UNIVERSITEIT GENT

FACULTY OF ENGINEERING AND ARCHITECTURE

Numerical Investigation of Process Intensification of Biomass Fast Pyrolysis in a Gas-Solid Vortex Reactor: Gas flow study

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http://www.lct.UGent.be

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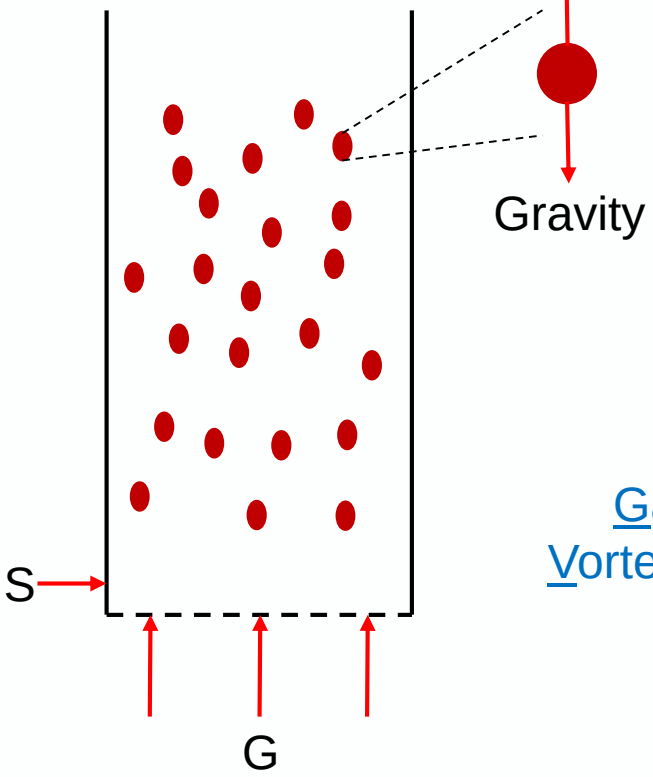
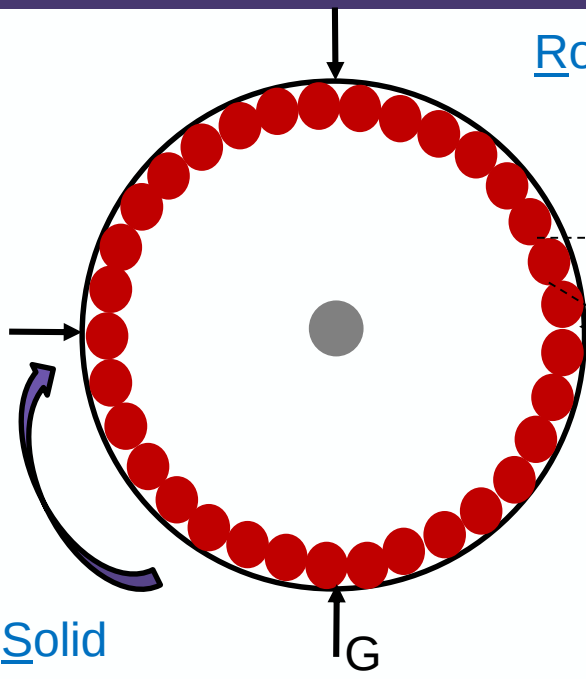
Introduction: G-S Reactors

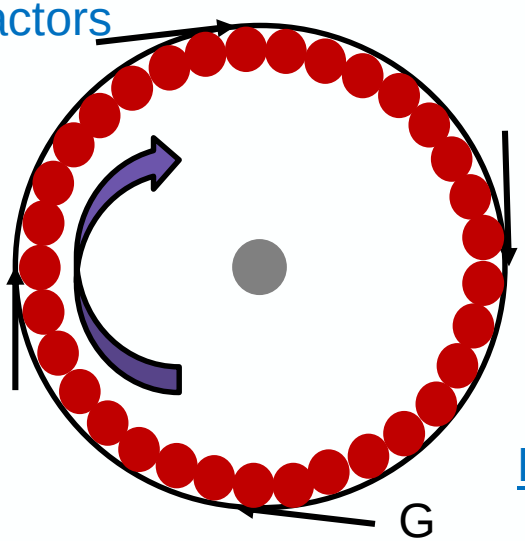


- Gas flow restrictions
- Dispersed flow

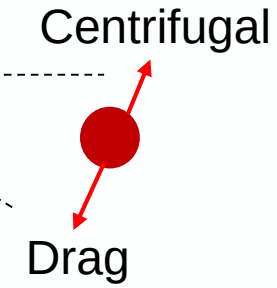
Fluidized Bed Reactor

Gas-Solid Vortex Reactors





Rotating Fluidized Beds

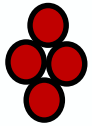


- Densely packed rotating beds
- Higher gas flows

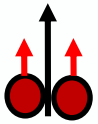
Rotating Fluidized Beds In Static Geometry

Contents

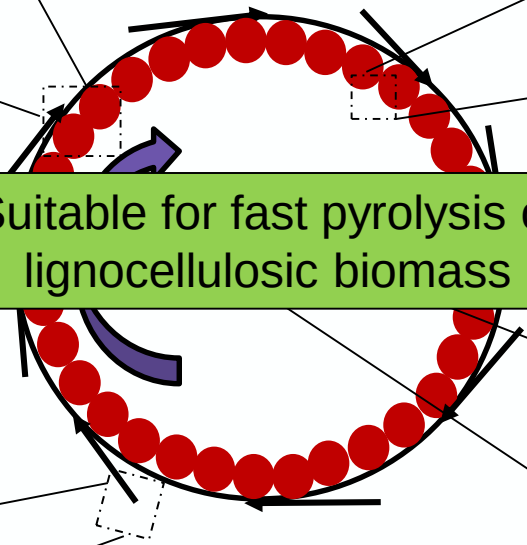
Process Intensification in GSVR



Densely packed beds → Temp uniformity



Increased slip velocity → Effective G-S mass, heat transfer



Suitable for fast pyrolysis of lignocellulosic biomass

Solid particle entrainment

Shorter gas residence time

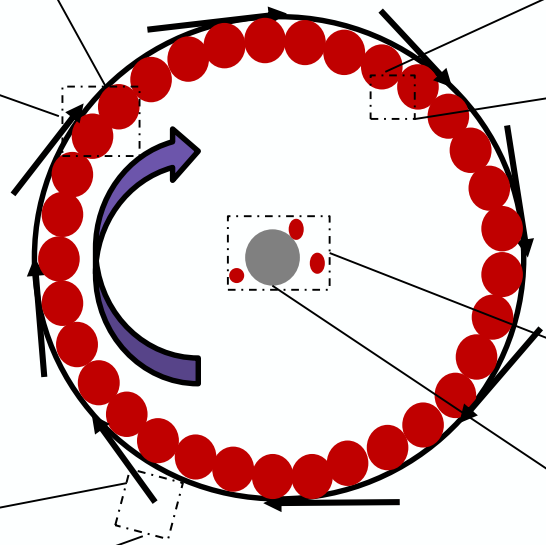
Process Intensification in GSVR

Heat & mass transfer study, Volchkov et al., 2007

Densely packed beds → Temp uniformity

Biomass Drying, Eliaers & De Wilde, 2013

Increased slip velocity → Effective G-S mass, heat transfer



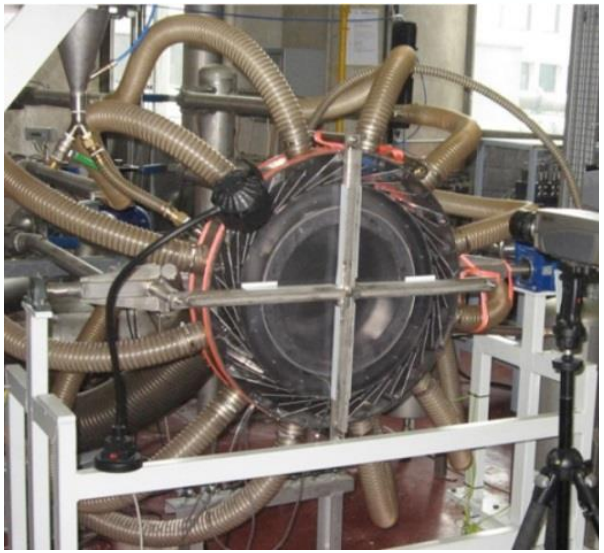
Shorter gas residence time

Ashcraft et al. 2013

Solid particle entrainment

Particle milling, Rodnianski et al. 2013

GSVR Research at LCT

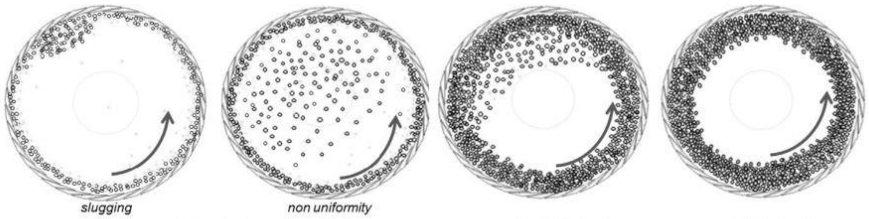


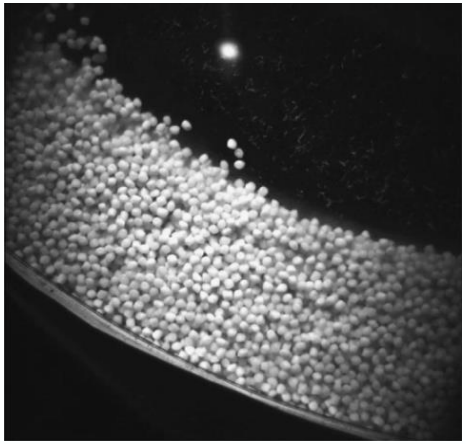
Cold-Flow Setup

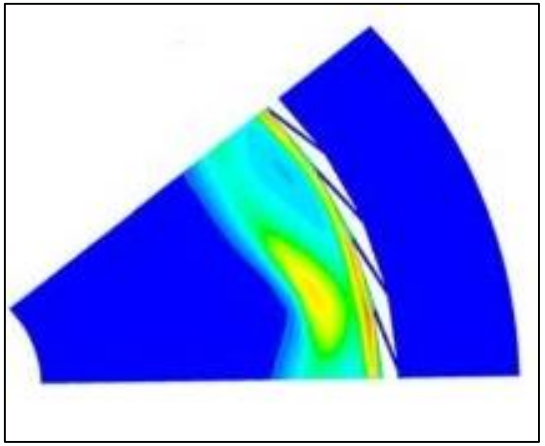
Hot-Flow Setup

Bed stability and maximum solids capacity in a Gas–Solid Vortex Reactor: Experimental study

J.Z. Kovacevic, M.N. Pantzali, G.J. Heynderickx*, G.B. Marin







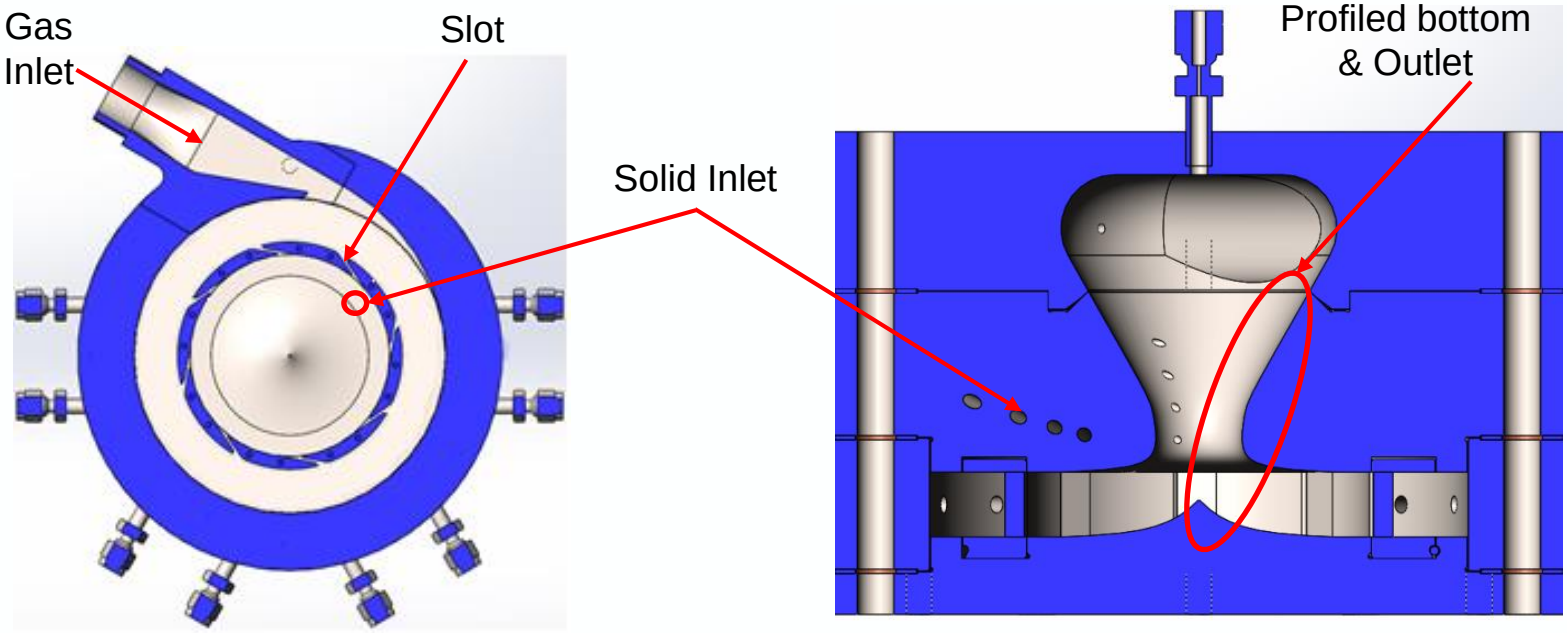
Modeling fast biomass pyrolysis in a gas–solid vortex reactor

Robert W. Ashcraft, Geraldine J. Heynderickx*, Guy B. Marin

Assessment of a Gas–Solid Vortex Reactor for SO_2/NO_x Adsorption from Flue Gas

Robert W. Ashcraft, Jelena Kovacevic, Geraldine J. Heynderickx,* and Guy B. Marin

Reactive GSVR



Operating Conditions:

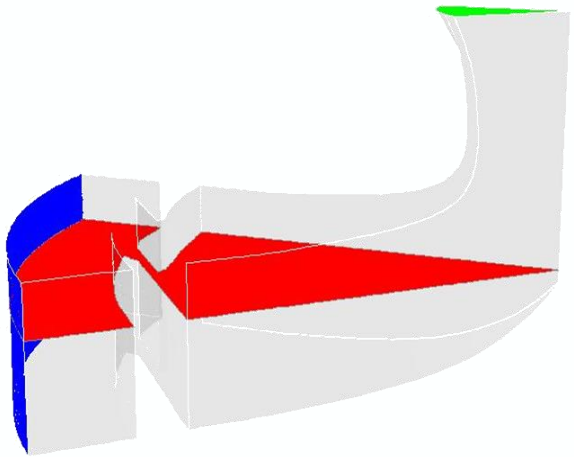
- Gas Flow: 5 - 10 g s^{-1}
- Biomass Flow: 0.14 – 1.1 g s^{-1}
- Gas Temp: 800 – 950 K

Schematics:

- Internal Diameter: 80 mm
- Length: 15 mm
- 8 slots, 1 mm width
- Outlet Diameter: 20 mm

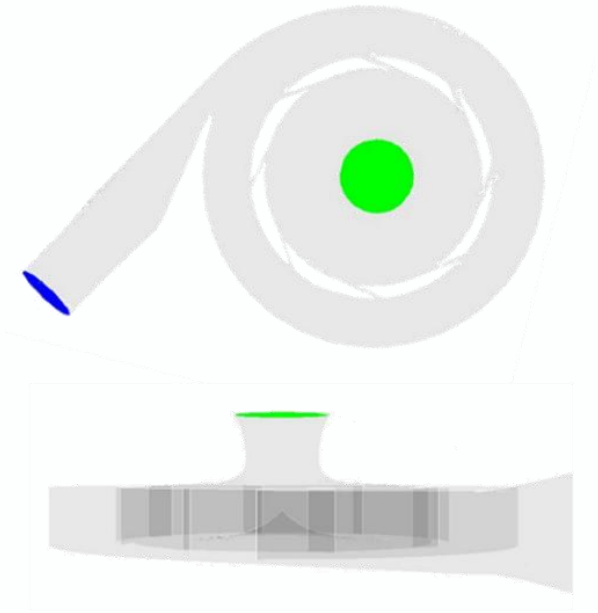
Simulation Conditions

Gas	Nitrogen
Density Modeling	Ideal-Gas
Inlet Temperature	842 K
Flow rate	10 g s^{-1}
Boundary Conditions	
Inlet Pressure	50 kPa (g)
Outlet Pressure	10 kPa (g)
N_2-Walls	No-slip
Gravity : Enabled (not significant)	
Eulerian-Eulerian model; ANSYS Fluent 15.0	

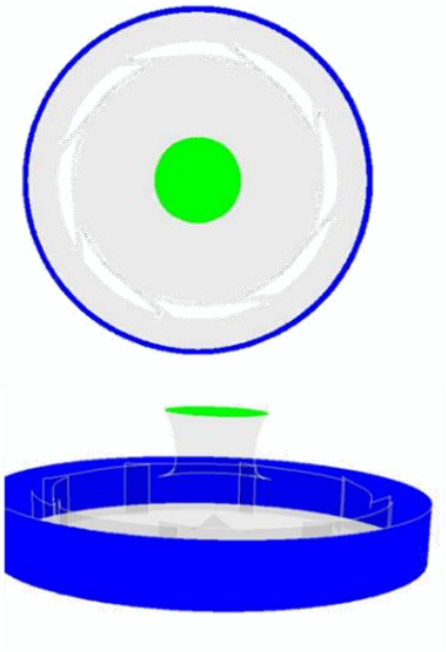


All results of these 3D simulations are studied on a horizontal plane at z = 10 mm.
Circumferentially averaged values are plotted.

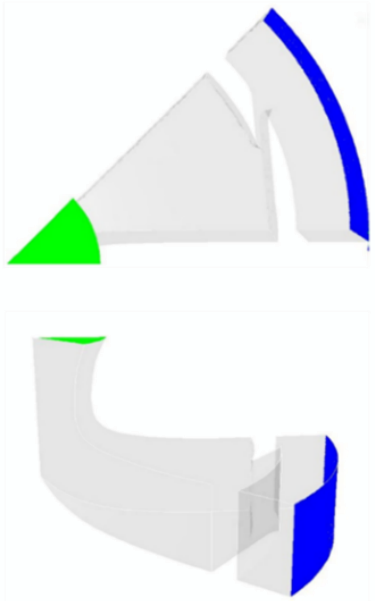
Computational Domain Study



Original inlet
(~2.3 mil cells)



Circular inlet
(~1.7 mil cells)

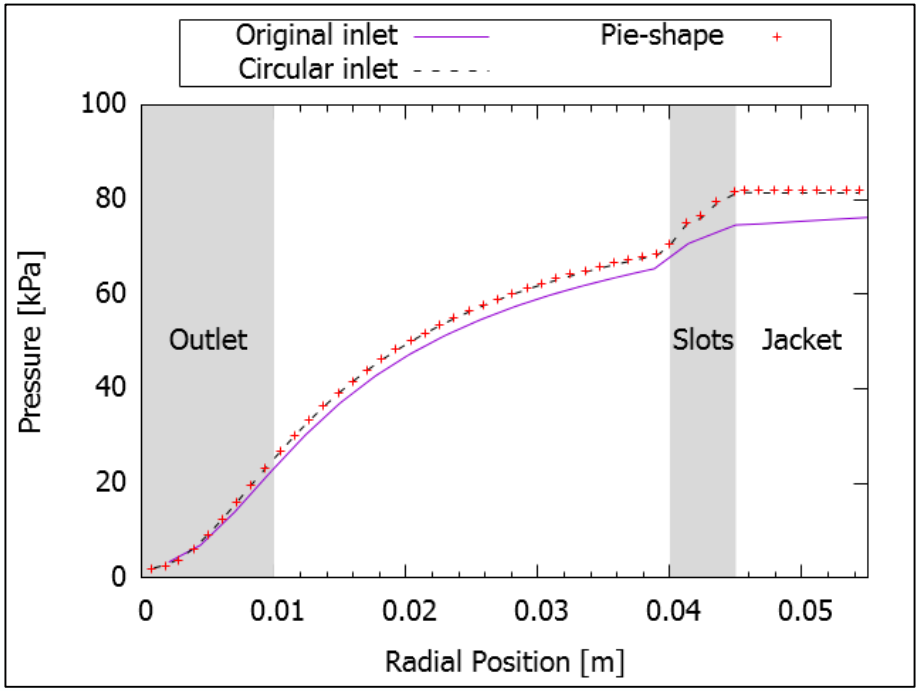


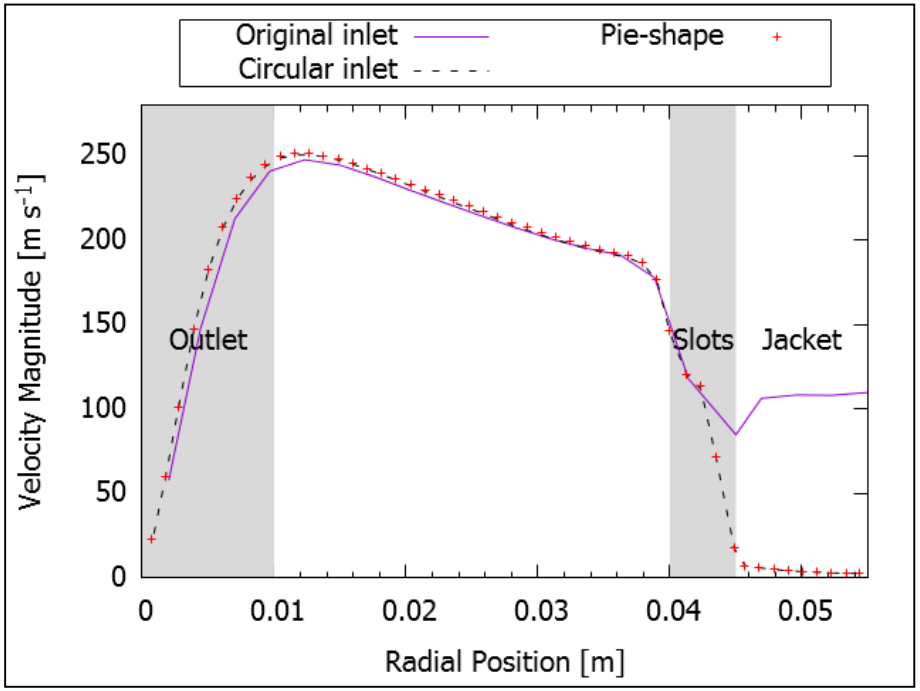
Pie-shape
(~0.25 mil cells)

CPU Hours	3400	2050	450

Turbulence model used: realizable k-ε

P, V Plots | Various geometries





Flow characteristics in reactor are captured in all configurations
→ pie-shape chosen for computational ease

Turbulence in GSVR

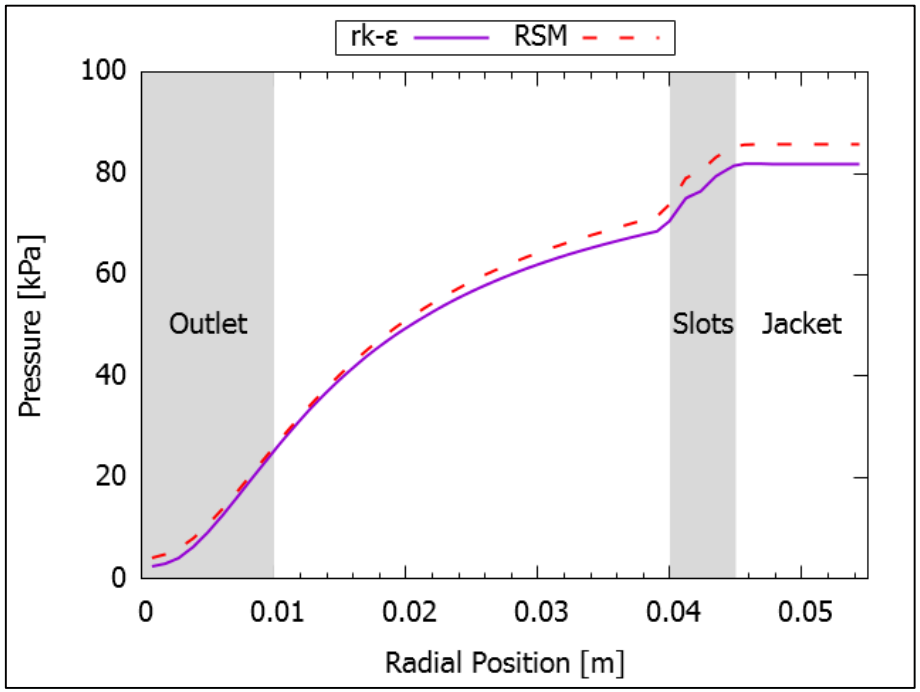
- Gas velocities: 60-140 m s^{-1} (at slots)

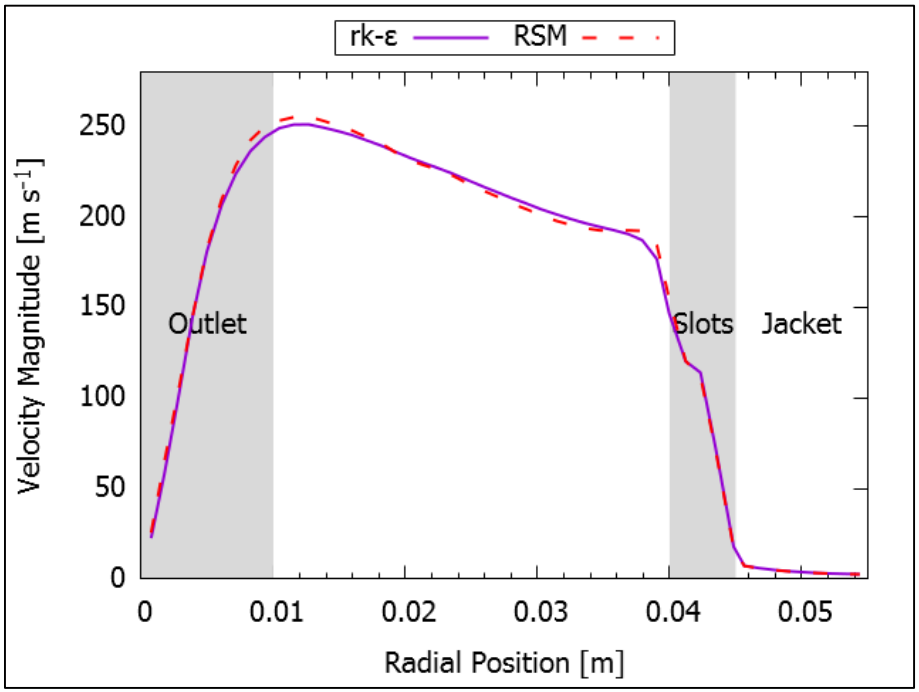
$$\text{Swirl Ratio } (S_{in}) = \frac{(\text{Gas azimuthal velocity})_{in}}{(\text{Gas radial velocity})_{in}}$$

- For reactive GSVR: S_{in} ~ 3-4; & Re: ~10^4-10^5
- S_{in} > 0.5 → turbulent flow [1]
- Highly turbulent, swirling flow in GSVR : realizable k-ε (rk-ε) or Reynold Stress Model (RSM) [2]
- Detailed secondary flow study (recirculation, counter-flow) crucial, specially in reactions where behavior of system with particles like fast pyrolysis is involved

[1] Vatistas et al., (1986), Reverse flow radius in vortex chambers, AIAA Journal
[2] ANSYS Fluent User's Guide, (2013)

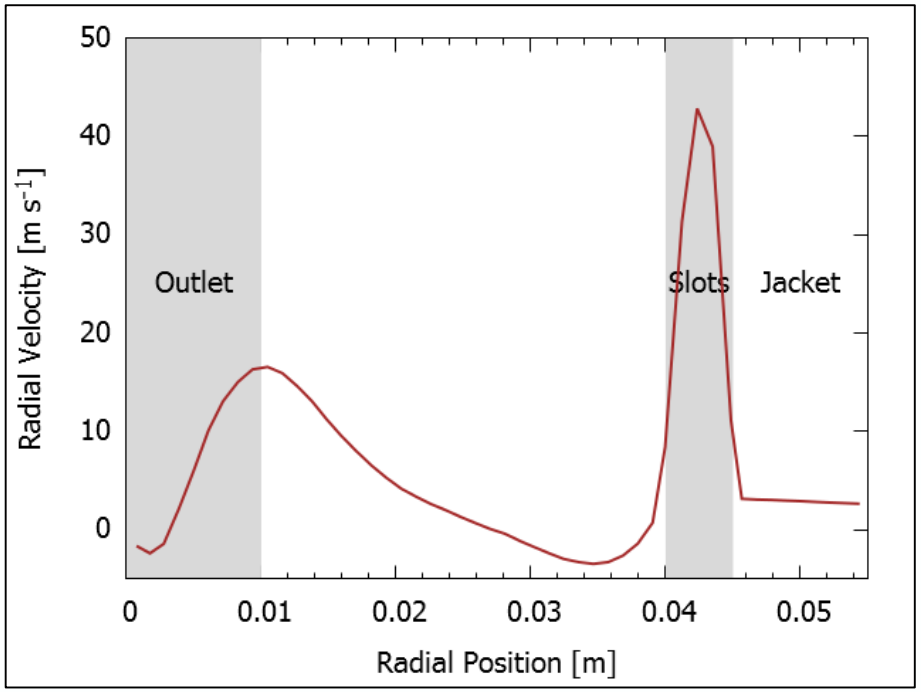
Turbulence Models Comparison

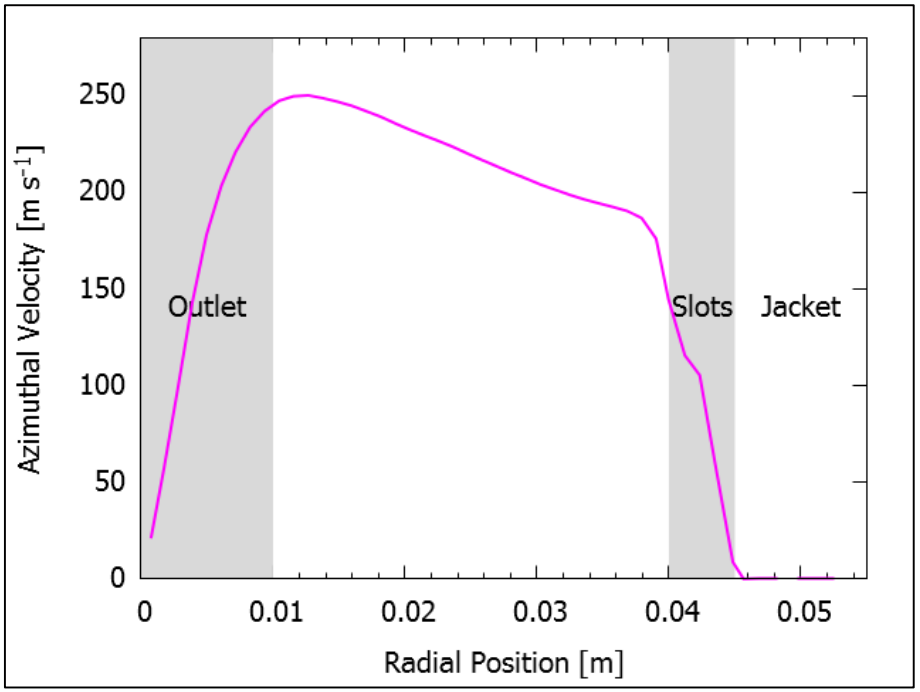




Both models perform satisfactorily at pyrolysis conditions → k-ε chosen for computational ease.

Gas Velocity



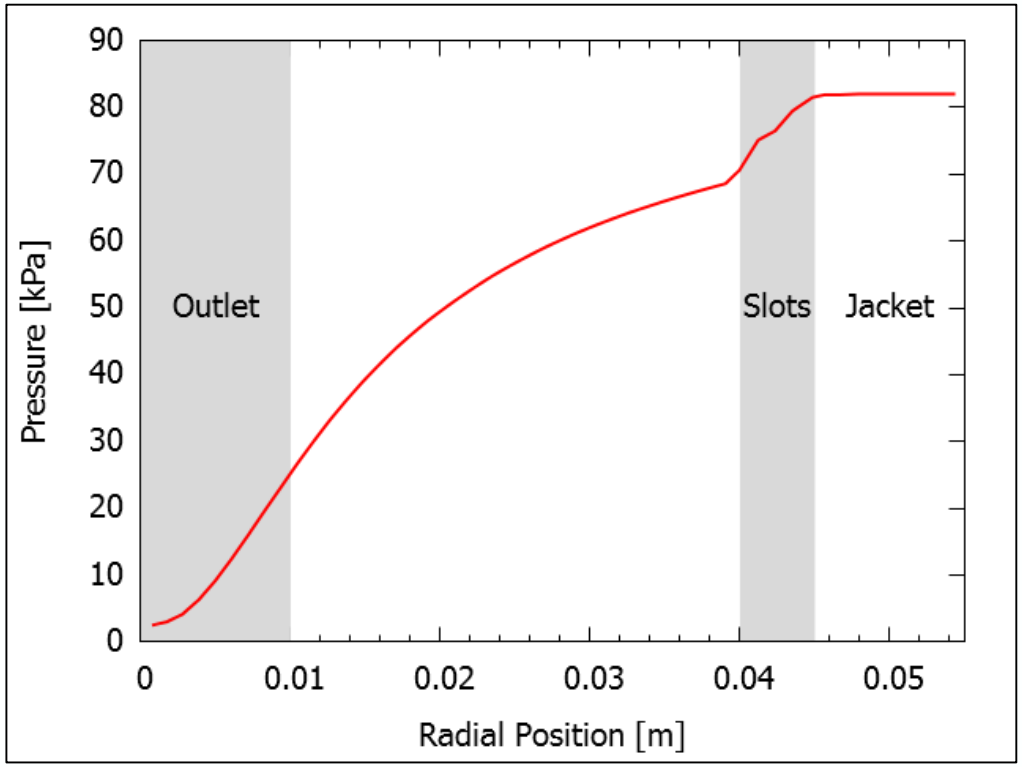


- Negligible radial velocities
- Rise towards outlet, more outflow

- Very high azimuthal velocities in slots.
- Sets up strongly swirling flow.

Gas Pressure

~40-45 kPa [1]



~10-12 kPa

Drop in pressure, indicates backflow

- Pressure drop will reduce with solids.
- Total pressure drop: ~ 20 kPa [2]

[1] Niyogi et al., (2016), On near-wall jets in a disk-like vortex chamber, AIChE Journal
[2] Pantzali et al., (2015), Radial pressure profiles in a cold-flow gas-solid vortex reactor. AIChE Journal

Summary & Conclusions

- GSVRs exhibit densely packed solid beds with larger width-to-height ratios & higher gas-solid slip velocities than FBs.
- Enhanced heat transfer characteristics allow for closer temperature control and is suitable for pyrolysis.
- Pie-shape (1/8th of entire reactor) chosen for computational advantages.
- Both realizable k-ε and RSM capture gas flow features in GSVR.

Future Work

- Study of solid beds under pyrolysis conditions.
- Incorporating various reaction mechanisms for biomass fast pyrolysis.
- Segregation and behavior study of various stages of biomass during pyrolysis.
- Quantifying heat transfer and process intensification assessment for biomass fast pyrolysis.

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