Decarbonizing Biomass Drying by Incorporating a RF Preheating Module into Convective Dryer Systems

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Overview

- Most industries utilizing biomass materials store their high-moisture materials outside or otherwise in ambient conditions ahead of drying. This means that high moisture materials are often at wet-bulb temperature during the summer months and close to freezing during the winter.
- While heat of vaporization dominates the energy consumed during evaporative drying, the energy to heat the materials and their water content from 3C to 90C can be considerable.
- The time to heat the materials from ambient/wet-bulb to 90C is very long in belt dryers which drives up capital cost, increases the system footprint, and increases carbon emissions.
- Wood chips and biomass particles do not conduct heat well which leads to low efficiencies for air-based systems. Thus, decoupling raw material heating from the actual evaporative drying equipment can improve overall system efficiency, cost, and carbon emissions.
- A radio frequency (RF) preheating module is proposed as an addition to modular convective dryers. Radio frequency heating at intermediate frequencies (e.g., 27 MHz) maximizes the delivery of energy to the materials of interest and has relatively higher bed penetration.
- RF energy is preferentially absorbed by water molecules, causing rapid heating when water comprises a substantial portion of the mass of the material being heated.
- While the energy efficiency (energy absorbed by product / total energy consumed) of heated-air dryers is in the range of 40%, industrial tunnel RF heating systems can operate in the 75-80% energy efficiency range.
- Dryer modulization and utilization of RF heating during the material warming part of the drying curve allows for partial electrification providing further reduction in carbon emissions.

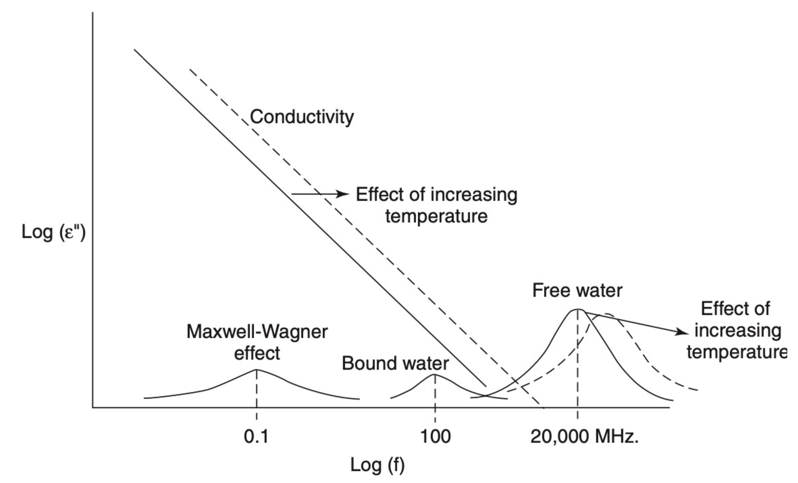
Technical Approach

- Washington State University's team led by Dr. Juming Tang with Ren Yang and Shuang Zhang have measured the dipole properties of Douglas fir chips and corn stover across a range of moisture content levels, temperatures, and bulk densities. They have similarly measured the dipole properties of corn stover.
- With the measured dipole they have built a FEM based simulation model and validated the simulation with a 12kW laboratory batch RF heater.
- Forest Concepts team led by Dr Jim Dooley, PE and Chris Lanning, PE have built on past work to create a comprehensive drying model to represent small biomass particles in convection dryer.
- A preliminary TEA suggested that using RF energy to heat materials ahead of convection drying may save more than 10% in time and more than 25% in energy.
- A comprehensive TEA based on the completed RF data sets and convection drying model is underway.

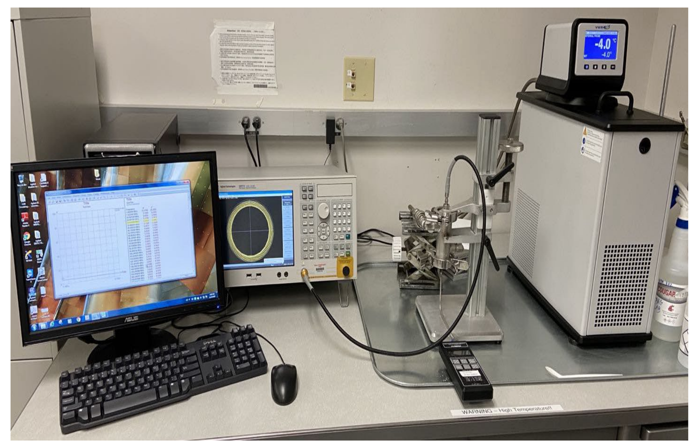
Citations

[1] Whitaker, S. (1977). Simultaneous Heat, Mass, and Momentum Transfer in Porous Media: A Theory of Drying. In J. P. Hartnett & T. F. Irvine (Eds.), Advances in Heat Transfer (Vol. 13, pp. 119-203): Elsevier.
[2] J. Tang, H. Feng, and M. Lau, Microwave heating in food processing, in X. Young and J. Tang, eds., Advances in Bioprocessing Engineering, World Scientific, 2002

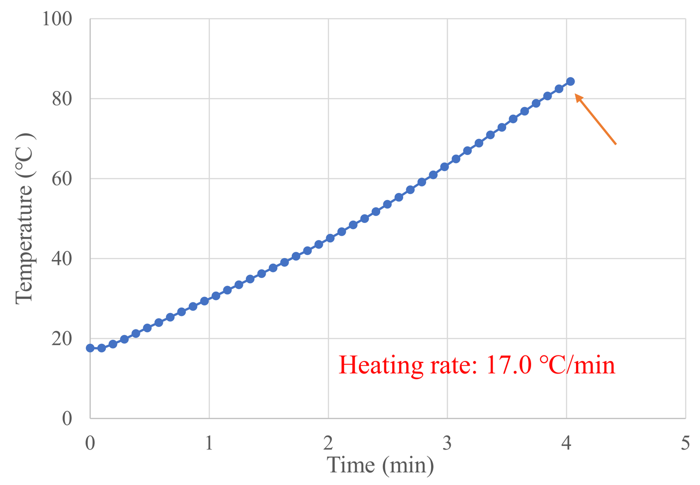
RF Measurements and Simulations (WSU)

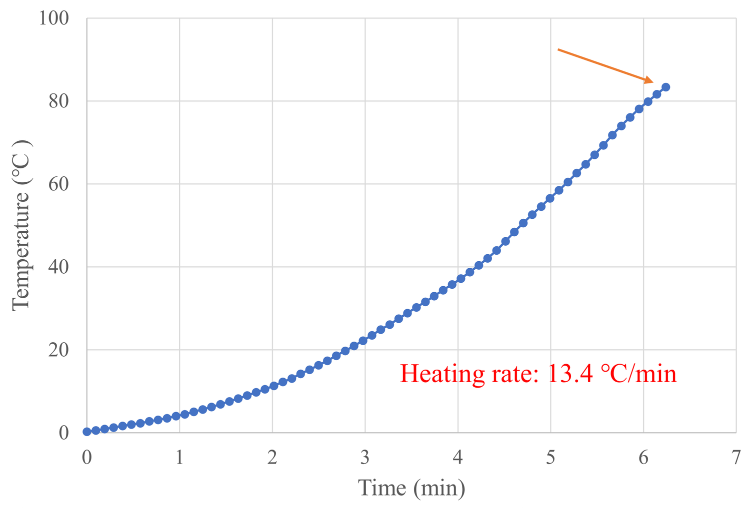


Contributions the loss factor (ε") as a function of frequency (f)[2]
At RF range, electric energy can be converted to thermal energy throughout the body of material. In low moisture material, bound water helps convert electrical energy to thermal energy.



Dipole Measurement System, Washington State University Lab
The system is specifically designed to measure key dielectric properties of materials over a range of densities and moisture levels.



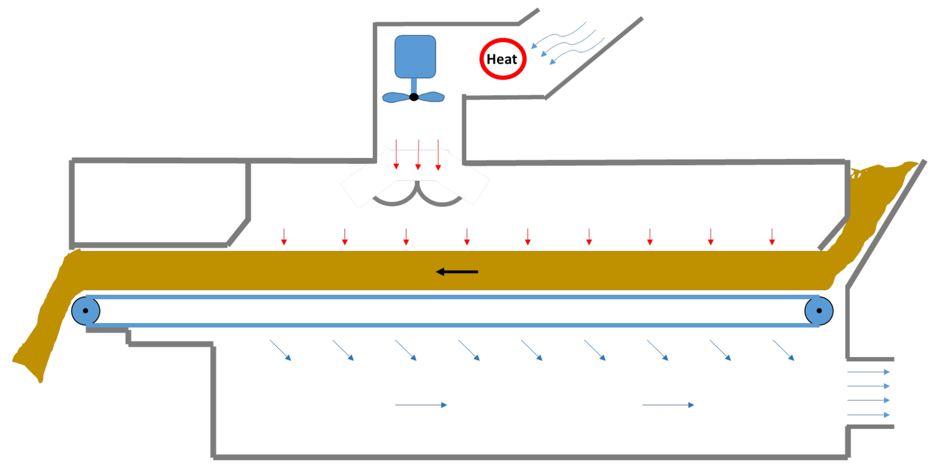


Experiment results: Average RF heating of 50% MCwb 6mm Crumbles from wood chips

Rate of temperature increase from room temperature

Rate of temperature increase from frozen temperature

Basic down-draft convection air dryer
A simple representation of the down-draft belt dryer at Forest Concepts. The RF and convection models and resulting TEA are applicable to any variation of belt dryer including those with re-circulation and "fluffing".



Acknowledgement

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- DOE SBIR DE-SC0002291

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USDA United States Department of Agriculture

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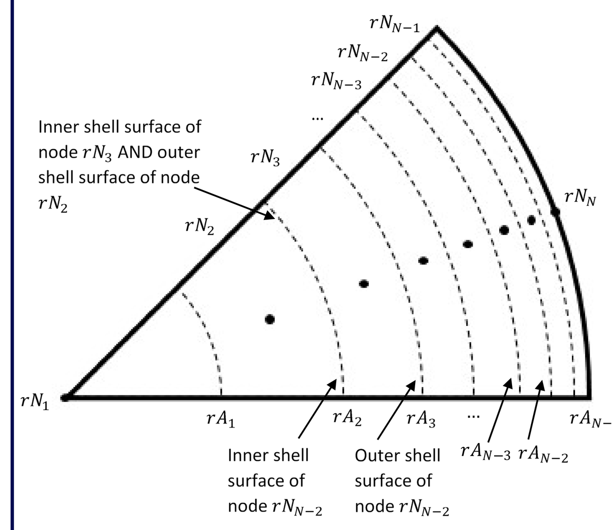
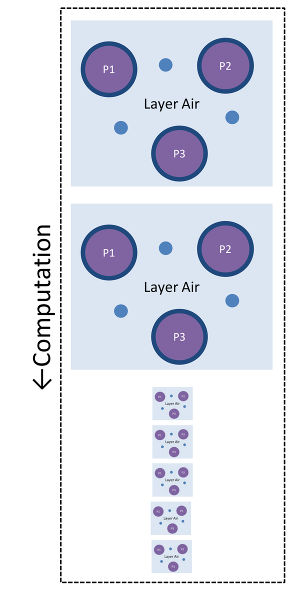
Convection Modeling



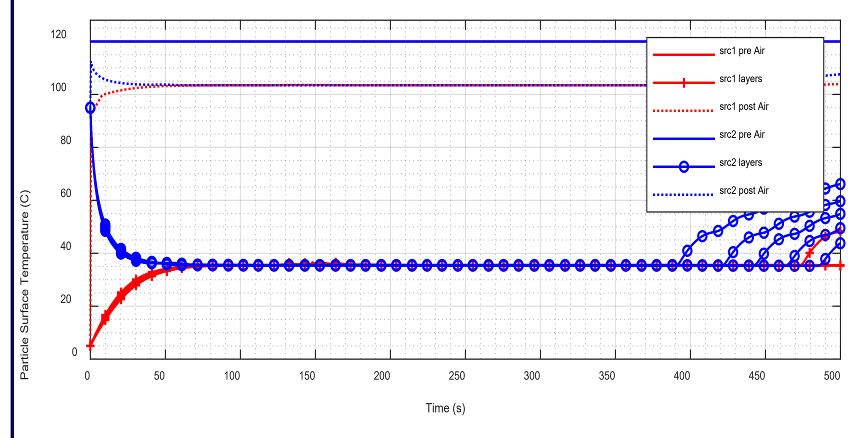
The particle interior model is based on Whitaker's Finite Volume Model[1]. One or more spherical particles are formed as need to represent the complexity of a specific biomass feedstock. The conservation of energy, conservation of mass of water, and conservation of mass of air in conjunction with material properties such as diffusivity and true particle density are utilized to determine mass and energy migration within each particle.

The bed of material is evaluated at layer intervals equivalent to the thickness of an average particle. At each layer, boundary conditions derived from Reynolds and Nusselt numbers and a correction due to non-spherical nature of the real materials are used to balance the mass and energy transfers in and out of the all particles in a layer. The layer air state, which may include steam and/or condensing liquid, is also determined by water-air stoichiometry and mass and energy balance before passing the air on to the next layer.

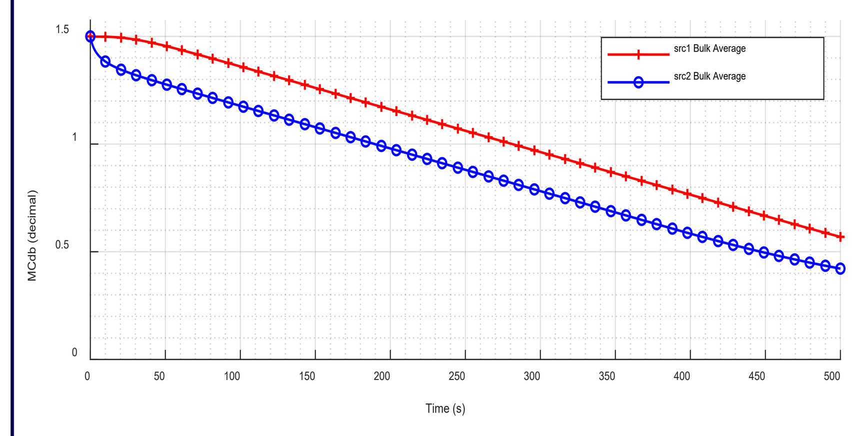


Simulation Output
The three graphs left show the comparison of a material starting at 5C (src1, red) vs 95C (src2, blue). All other simulation inputs were identical. The material represents a 6mm Crumbles® material with:

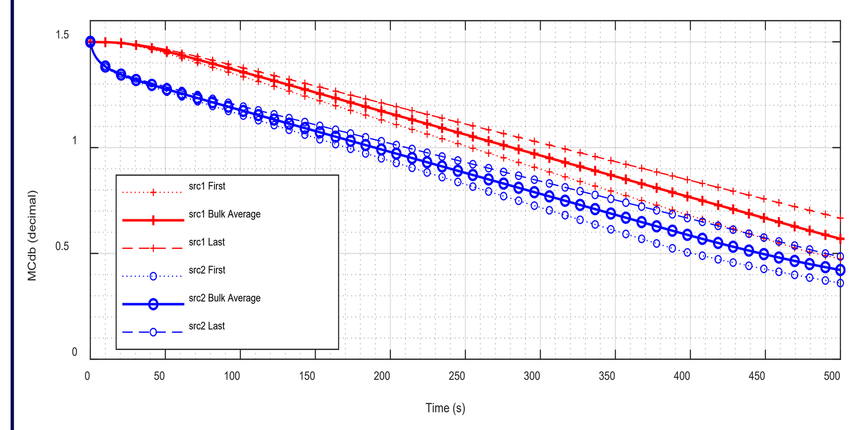
- An initial moisture content of 150% db (60% wb)
- A bed depth of 7cm (2.75")
- 1.0 m/s free stream (above bed) airflow rate at 120C and 1.0% rh.



Top
The "layers" lines show that regardless of initial temperature, the material stabilizes at about 36C in at 1 minute. Though the air leaving the material (src_x post Air) is over 100C, the particles are cooled due to evaporation (constant rate period) until a layer reaches the point where the surface of the particles dry below fiber saturation. Then, seen at 390s for src2, the layers begin to rise in temperature as the moisture front recedes. This is the falling rate period for that layer.



Middle
Particle starting at 5C (src1) have negligible initial moisture loss as they warm up to approximately wet-bulb temperature, only then do they enter the constant rate drying period. Conversely, particles starting at 95C quickly dump moisture until they are cooled to wet-bulb and settle into the same constant drying rate. The initial moisture loss is significant and the opportunity to use RF as a preheating energy source.



Bottom
Same chart as the middle, however 2 additional lines are drawn for each src. The additional lines show the divergence between the moisture content of the first and last layers in the stack of particles. At 400s, the top layer of src2 has dried to just 50% db while the bottom layer is still 65% db. Src1 exhibits the same top/bottom difference, but later in time. That is with on 7cm depth!