Microwave-Assisted Heating for Gasification

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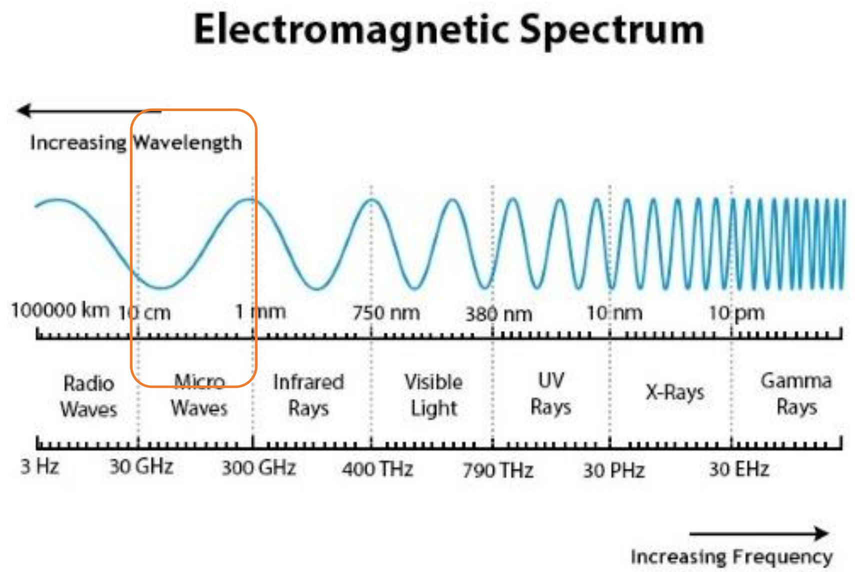
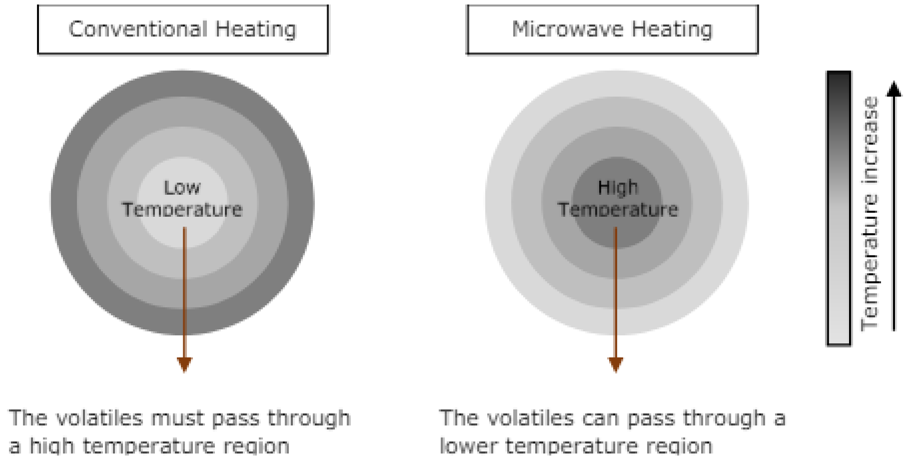
Introduction

Advantages

- Selective heating is key to process intensification
- Microwave (MW) heating enhances catalyst activity, selectivity, and stability
- Negligible heat losses compared to traditional heating: >60-65% conversion efficiency





Limitations

- High energy consumption
- Difficult to scale-up

[1]Adam, *Understanding microwave pyrolysis of biomass materials*. PhD Diss, 2017.
[2]Muley, et al. "Microwave-assisted heterogeneous catalysis." (2021).

Maxwell's Equations

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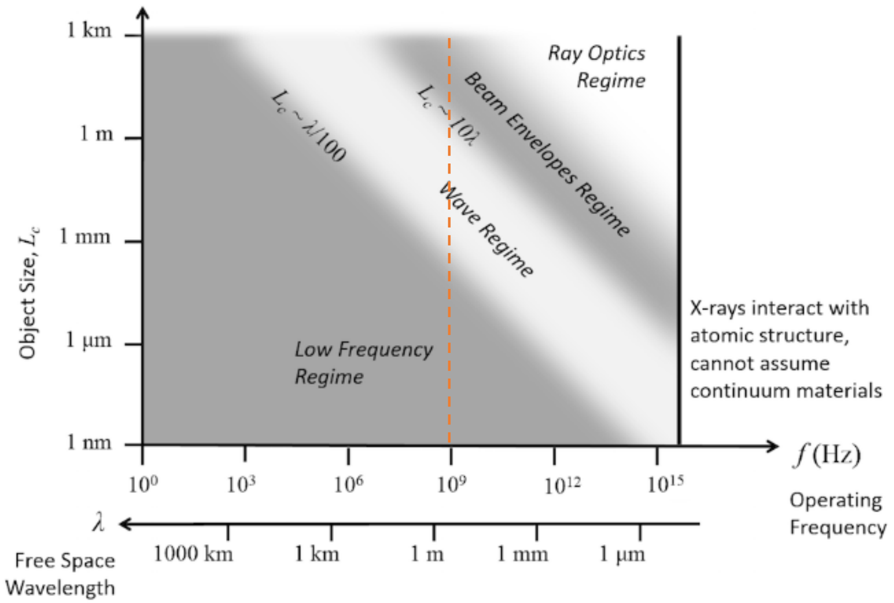
Maxwell's Equations: Frequency Domain

$$\nabla \times (\mu^{-1}\nabla \times \mathbf{E}) + (i\omega\sigma - \omega^2\epsilon)\mathbf{E} = \mathbf{0} \qquad \mathbf{B} = \mu\mathbf{H}$$

$$\mathrm{i}\omega\mathbf{B} = \nabla \times \mathbf{E}$$



<u>Electric properties</u>

$$\epsilon = (\epsilon' - i\epsilon'')$$

- ϵ': Ability to store electric energy
- ϵ'': Amount of electric energy that can be converted to heat

<u>Magnetic properties</u>

$$\mu = (\mu' - i\mu'')$$

- μ': Ability to store magnetic energy
- μ'': Amount of magnetic energy that can be converted to heat

σ = Electric conductivity

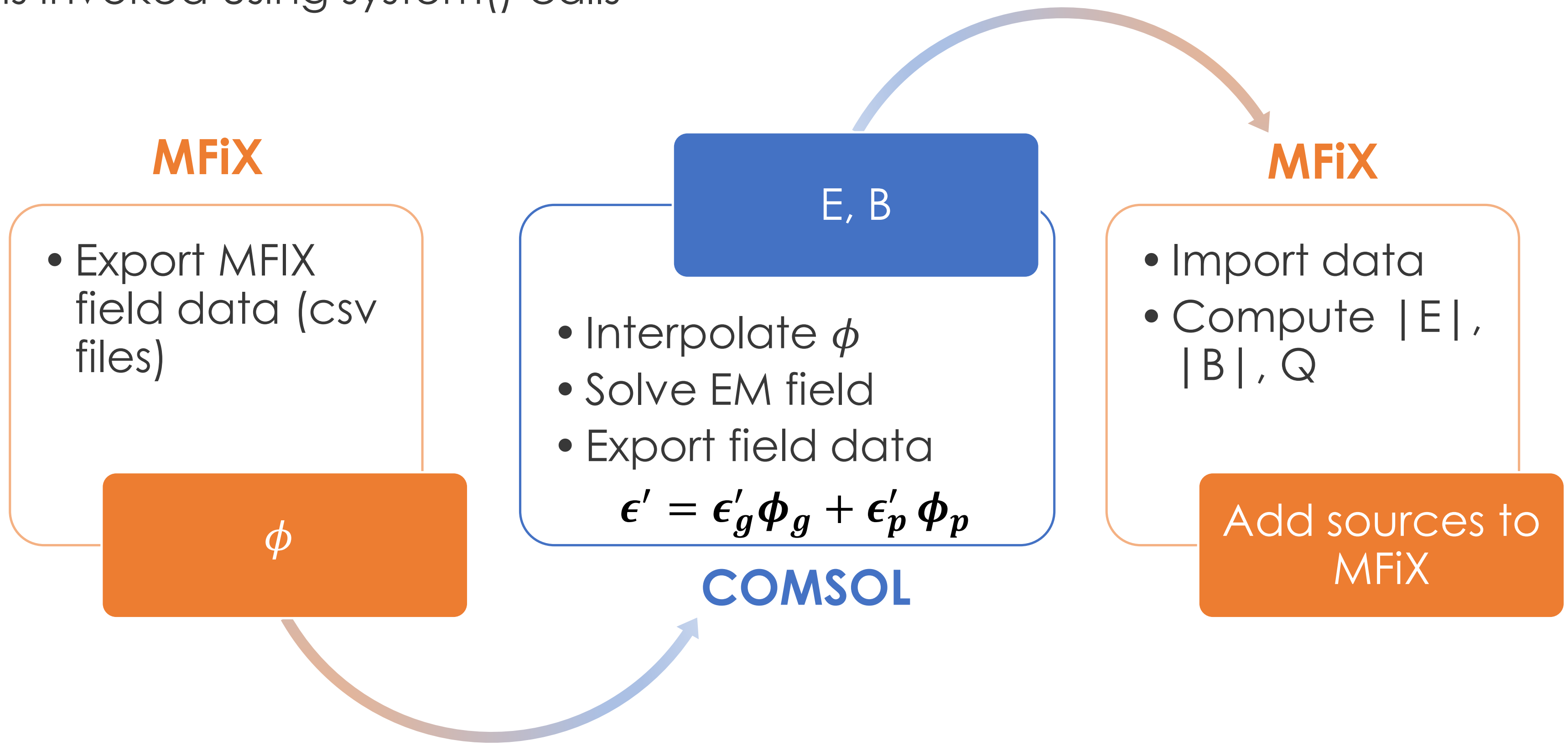
ω = Angular frequency

$$\epsilon, \mu, \sigma = f(\omega, T, humidity)$$

Volumetric power dissipated: $P = 0.5\sigma|\mathbf{E}| + 0.5\omega\epsilon_0\epsilon''|\mathbf{E}| + 0.5\omega\mu_0\mu''|\mathbf{H}|$

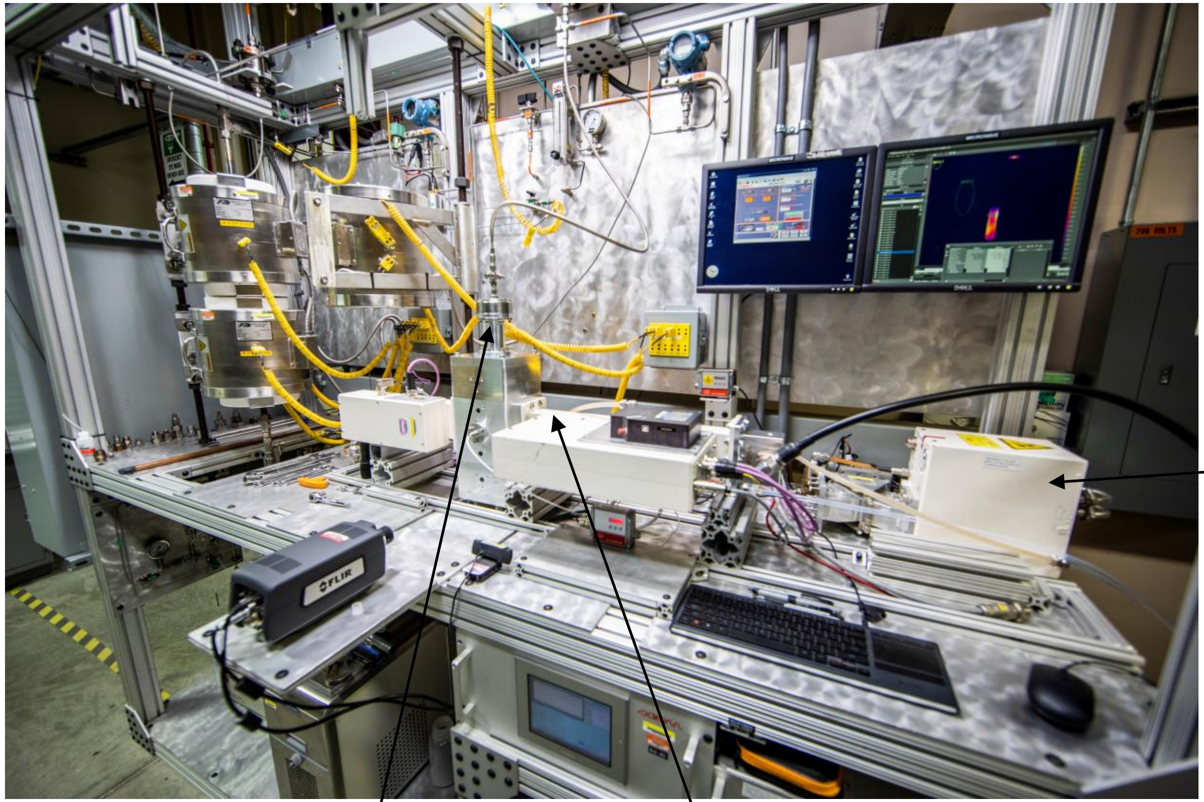
Methodology

- MFiX (fluid dynamics) and COMSOL (electromagnetics) are coupled via file input/output
- COMSOL is invoked using system() calls



MW-Fluidized Bed

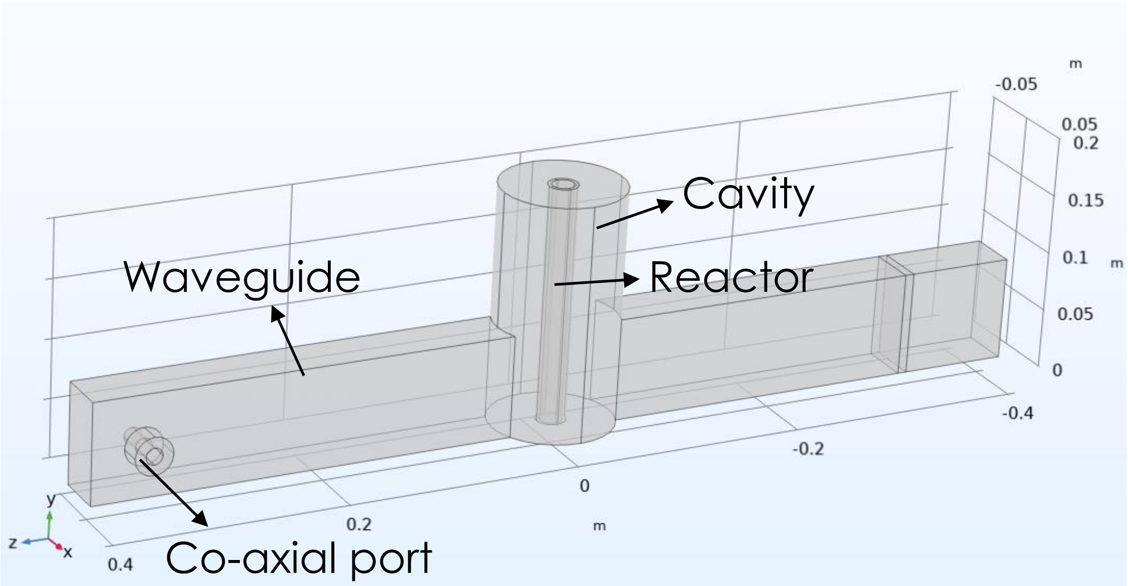
Microwave Setup at NETL

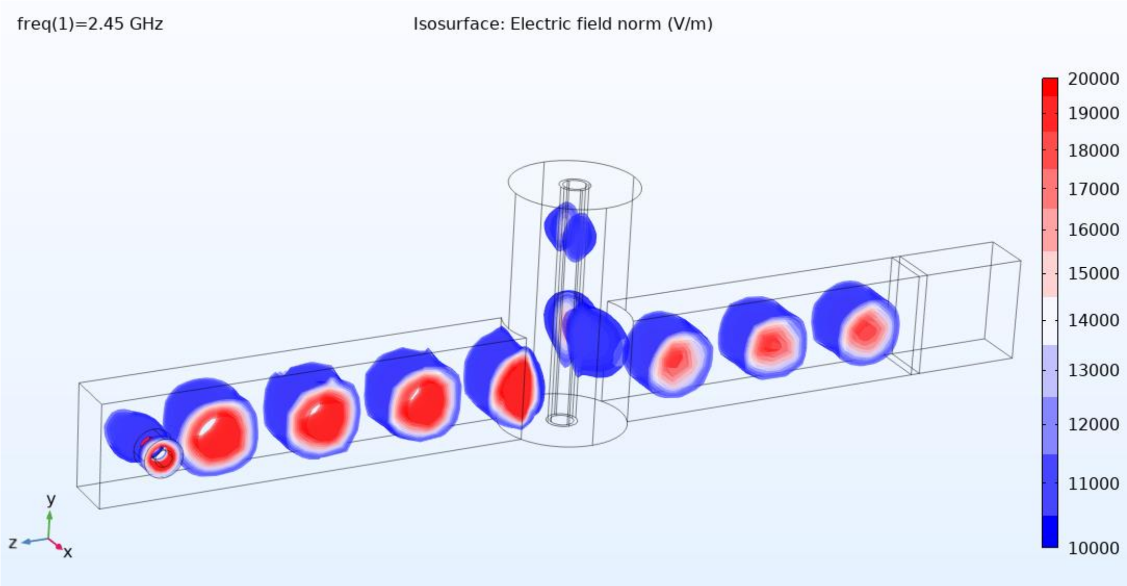


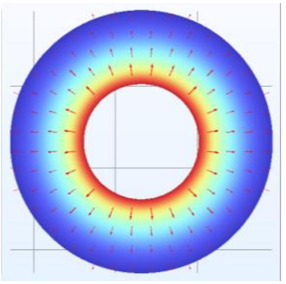
- Reactor: D = 19 mm, H = 200 mm
- Bed mass = 18 g
- Input power = 100 W

MW-Fluidized Bed

COMSOL Setup



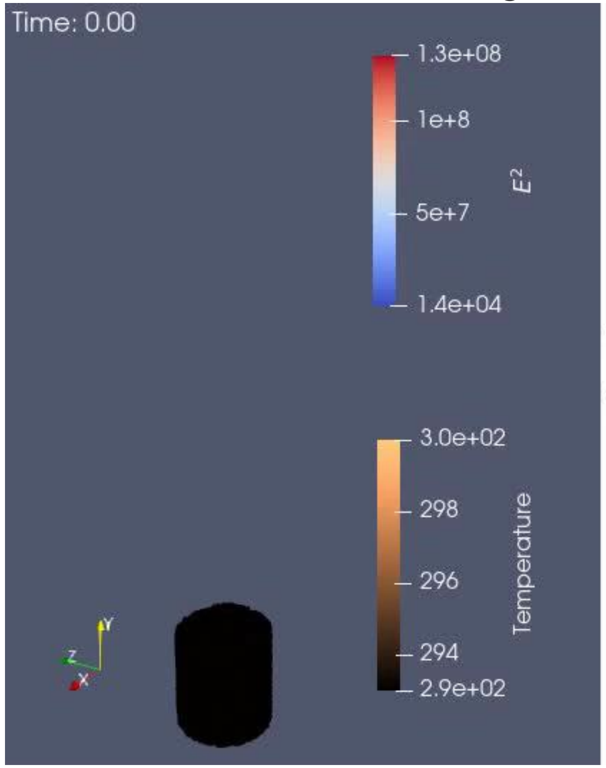


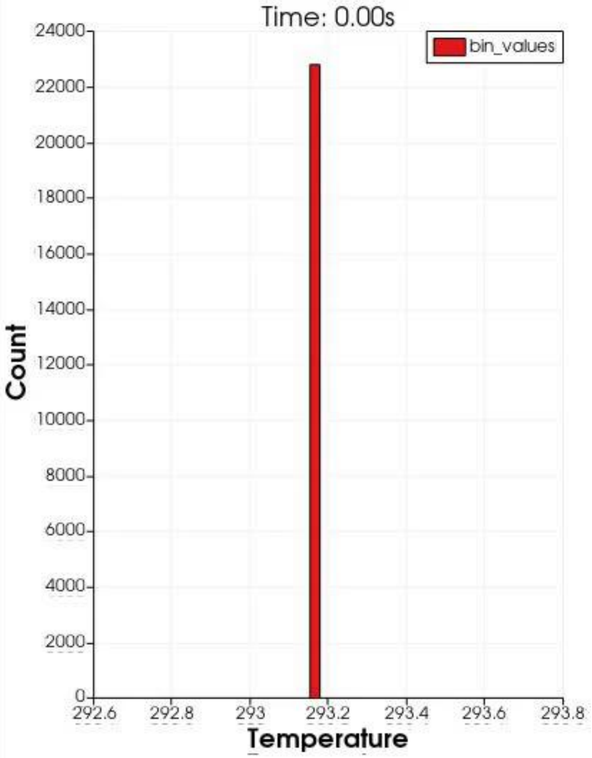


SMD (μm)	Density (g/cc)	κ (W/mK)	$C_{p,s}$ (J/Kg.K)	ε', ε''	μ', μ''	σ (S/m)
180	5.17	8	1340	**12.57, 0.89**	**1.52, 0.31**	**5.4**

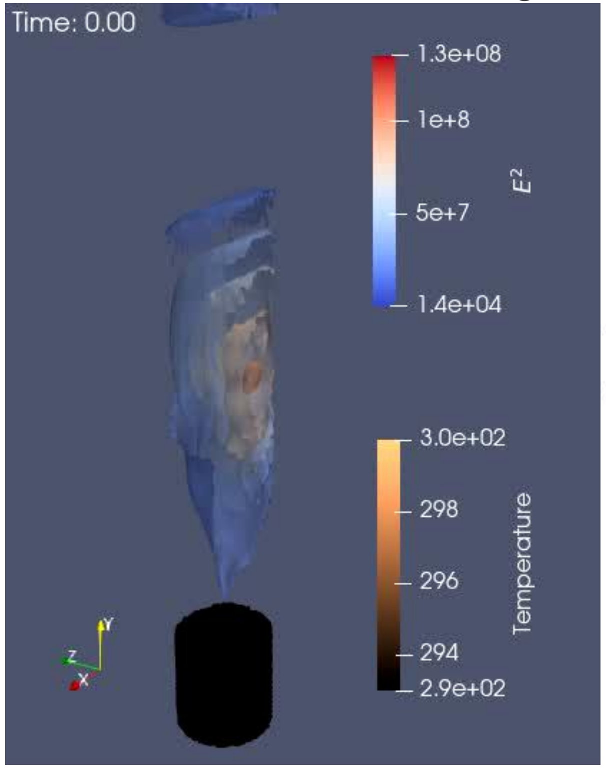
MW-Fluidized Bed

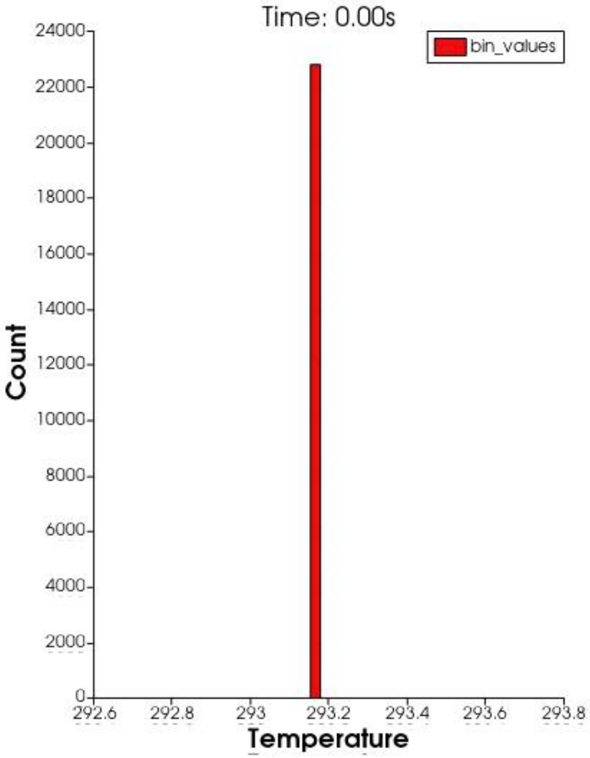
U_g = 32 cm/s





U_g = 53 cm/s





Direction of electromagnetic field

Results

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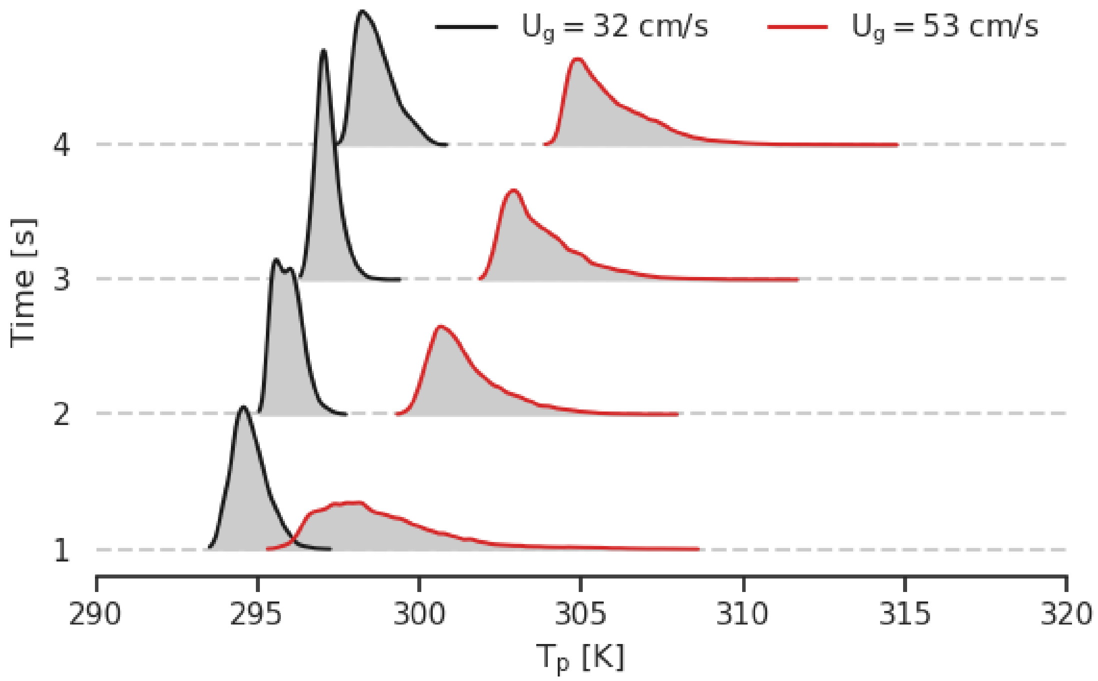
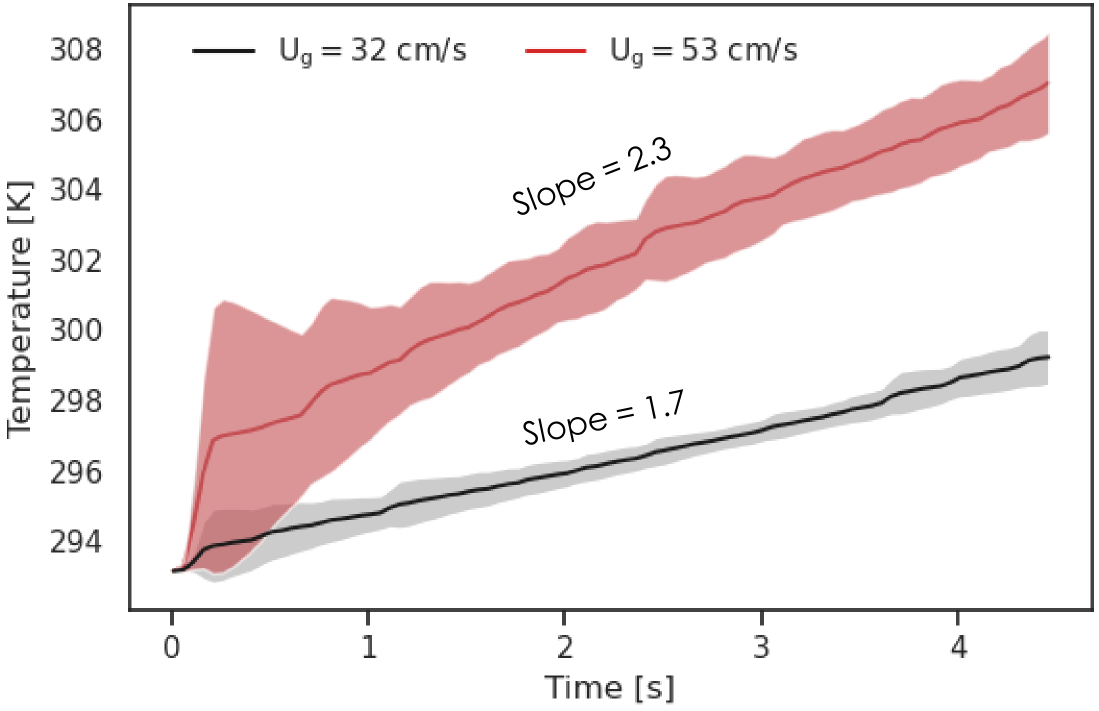
- At higher velocity, the particle temperature distribution is wider with a large right tail
- The temperature increases linearly with time



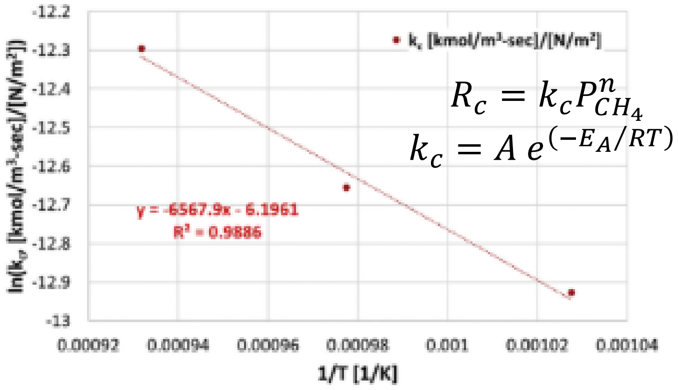


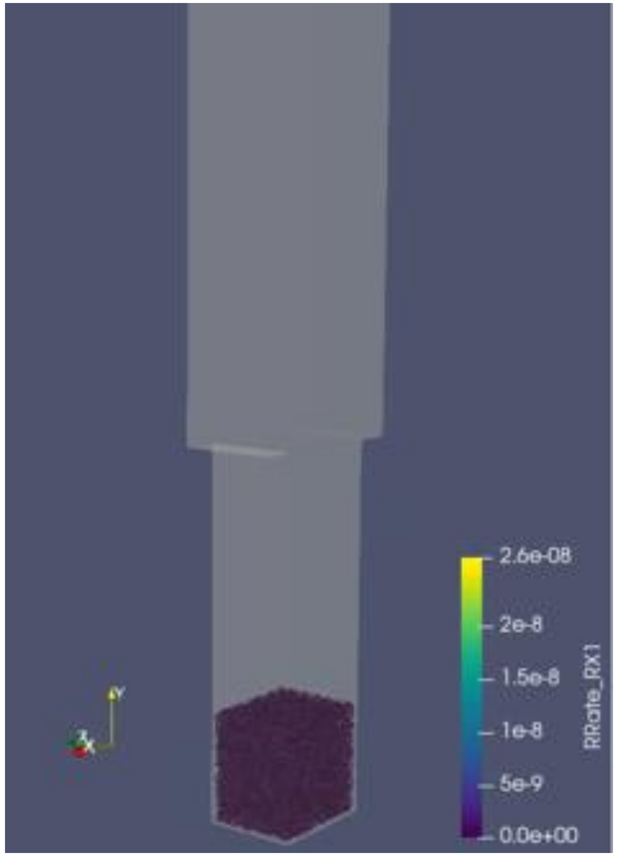
Methane Pyrolysis

- Reaction: $CH_4 \rightarrow C + 2H_2$

	Solids	Gas
$\rho(kg/m^3)$	2900	~1.18
$V_{in}(m/s)$	0	0.3
T_{in}(K)	953	953
P (Pa)	-	1e+6
Y	-	H_2 : 0.04, CH_4: 0.96

Chemical Kinetics[1]



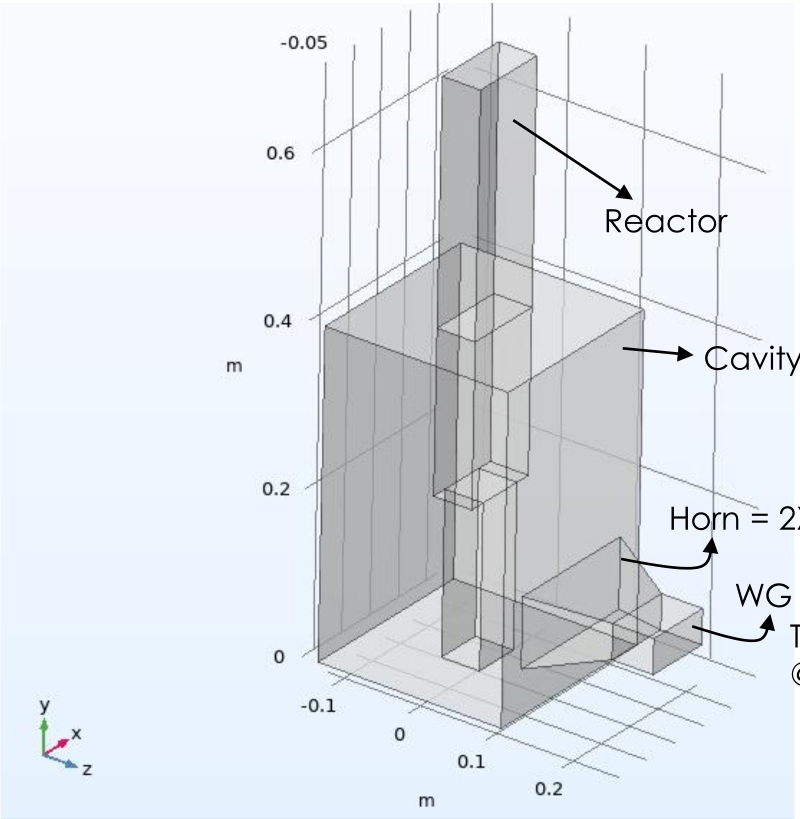


- Bed mass = 0.26 kg
- Adiabatic walls
- Drag-model: Gidaspow blend

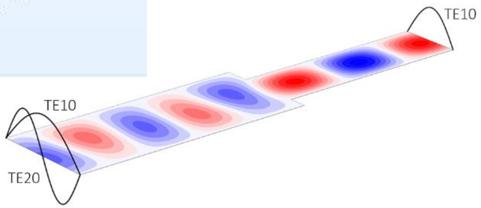
[1] Jarrett, et al. IJHE 46.39 (2021): 20338-20358.

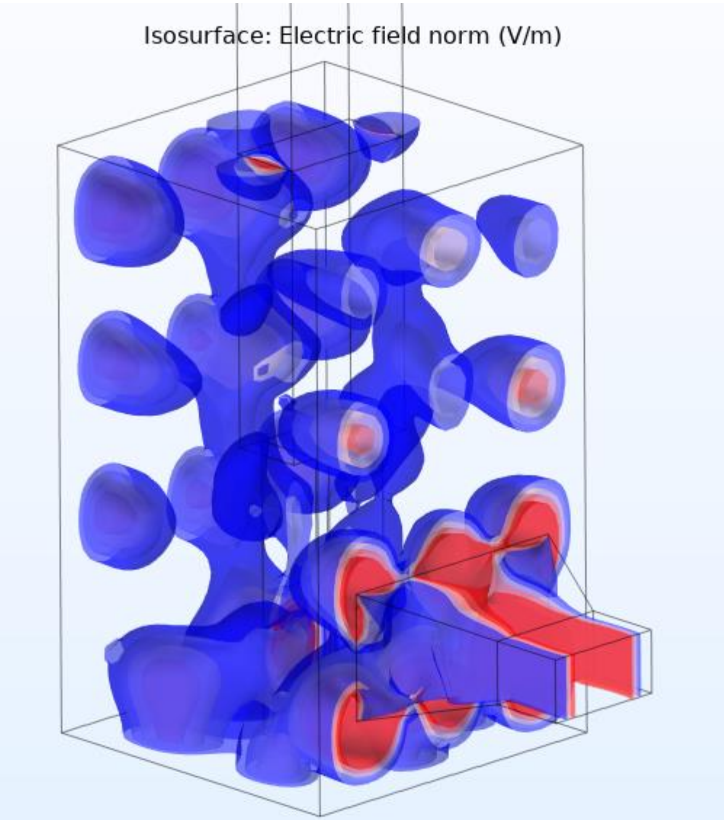
Methane Pyrolysis

COMSOL Setup



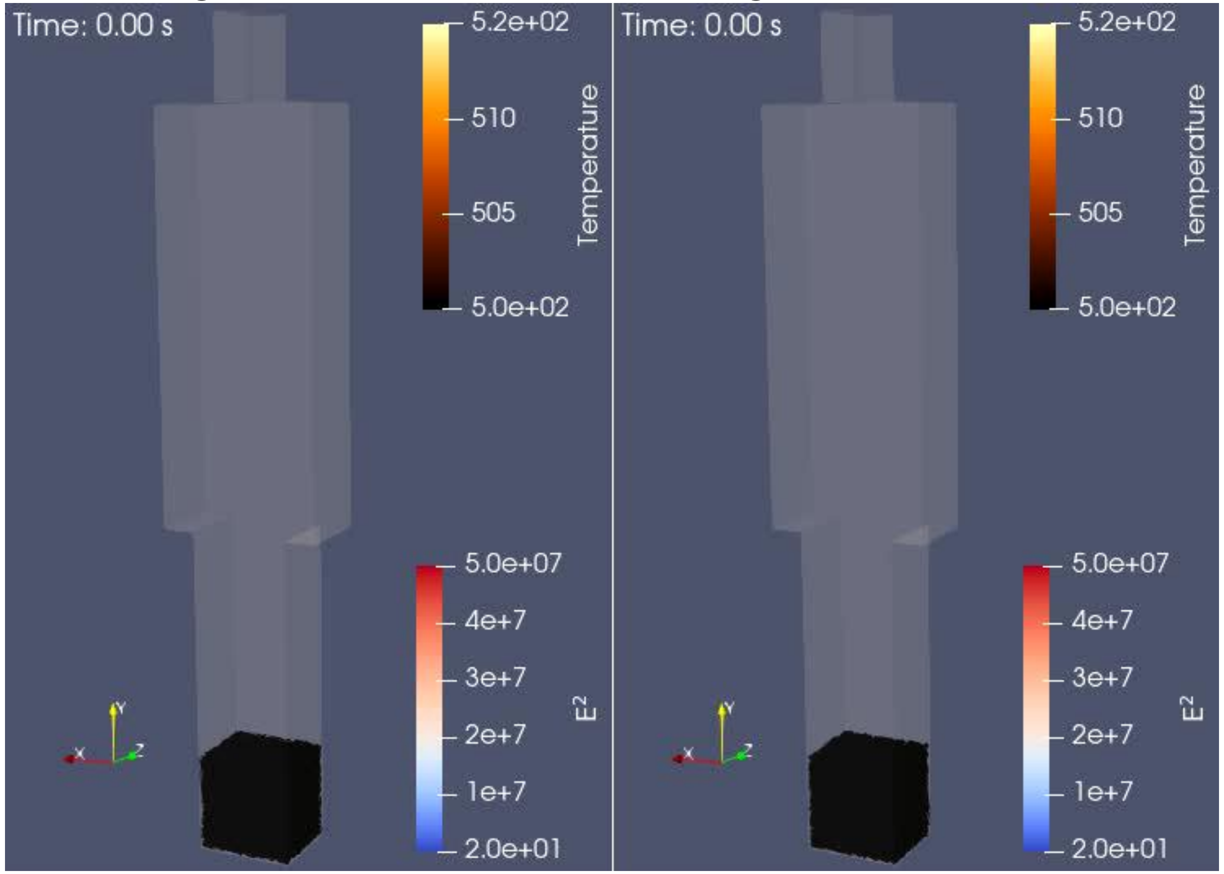
P (W)	$d_p (\mu m)$	ε', ε''	μ', μ''	σ (S/m)
200	350	**4, 0.18**	**1, 0**	**0**





Methane Pyrolysis

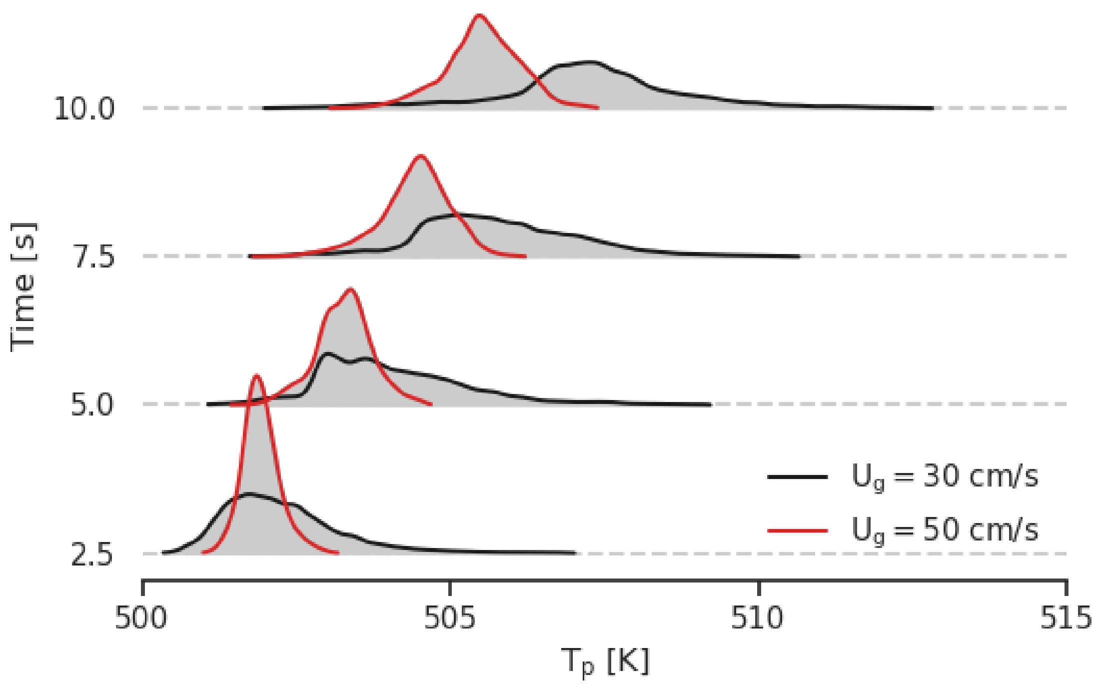
U_g = 30 cm/s $\qquad$ U_g = 50 cm/s

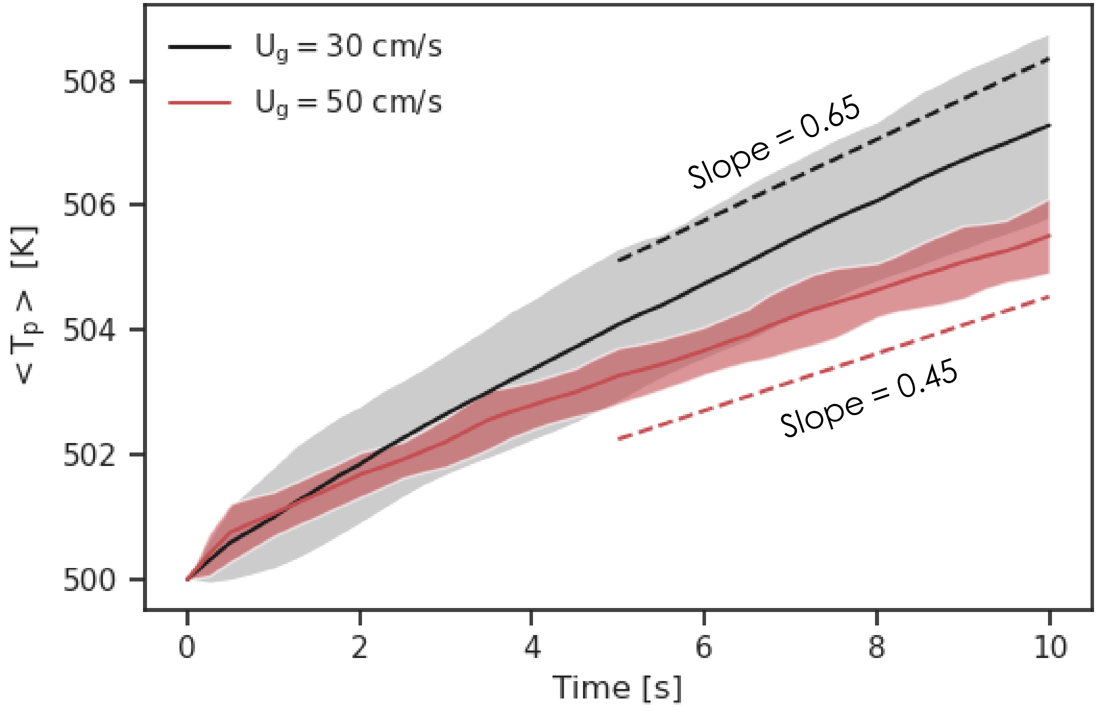


Direction of electromagnetic field

Results

- At lower velocity, the particle temperature distribution is wider with a large right tail
- The temperature rise is quadratic initially and linear after that
- Compared to the fluidized bed, the trends are inverted. Likely due to differences in electric field





Summary

- COMSOL and MFiX are coupled to investigate MW heating in gas-particle systems
- Investigated particle heating in reacting and non-reacting fluidized beds
- Future directions
  - Validate coupling using data from fixed bed experiments
  - Compare heated gas v/s wall heating v/s MW heating
  - Heating from multimodal EM waves
  - Couple MFiX and Elmer via Message Parsing Interface (MPI) Multiple Programs Multiple Data (MPMD) execution model

Acknowledgments

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