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Modeling and process features of plug flow reactor with internal recirculation for biomass pyrolysis

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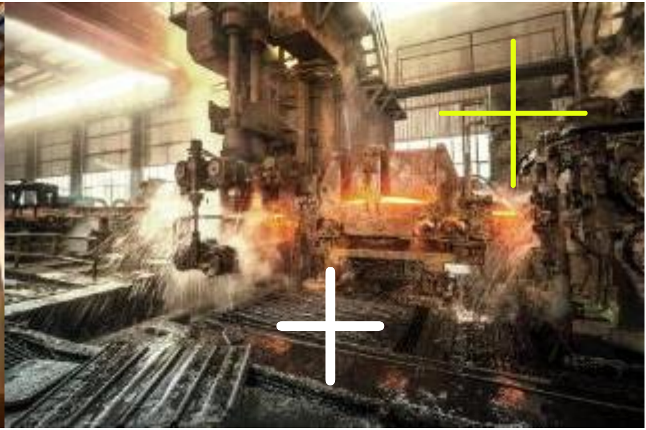
Modeling and Process Features of Plug Flow Reactor with Internal Recirculation for Biomass Pyrolysis





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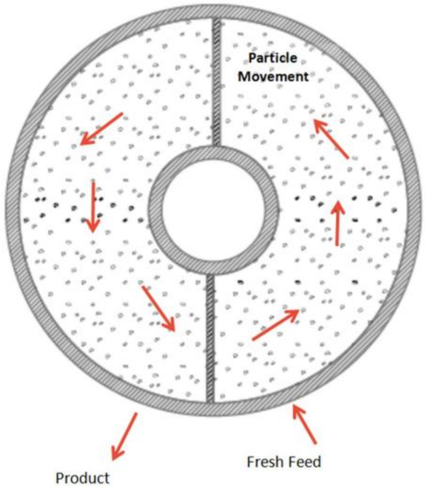
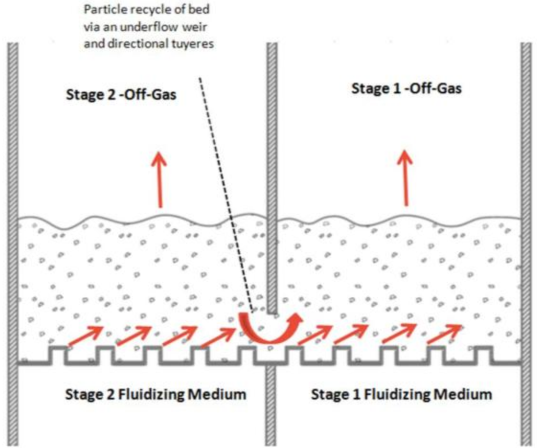
Plug Flow with Internal Recirculation (PFIR)

- Hot bed of sand mixed with biochar formed in-situ is internally circulated within a single fluidized bed between a pyrolysis zone and a heating zone.

- Circulation of material is achieved via momentum provided by the fluidizing gas which is introduced into the reactor using directional tuyeres.





Biomass Pyrolysis

- Fluidized beds offer a natural choice for pyrolysis reactors.

- Challenges:
  - Difficult to fluidize various biomass,
  - Need to supply heat to the process,
  - Maintain reducing gas environment.

- PFIR provides a concept, where both the pyrolysis and heating occur in a single reactor with well fluidized sand media circulation.

Theory

- Products of biomass pyrolysis include condensable fuel, light gases and biomass char.

- Char remains within the bed of sand, and is subsequently combusted in the heating zone, with the sand circulated back to the pyrolysis zone.

- Minimum sand circulation rate of 2– 5 X biomass feed rate is required for heat balance.

- At least 10 -15 % of biomass should be converted to combustible char, for PFIR to be autothermal.

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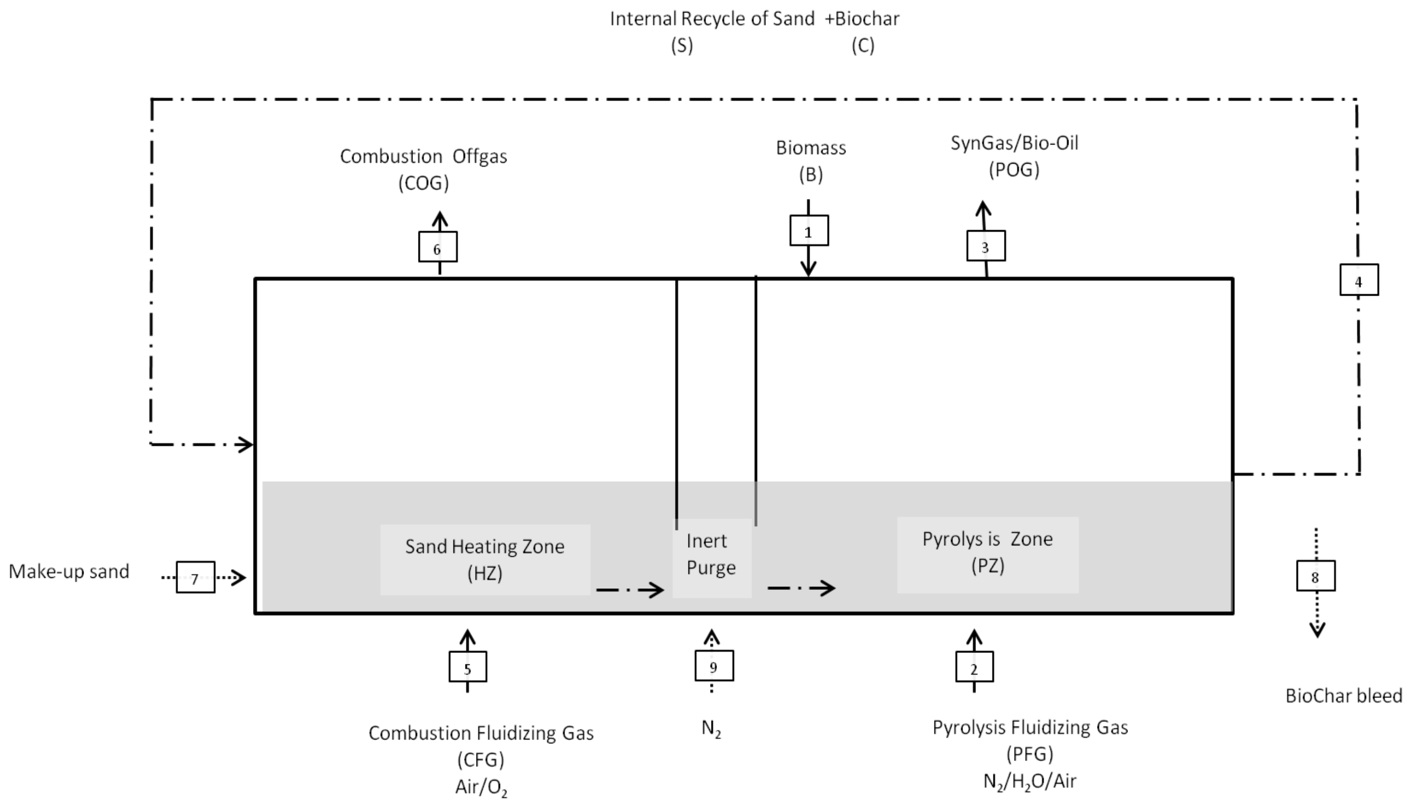
General arrangement



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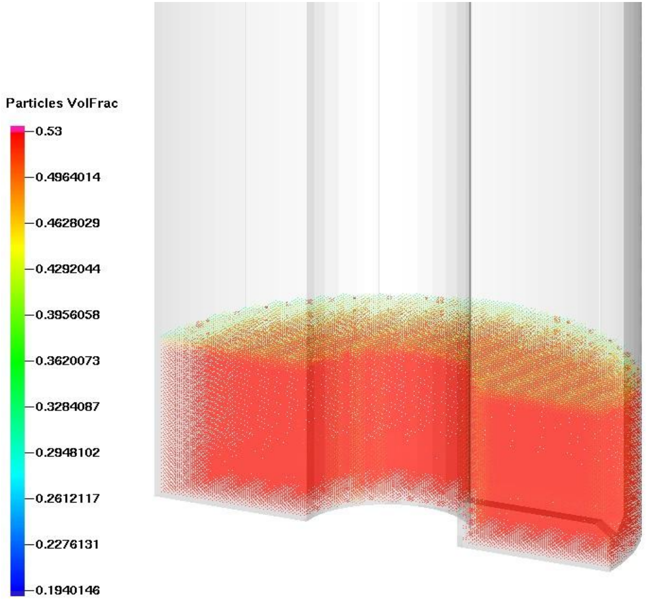
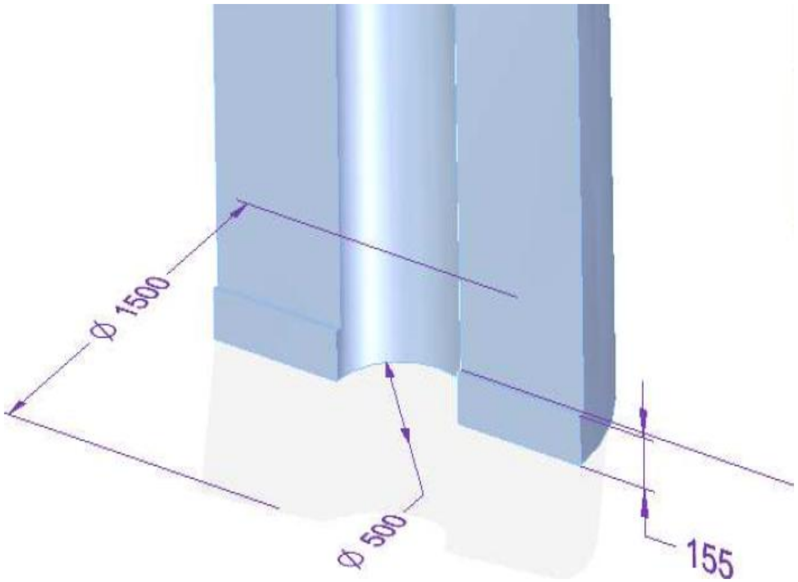
Modeling

- CPFD model using the commercial simulation software Barracuda® was created to understand the hydrodynamics within the vessel.





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Parameters

Parameter	Unit	Value
Reactor outer diameter	mm	1500
Reactor inner diameter	mm	500
Underflow weir channel height	mm	155, 250, 350
Number of underflow weirs	--	1, 2
Nozzle density	$\#/m^2$	100
Tuyere jet angle from horizontal	^{o}	25
Gas tuyere velocity	m/s	40, 60, 80
Fluidizing velocity	m/s	1
Bed height	mm	500
Particle diameter	µm	500
Particle solid density	kg/m^3	2000

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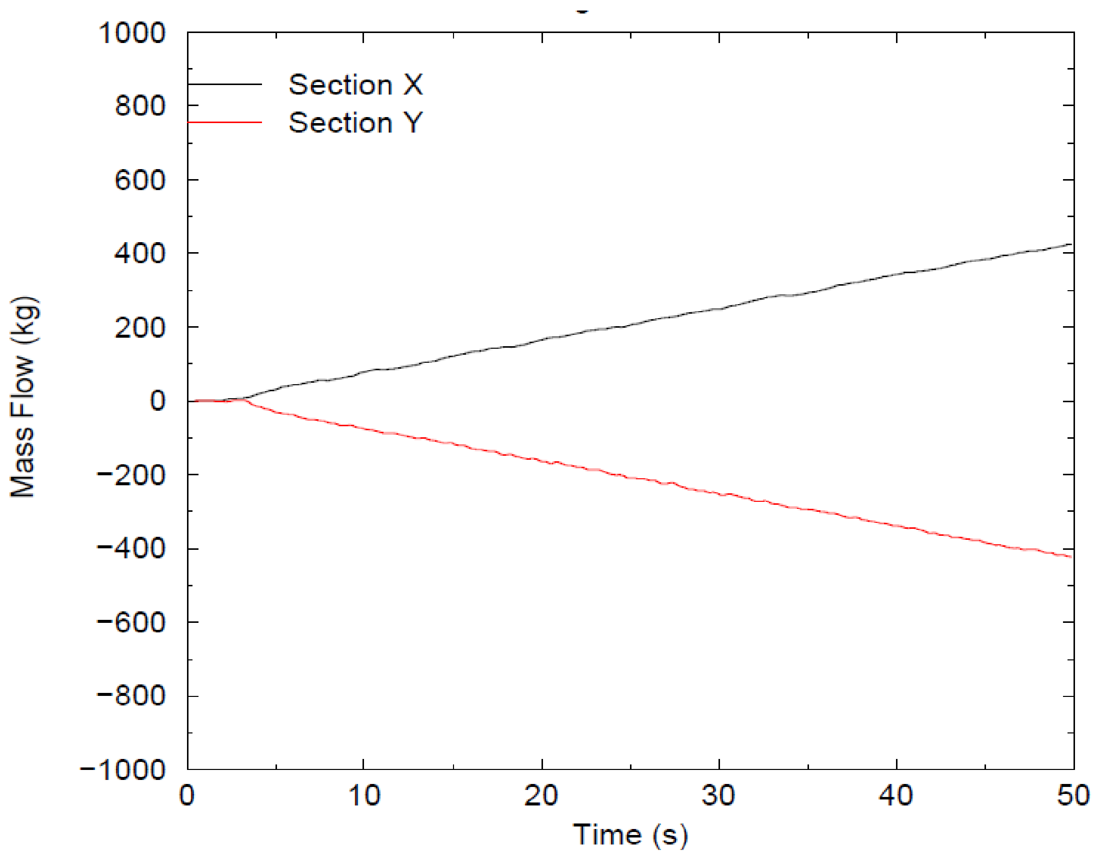
Results – 1/3

- Mass of circulating solids calculated by tracking total net mass which passes through a plane parallel to the vessel radius

- Sections X and Y are normal to the distributor and 180 degrees apart.

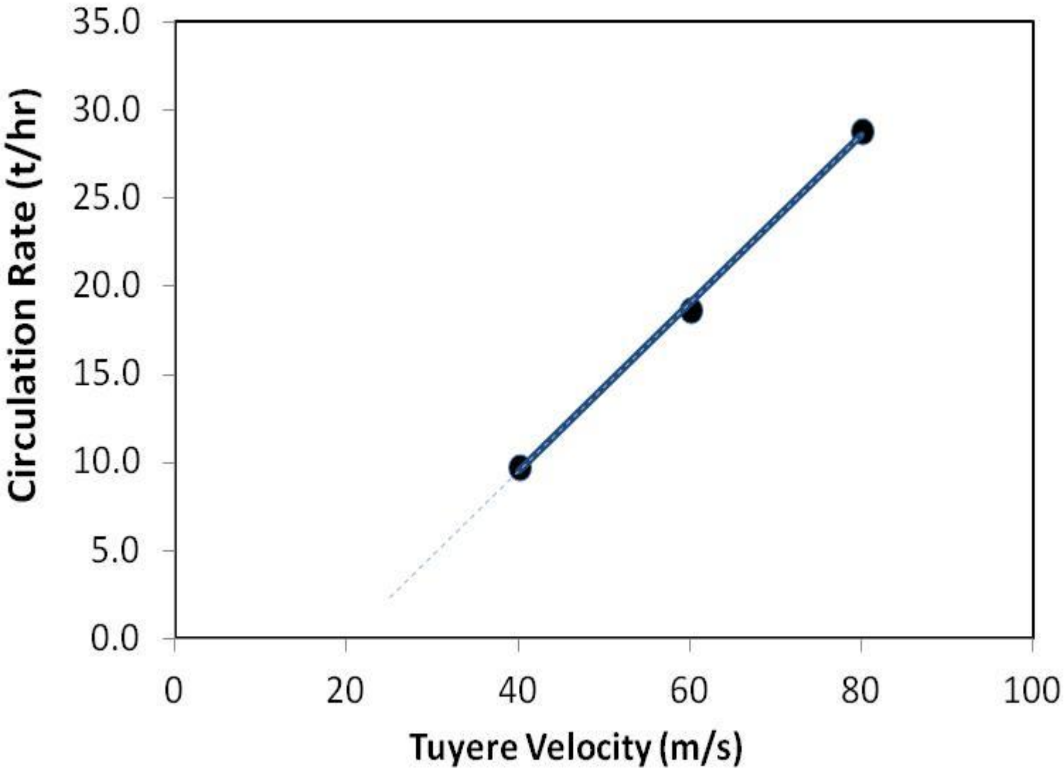
- Continuity and steady state were confirmed.



Results – 2/3

- Total mass flow rate of gas injected into the vessel was kept constant, and the tuyere velocity adjusted by adjusting the diameter of the tuyere entrance nozzles

- Mass flow rate averaged over 50 seconds of simulation for the three different gas velocities showed a linear relationship between circulation rate and tuyere velocity.



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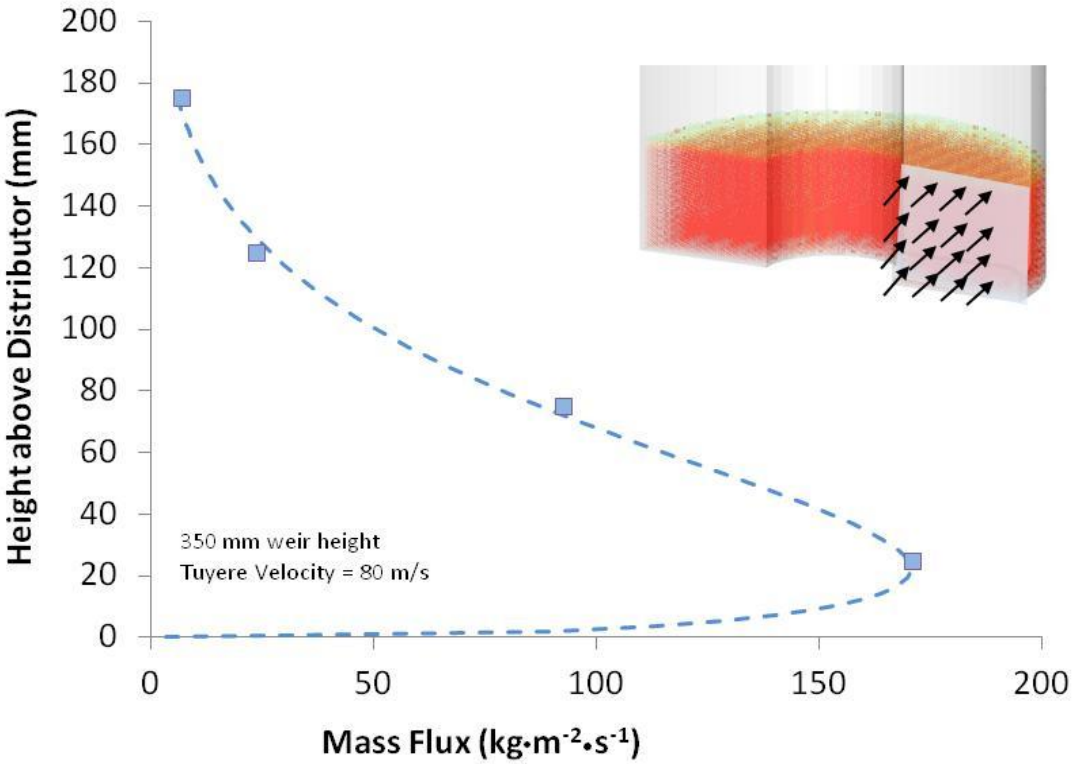
Results – 3/3

- Mass flux as function of height above the distributor was investigated.
- Modeling shows a distinct zone of rotation.
- Mass flux (solids momentum) decays as a function of height above the distributor.



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Conclusions

- Circulation rate can be controlled by proper selection of gas velocity at the exit of tuyeres.

- There is a distinct zone of rotation, and the mass flux (solids momentum) decays as a function of height above the distributor.

- Once the bed height is above this circulation zone, the fluidized bed is composed of two distinct zones: a rotating solids zone and a standard bubbling fluidized bed at heights above that.

- Height of this circulation zone appears to be independent of the number or height of the underflows weirs examined.

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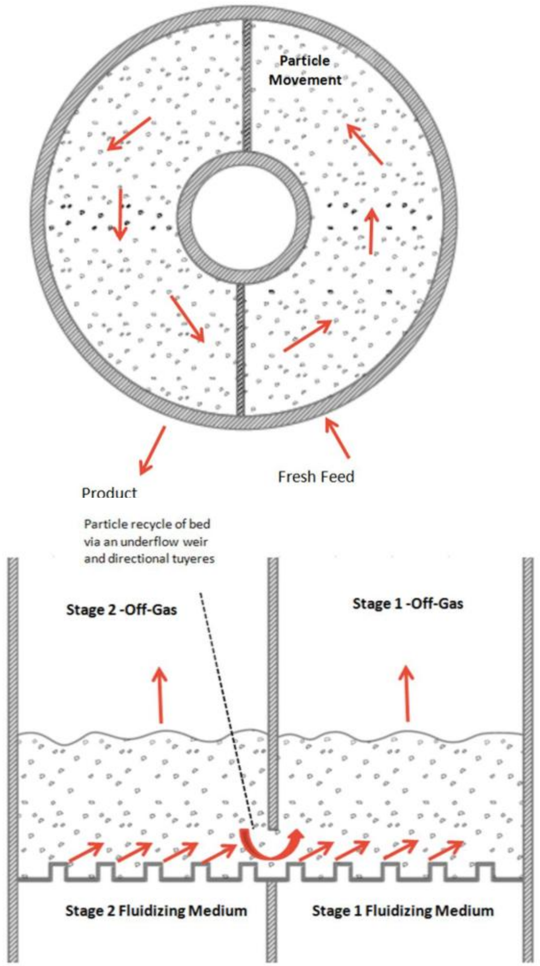
Next steps Required For Development

- Additional CPFD Study Items
  - Include feeding and discharge of solids
  - Impact of tuyere angle on circulation rate
  - Model with complete PSD of solids
  - Examine residence time distribution and reactor mixing
  - Tuyere and nozzle density (#/m^2)

- Experimental
  - Simple lab scale cold fluidization tests – confirm CPFD results
  - Small scale reactor performing pyrolysis at temperature

Applications of PFIR

- Biomass Pyrolysis
- Drying of hard-to-fluidize material
- Chemical Looping Reactors
- Two-Stage Roasting (e.g. Ox & Red)



Thanks for your attention!

Questions?

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