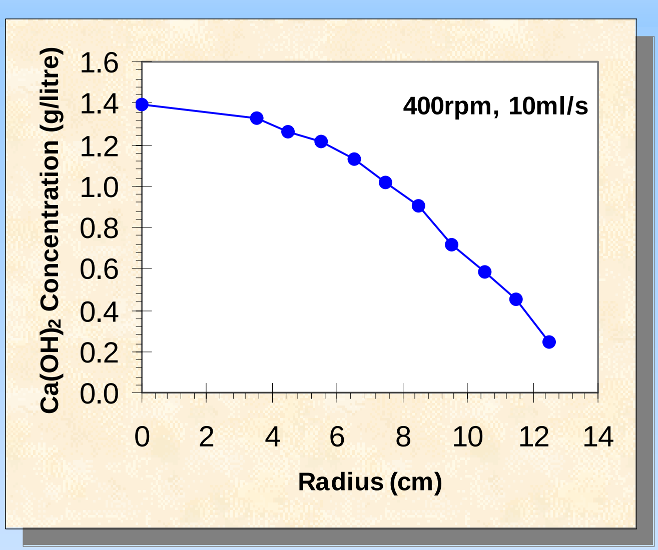
Polypropylene shroud plate to direct gas flow over the rotating disc.

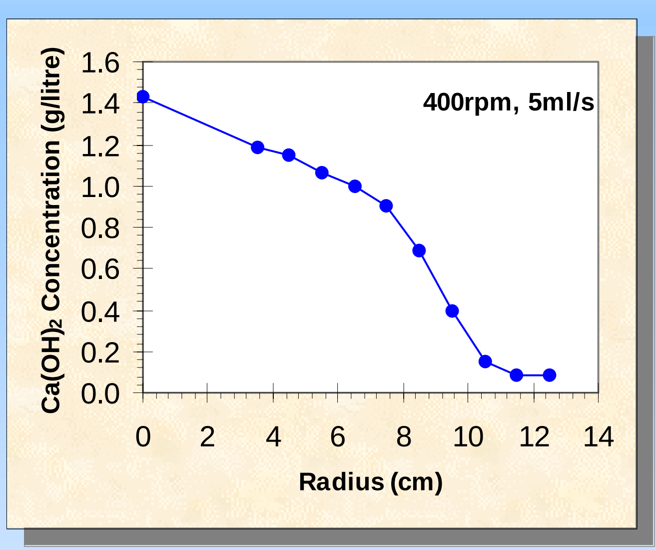


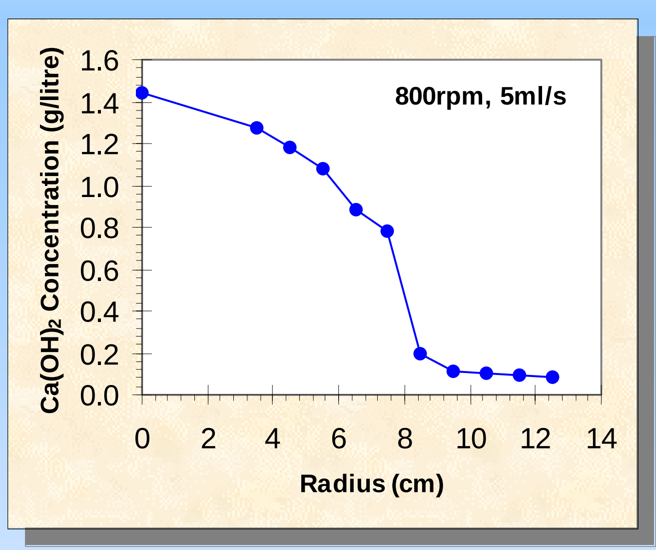


Disc with embedded concentric electrodes.

Rapid Mass Transfer - Particle Production from Gas-Liquid Reaction

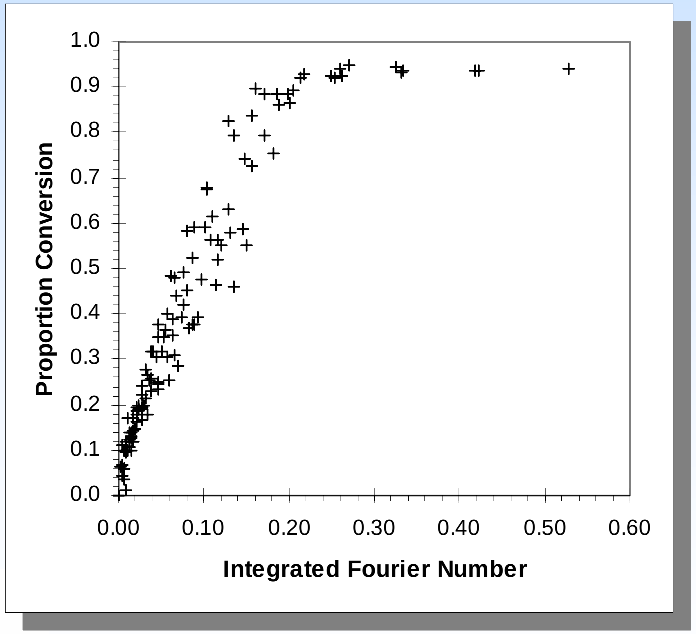






Monitoring of $Ca(OH)_2$ Conversion by Conductivity

- Rapid mass transfer allows complete reaction within one pass across the disc (under 1s residence time).
- Performance can be simply linked to Fourier number.
- Throughput can be scaled with disc area, transport rate can be varied with disc speed.



Scale-Up Example - 76cm Pilot SDR

Lab Test - 30cm Disc for 10 - 40 ml/s (0.6 - 2.4 litres/min)

Pilot Scale - 76cm Disc for 4 - 16 litres/min

Same Film Thickness, Same Residence Time, Same Disc Rotation

Concluding Remarks

Rapid heat and mass transfer can be used to drive processes into new regimes offering,

- Orders of magnitude faster transport rates.
- Exploitation of chemistry unsuitable for conventional equipment.
- Ability to more easily predict performance and scale production.

What might this lead to?

- Novel products.
- Cleaner and more selective routes.
- Shorter routes for discovery to production.