UNIVERSITEIT GENT

FACULTY OF ENGINEERING

Experimental Investigation of Gas-Solid Rotating Bed Reactor in Static Geometry: Effect of Particle Diameter

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Outline

- Introduction

  - Background & concept of Rotating Bed Reactor in a Static Geometry (RBR-SG)

  - General multiphase devices based on the concept of RBR-SG

- Experimental set-up

  - Description of the set-up

  - Operating conditions

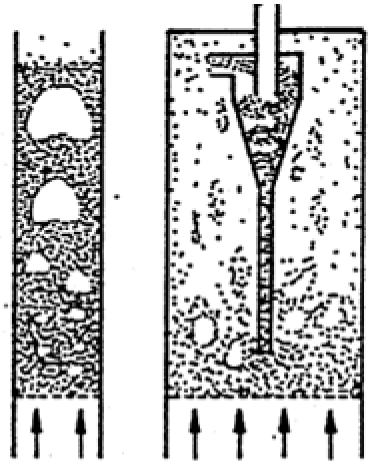
- Results and discussion

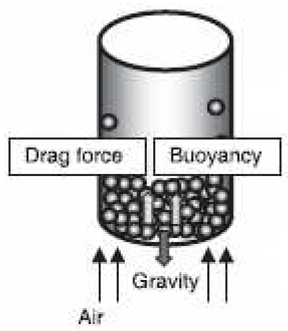
  - Pressure drop, bed void fraction, solid particles behavior

  - Comparison with conventional fluidized bed reactor

- Conclusions

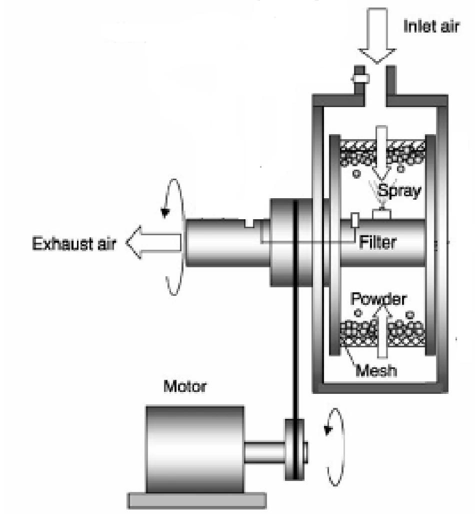
Gravitational fluidized bed reactors

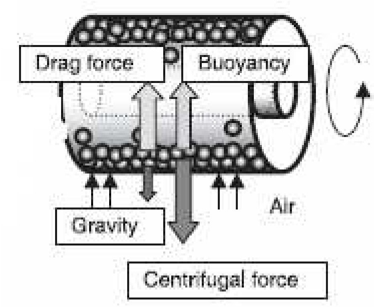




Drag force ~ Gravitational force

Rotating Bed Reactors





Drag force ~ Centrifugal force

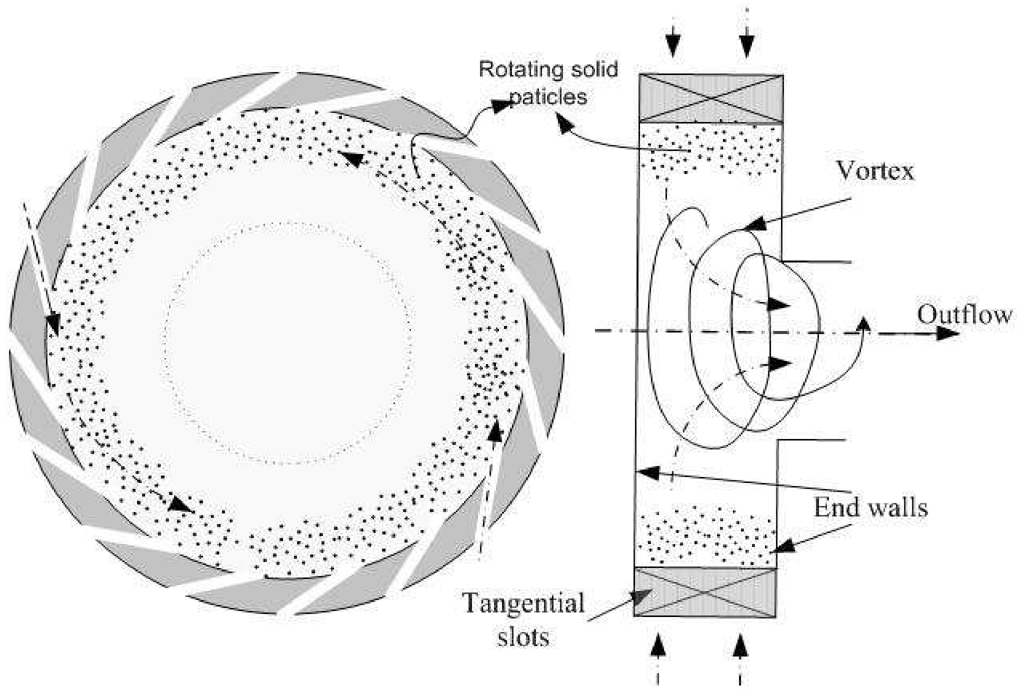
- Advantages of centrifugal fluidization in gas-solid operations

- Higher slip velocity, gives, *higher heat and mass transfer* at particle scale
- *Uniform temperature* distribution at reactor scale
- Ability to work with *high feed flow* rates
- Reaction and separation in *one step*

- General applications of centrifugal reactors

- Short gas-solid contact time operations
- Drying, polymerization, fluidization of nano-particles, gas-solid separation, dust emission control

Concept of RBR-SG

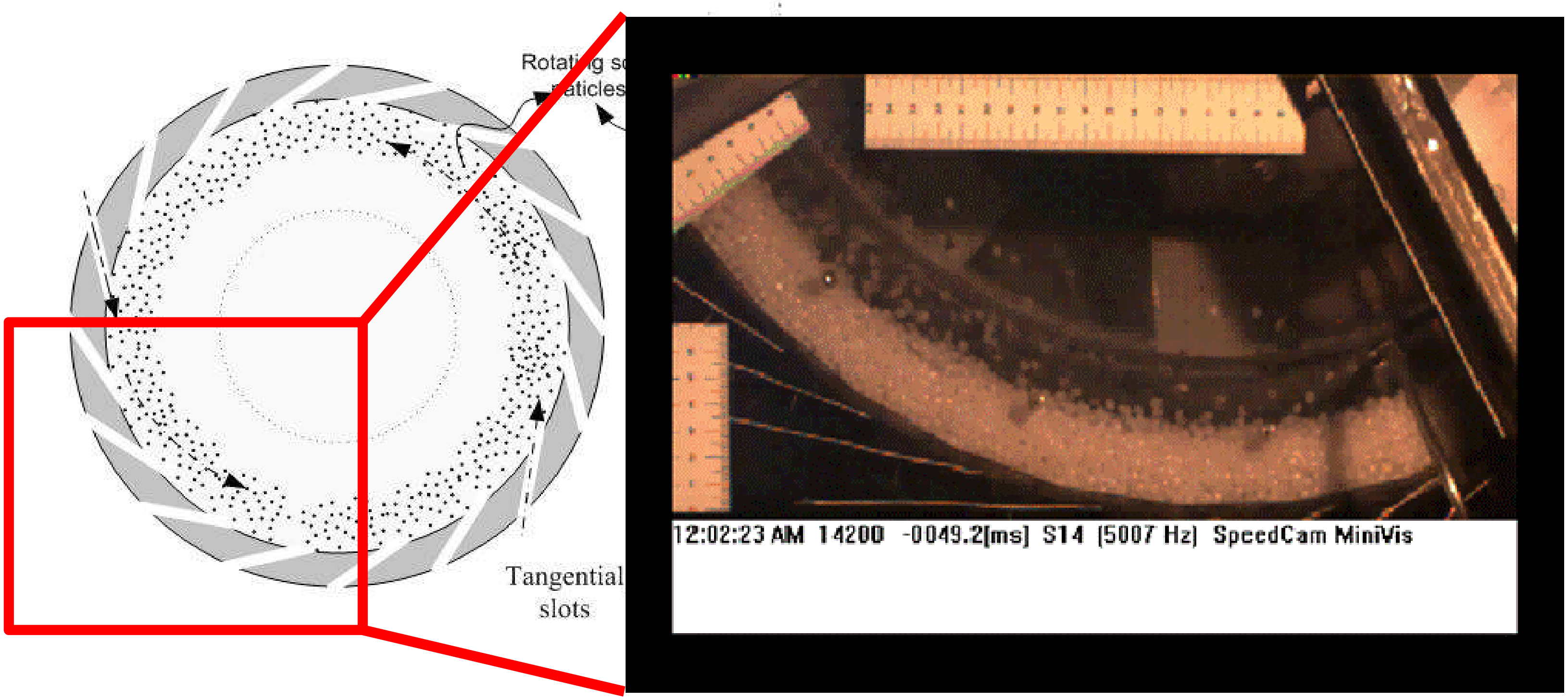


front view **side view**

- Generation of centrifugal force by means of tangential injection of *primary phase (gas/liquid)* in a static cylindrical chamber

- Introduction of *secondary phase(gas/liquid/solid)* into the static chamber via end walls, leads to rotational motion of the secondary phase

- One or both of the phase can be *axially discha*rged via an opening on one or both of the *end walls*



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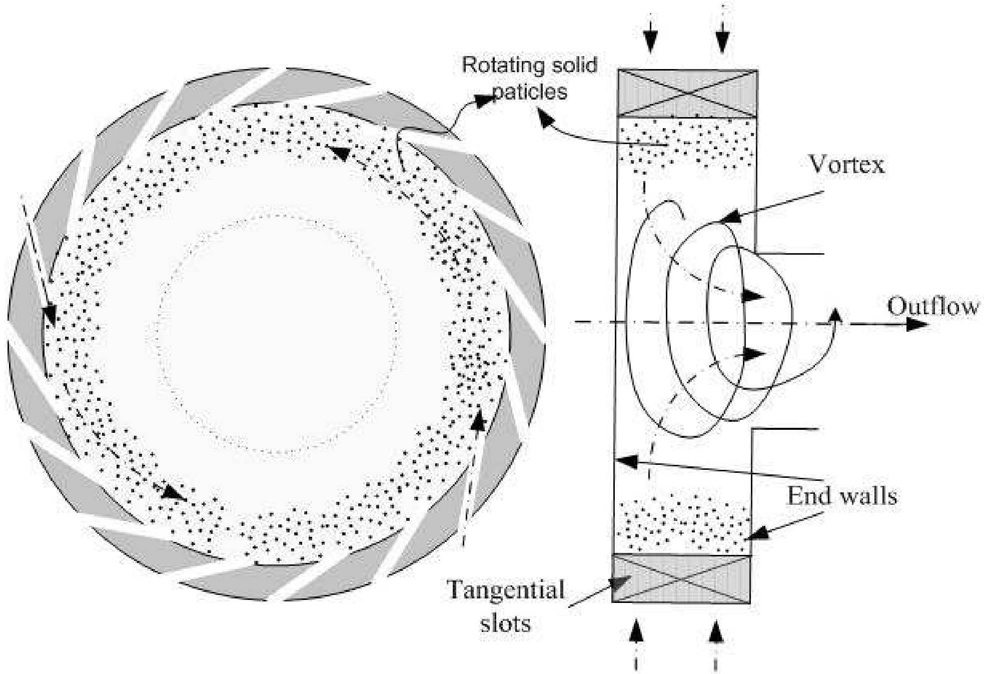
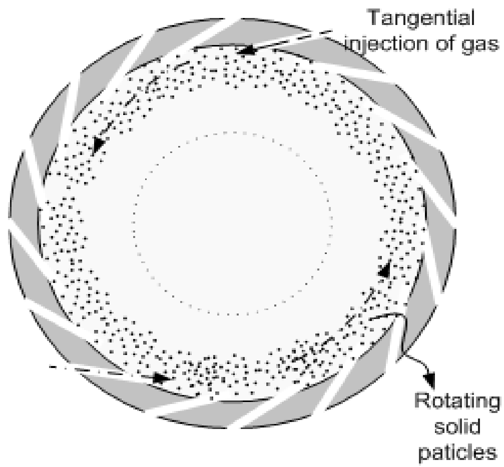
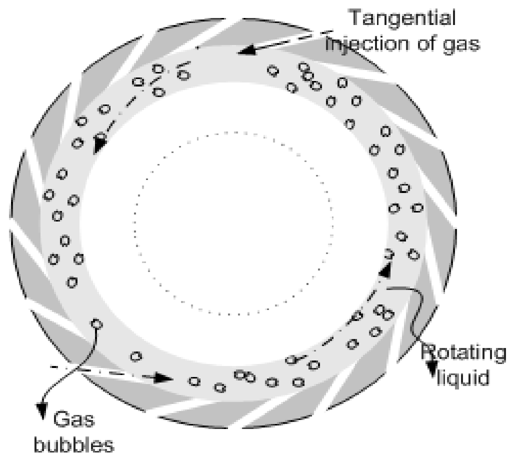


- **Some of the unique features and advantages**
  - Ability to handle high feed flow rates
  - Involvement of non-moving parts
  - High radial slip velocity (1 – 10 m/s) accompanied by high solid particles fraction (0.3 – 0.4)
  - High slip velocity may overcome the *external heat/mass transfer limitation* giving opportunity to use highly active catalyst

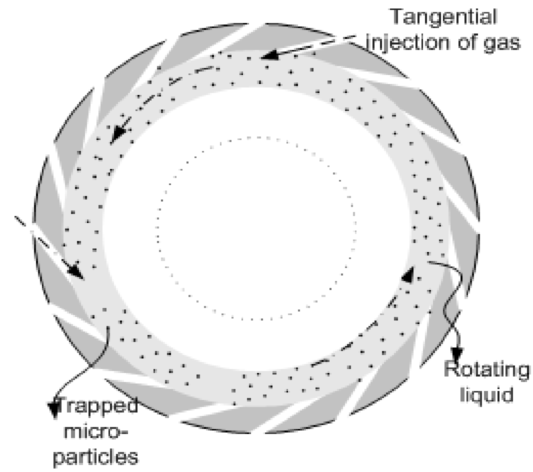
General multiphase devices based on RBR-SG concept



Gas-solid



Gas-liquid



Gas-liquid-solid

- *Gas-solid:* *(Anderson et al, Wright-Peterson air force base, Ohio, US, 1972)*

  - Significant increase in heat and mass transfer: *experimental evidence* of 2 to 3 orders of magnitude high *heat transfer coefficient* compared to gravitational fluidized bed reactors.

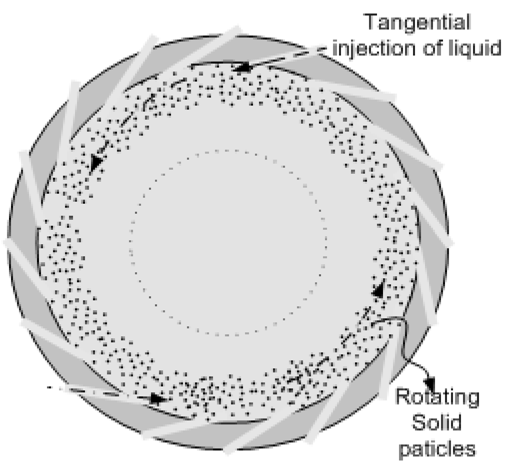
- *Gas-Liquid:* *(Kuzmin A and Parmon V, Boreskov Institute of Catalysis, Russia, 2005)*

  - *Experimental evidence* of 10 times increase in productivity compared to bubble columns at *comparable energy consumptions. High interfacial area (range of 10000 m^2/m^3).*

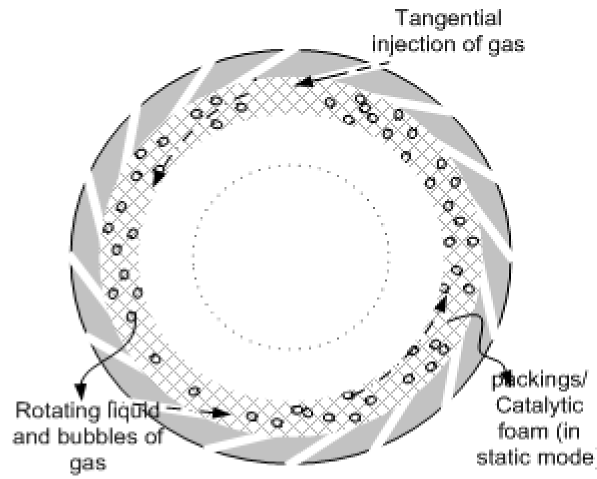
- *Gas-Liquid-Solid:* *(Loftus et al, Textron Defense System, MA, US, 1992)*

  - Particulate laden gas is forced to bubble through the rotating liquid layer. Each (micron-size) bubble acts as a *micro-cyclone*, separating particulate into the rotating liquid layer, leading to efficient separation of emission flue gases. System can be used as a G-L-S reactor.

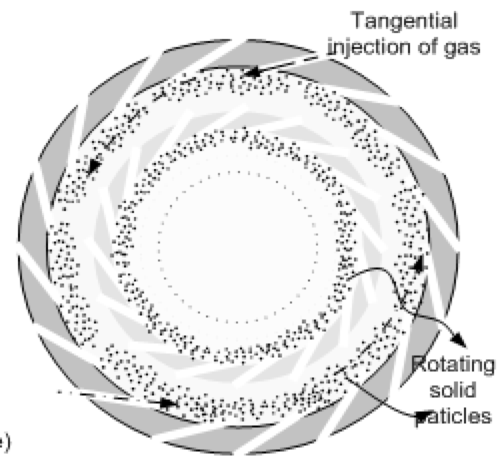
General multiphase devices based on RBR-SG concept



Liquid-solid



Gas-liquid with catalytic foam or packing



Multiple bed vortex reactor

- Concept used in various fields, such as nuclear industry, rocket propulsion, jet milling in mineral industry, emission control, even as a vacuum cleaner!

- Despite unique features, RBR or *Vortex type devices* are relatively less known to the chemical engineering academia and industrial researchers

- Stable rotation of secondary phase is key to the success of "all" multiphase operation

Haldipur P, University of Houston, 1999
Trachuk A. V., Novosibirsk State University, 2009
Entoleter Inc, UK, 1973

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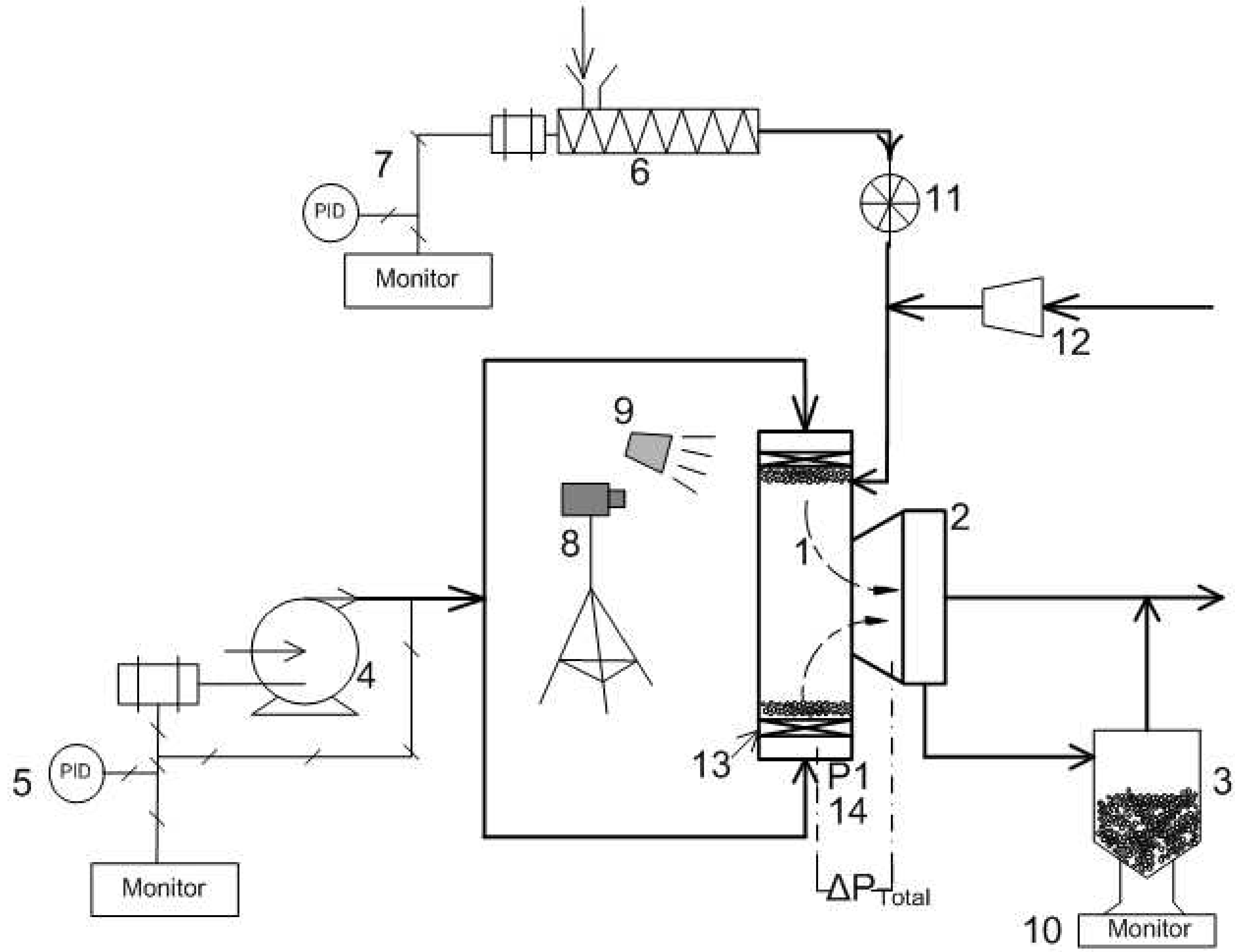
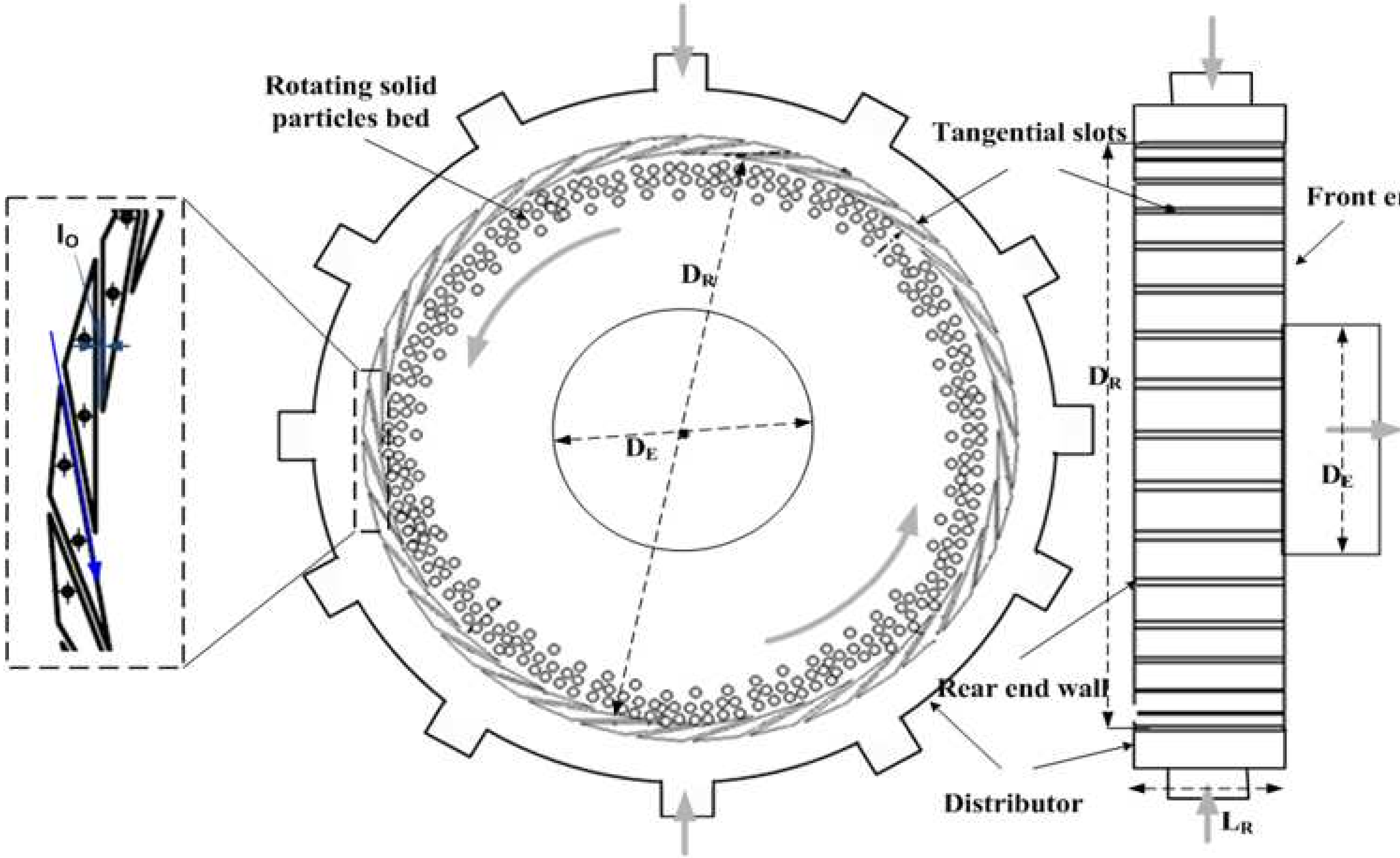


1 – Main RBR-SG body; 2 – Cyclone; 3 - Solid particles collection bin; 4 – Blower; 5 – Gas mass flow control system; 6 – Solid particles feeder; 7 – Solid particles mass flow control system; 8 – High speed digital camera; 9 – Lamp; 10 – Real time weigh balance; 11 – Back pressure valve; 12 – Secondary air supply; 13 - Tangential slots.
14 – Pressure probe

RBR-SG schematic



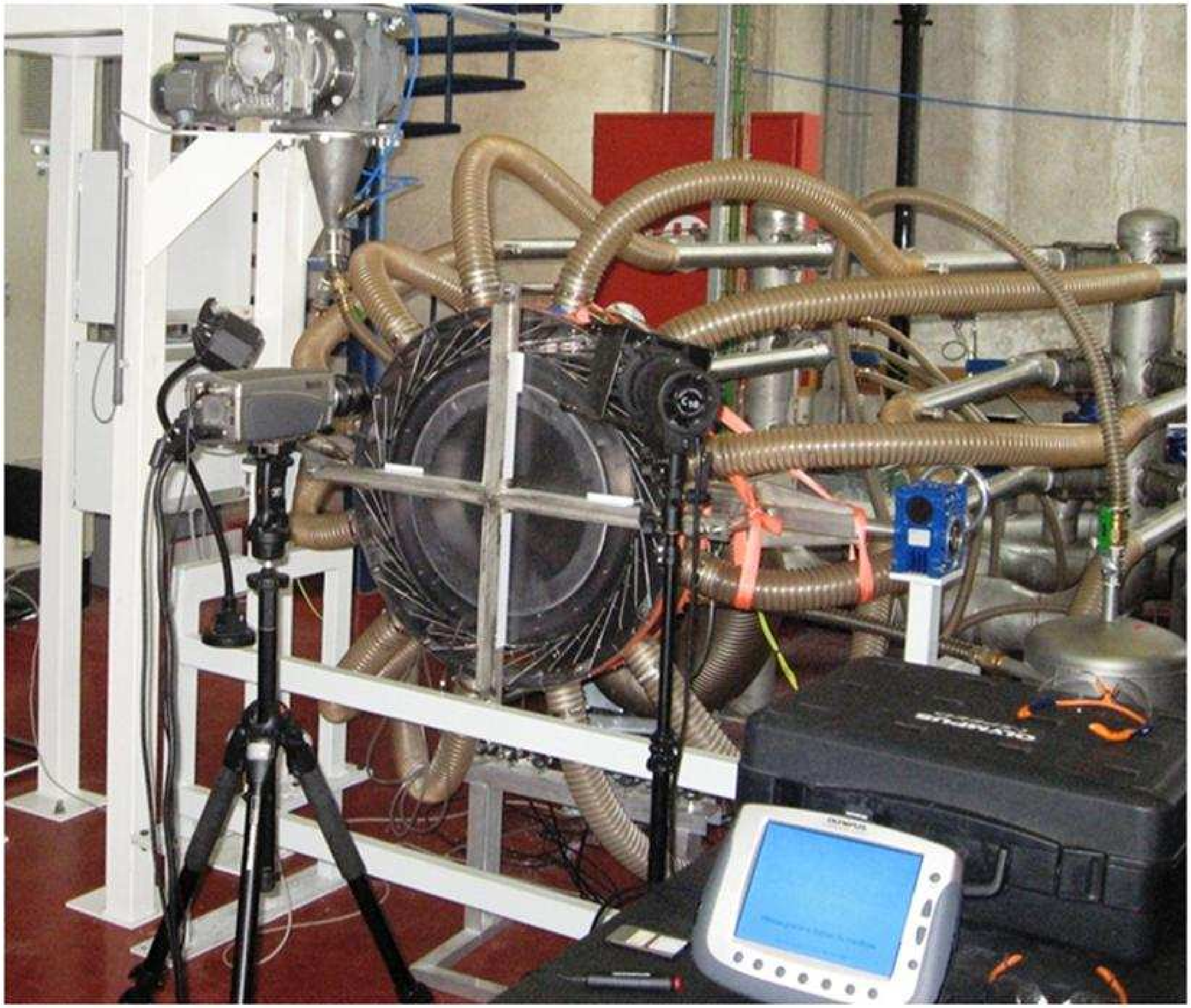
front view **side view**

- Flexible design

- Design of tangential slot is of critical importance

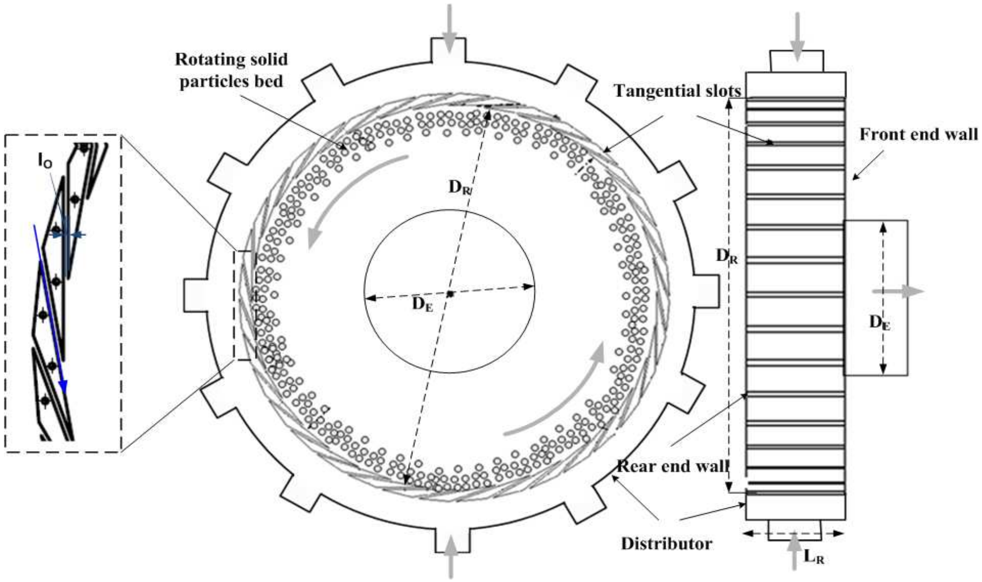
- Optimal geometrical ratios exists for efficient operation of the reactor

Actual experimental setup at LCT, Ghent University



- Horizontal axis of rotation

Parameter	Value	Unit
Main chamber diameter, D_R	0.54	m
Axial discharge diameter, D_E	0.15	m
Chamber length, L_R	0.10	m
Number of tangential slots, I_N	36	-
Width of tangential slot, I_O	0.002	m
Injection angle with respect to radius, θ	100	°
Axis of rotation	Horizontal	



Parameter	**Value**	**Unit**
Air mass flow rate, G_M	0.48 - 1.2	kg/s
Solid material	HDPE	[-]
Particle density, ρ_p	950	kg/m^3
Particle size, d_p	**2.4**	**mm**
	1.6	**mm**
	0.9	**mm**
	0.3	**mm**
Outlet pressure, P_{out}	101325	Pa
Mass of solid particles in RBR-SG, W_s	0.5-7	kg

$$\text{Performance of RBR-SG} = f\begin{pmatrix}\text{geometrical configuration},\\ \text{operating conditions}\end{pmatrix}$$

$$\left(\Delta P_{total}, \varepsilon_s, v_s, v_g, W_{s,min}, W_{s,max}\right) = f\begin{pmatrix}D_R, L_R, D_E, I_O, I_N \ldots \\ G_M, v_{g,inj}, W_s, d_p, \rho_p, \rho_g \ldots\end{pmatrix}$$

RBR-SG is said to be under *stable* operation once the solid particles in the reactor are uniformly rotating along the periphery of that reactor without *channeling or slugging* effects and there are *no or negligible* losses of solid particles along with the gas phase leaving the reactor through the axial discharge.

- $W_{s,min}$= Minimum amount of solid particles to form 'stable' rotating gas solid bed for the given set of operating conditions
- $W_{s,max}$= Maximum amount of solids that can be retained by RBR-SG under stable flow conditions for the given set of operating conditions

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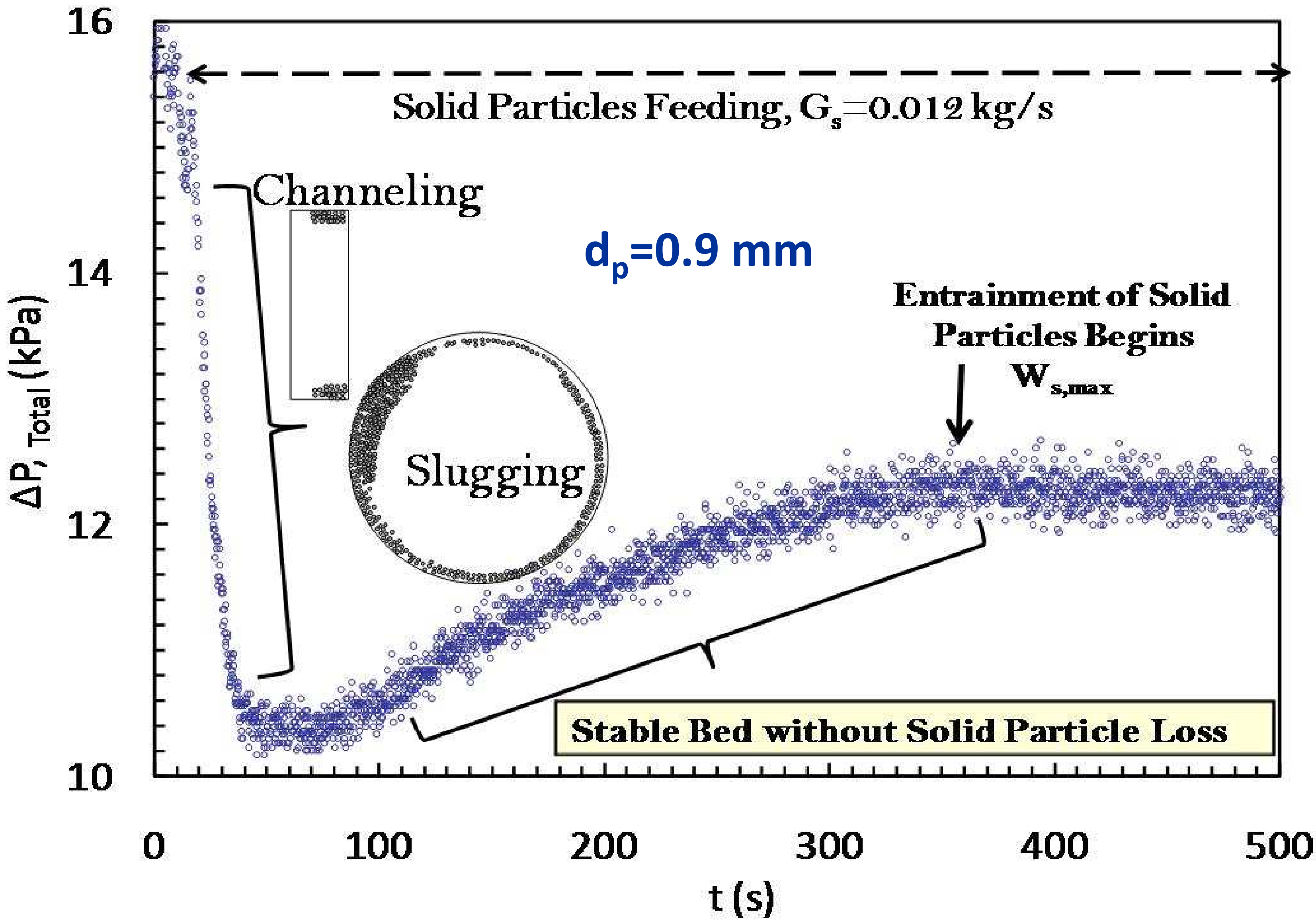
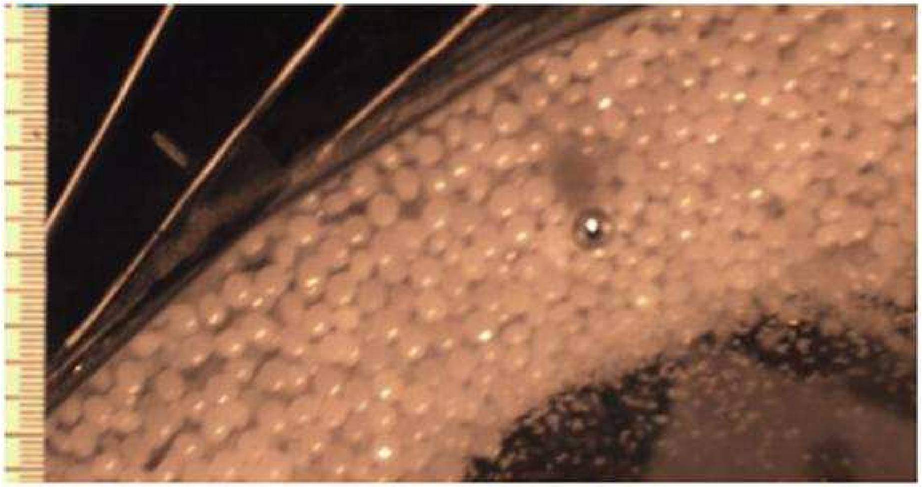
Time evolution of total pressure drop (larger particle diameter)

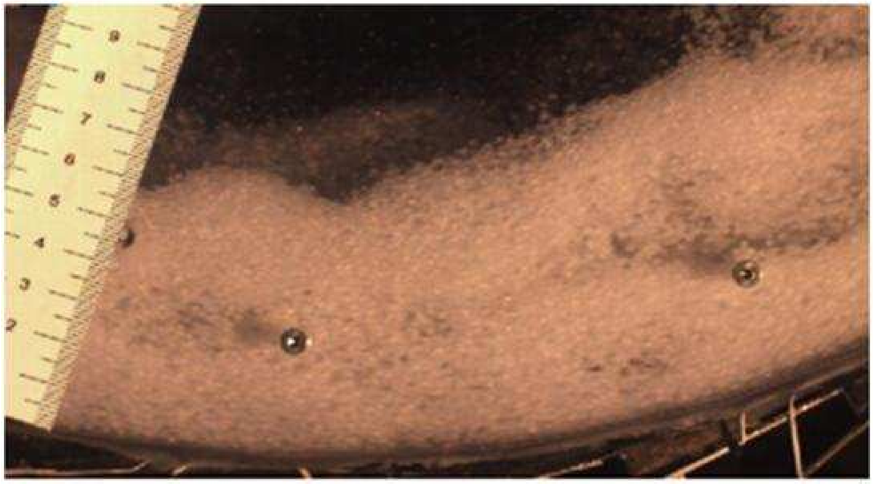


- Similar behavior for solid particles with d_p=2.4 mm and 1.6 mm

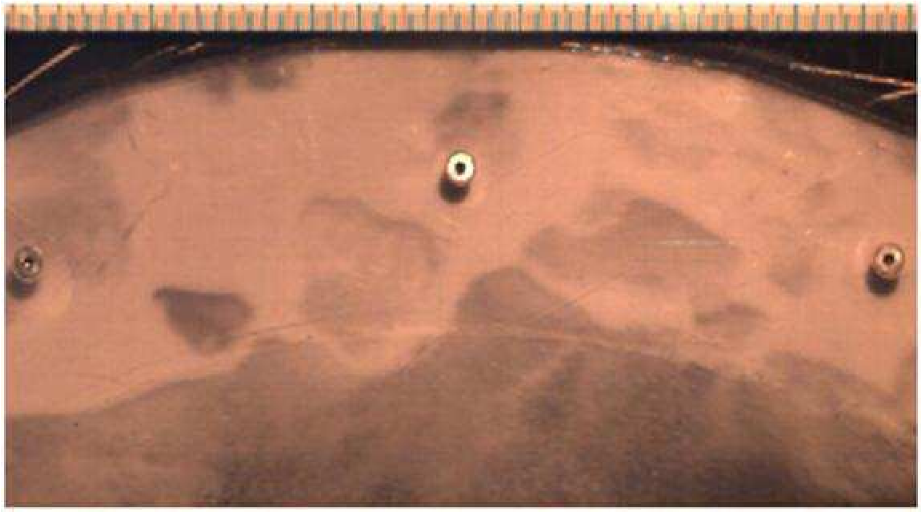
Snapshot of stable rotating gas solid bed



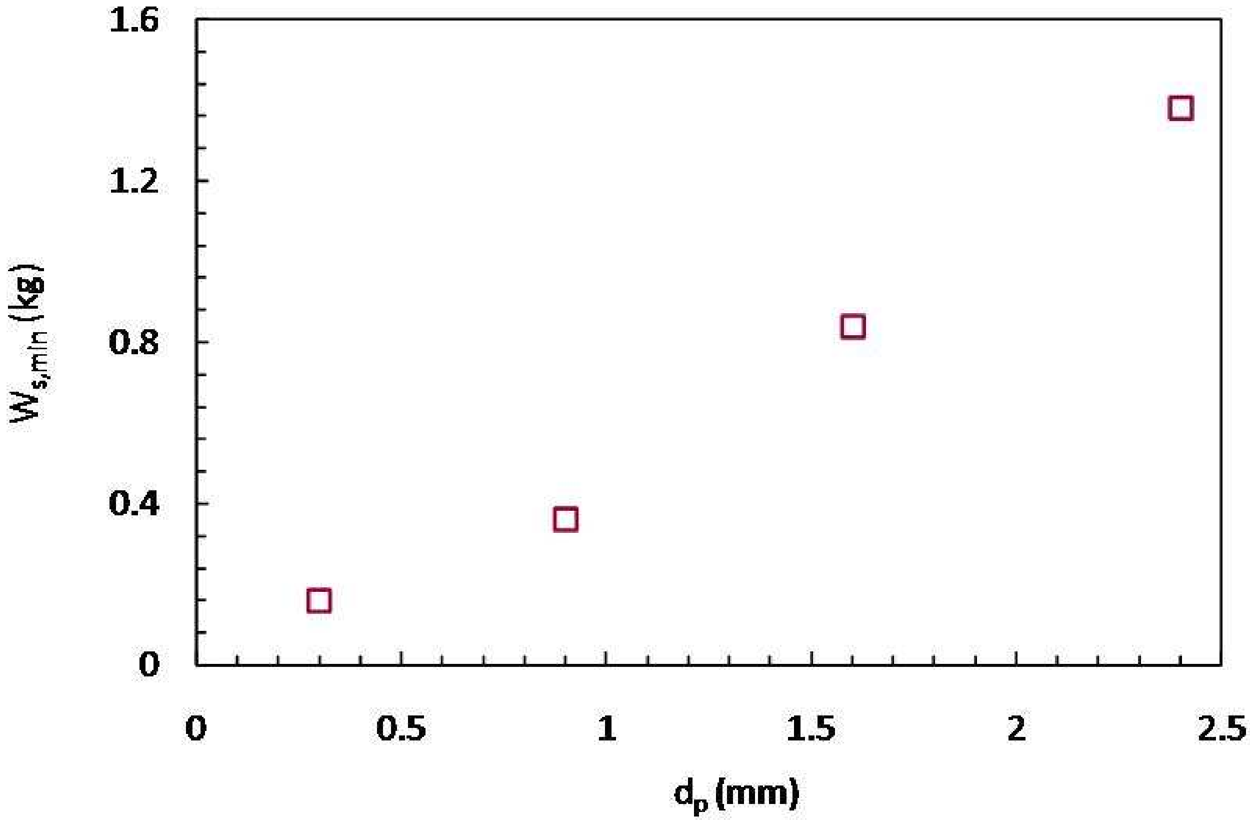
d_p=2.4 mm



d_p=1.6 mm



d_p=0.3mm

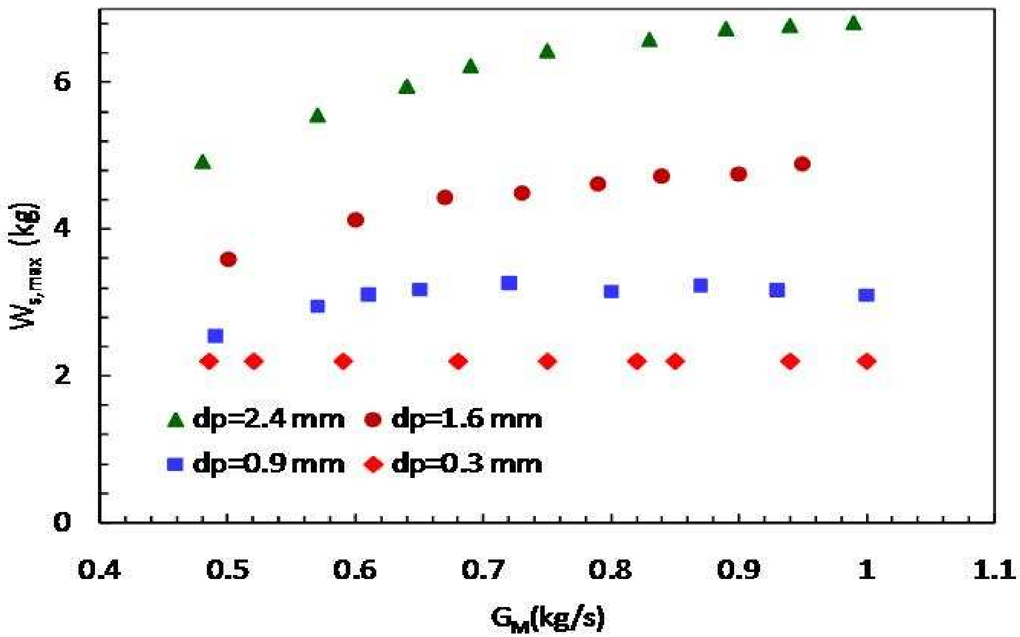


-Decreasing particle size decreases the minimum required solids content for stable rotating bed

- Increasing dominance of 'slugging' effect results into higher required minimum solids content with increase in particle size

- Minimum solids content is almost independent of gas flow rate (not shown)

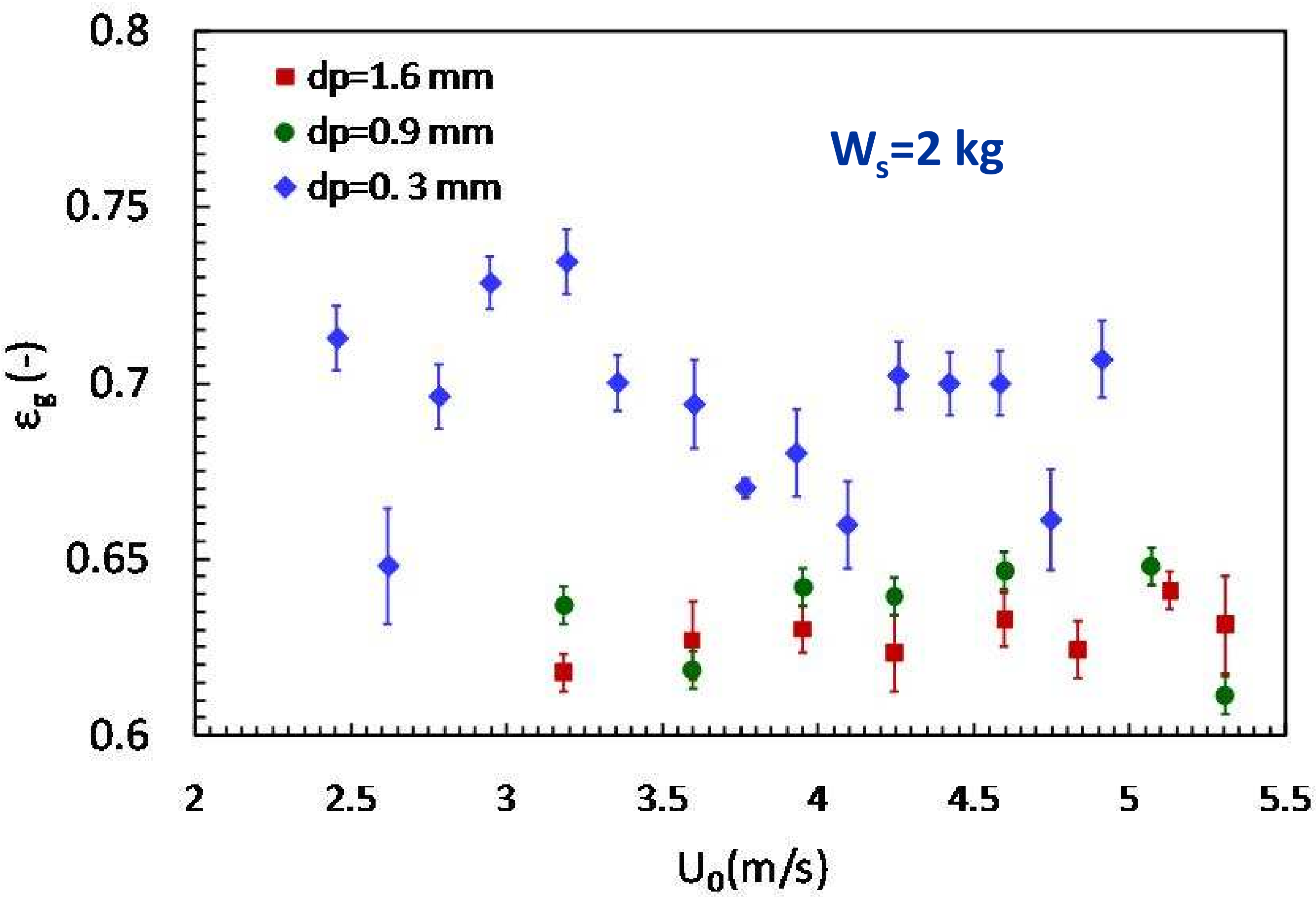
Maximum Solids Content



- At maximum solids content, centrifugal force is *balanced* by the gravity, resulting in *entrainment* of solid particles from the topmost position of the reactor axial discharge

- Increasing gas flow rate, increases centrifugal force, allowing an increase in solids capacity until *equilibrium* with gravity is reached

- At smaller particle size (1.6 and 0.9), *radial drag force* is dominant, resulting in early entrainment of solids from top positions of the reactor chamber



- Ratio of centrifugal force to radial drag force at any given radial position almost remains constant resulting into negligible variation in bed voidage with gas flow rate

Summary & Conclusions

- Potential of RBR-SG/Vortex type devices worth exploring as a *general multiphase* contacting reactors
- Large number of parameters can be varied to *optimize* the operating condition as per the requirement
- *Unique features* of the gas-solid vortex/RBR-SG were proven experimentally, by means of a flexible experimental set-up
- Under the given range of operating conditions 2.4 mm particles showed an 'almost *packed* rotating bed' whereas 0.3 mm particles showed 'bubbling *rotating* bed'
- Minimum solids content required for the stable operation as well as maximum solid content achievable is found to *decrease* with *reducing* particle diameter
- Bed void fraction is found to be almost *independent* of gas flow rate