Analysis of Mash Tun Flow:

Recommendations for Home Brewers

Conor Walsh and

Ernesto Gutierrez-Miravete

Rensselaer at Hartford

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Steps in the Brewing Process

- Malting – grains are wetted and allowed to partially germinate before being dried in a kiln to create easily fermentable sugars (usually not performed at home by homebrewers)
- **Mashing** – malted grains are soaked in hot water and then rinsed slowly to maximize extraction of fermentable sugars
- Boiling – fermentable sugar extract is boiled with hops to add bitterness, complexity and characteristic beer flavors
- Fermentation – yeast is added to convert sugars to alcohol

Milled Malting Grains and the Mashing Process

Mashing

- Mashing starts with **steeping** (where the grains simply sit in hot water at a temperature of around 160 to 165°F)
- This is followed by **sparging** (where the grains are rinsed)
  - The sugars and water (called **wort**) that are extracted from the mash must be filtered from the grain husks
  - The particular sparging technique examined in this paper is **continuous sparging**, where more water is added to the grain as the wort is drawn out of the grain bed, in order to keep the grain bed fully submerged
- All of these steps are performed in a device called a **mash tun**, which both insulates the mash and later filters out the grain husks from the extract

Mash Tun

- For home brewers, a mash tun usually consists of a rectangular cooler with some kind of filtering mechanism at the bottom
- A popular filtering design is the slotted copper pipe manifold
- Small slots cut in the pipe filter the wort from the grain bed, and allow the wort to pass through a hole in the side of the mash tun

Home-Made Mash Tun Components

Mash Performance Factors

- Highly **efficient** setups are desirable for home brewers for economic reasons
  - A highly efficient mash is defined as one that produces a higher sugar output per grain input, minimizing the amount of grain required to produce a certain amount of beer
- Continuous sparging techniques are widely used because of the higher efficiencies possible
  - However, continuous sparging also increases the risk of over-extraction and poor wort quality to to the presence of undesirable flavor compounds
  - Wort quality has also been found to correlate with the the **uniformity of flow** of water through the mash tun

Mash Optimization

- Computational fluid dynamics analysis was performed in order to further analyze how the different mash tun designs affect extraction efficiency and uniformity of flow
- Various proposed mash tun configurations were analyzed and compared in order to develop a set of recommendations for home brewers that maximize mash efficiency and wort quality

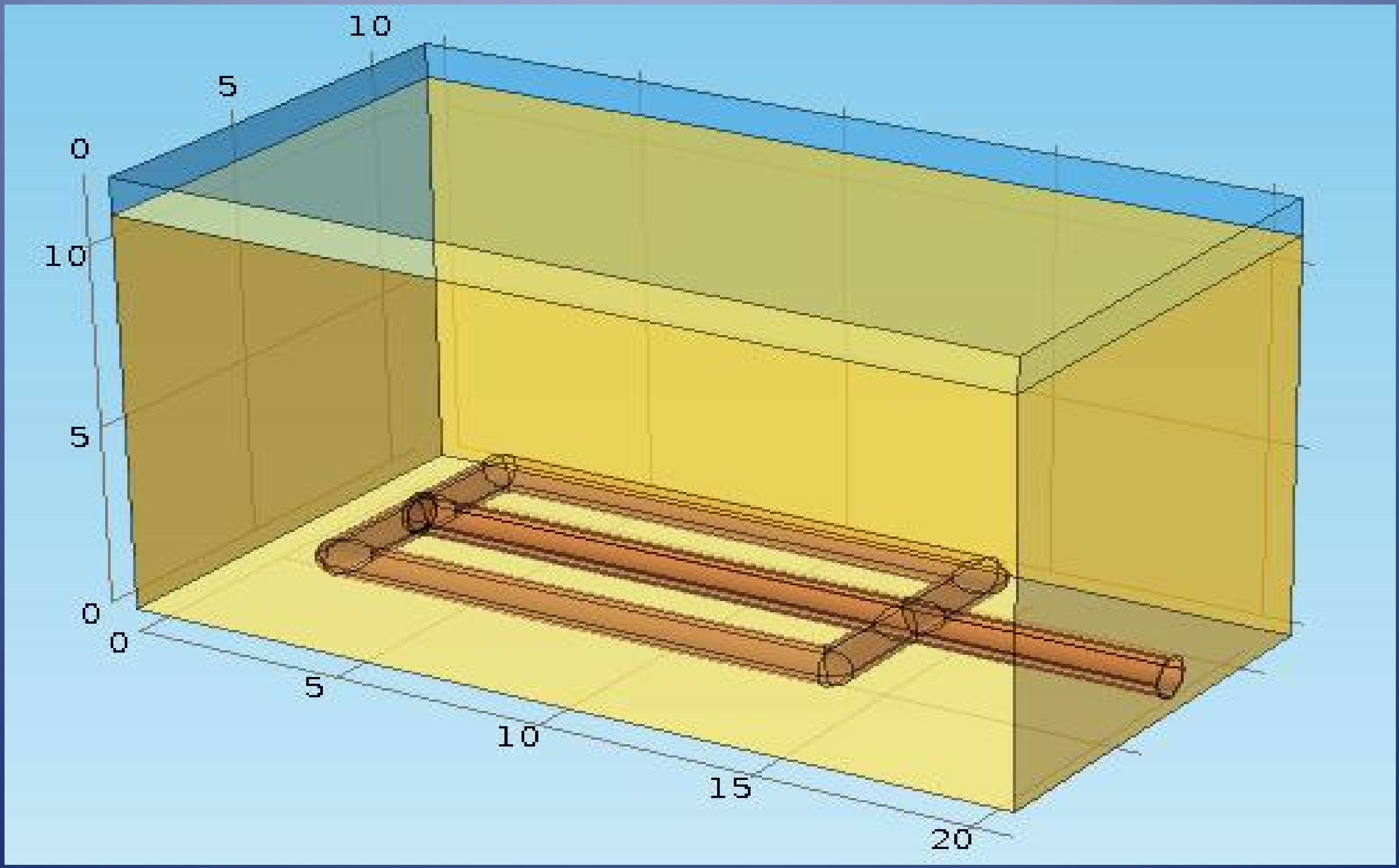
Use of COMSOL Multiphysics

- COMSOL Multiphysics' **Free and Porous Flow** module was used to model fluid flow through the grain bed and pipe manifold, which allowed easy coupling between free and porous flow regions
  - Flow through the grain bed was analyzed using Darcy's law for flow through porous media

$$q = -\frac{K}{\mu} \cdot \nabla p$$

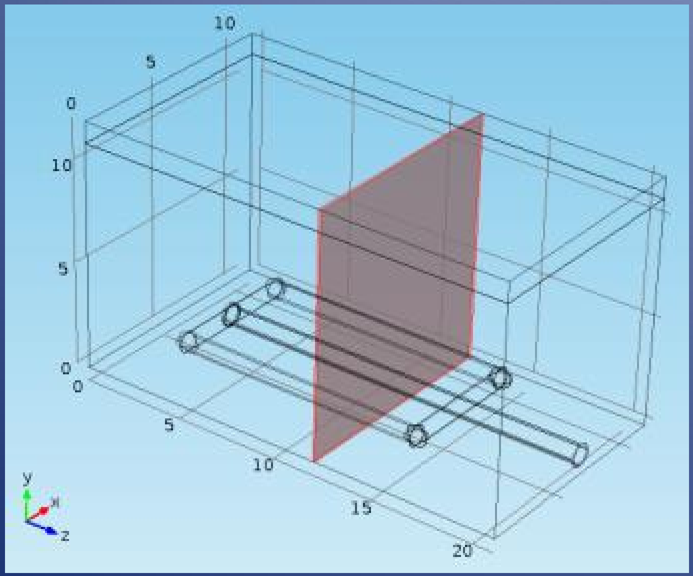
  - Flow through the pipe manifold was assumed to be laminar and evaluated using the Navier-Stokes equation
  - Gravity was the only body force applied

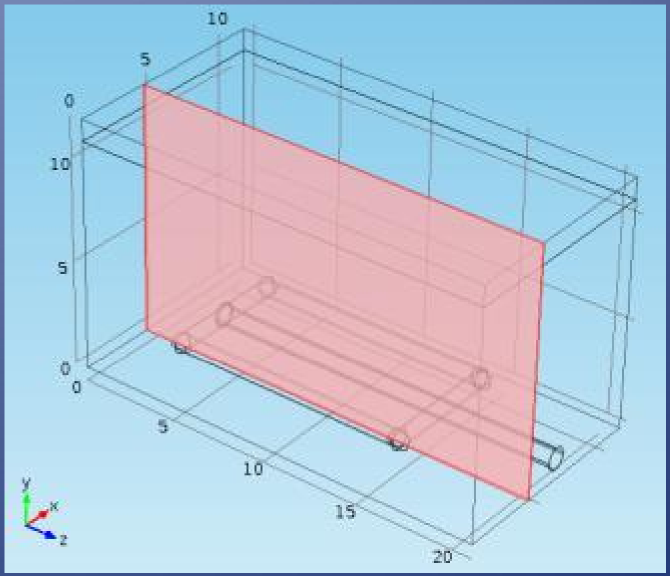
Mash Tun Model



Modeling

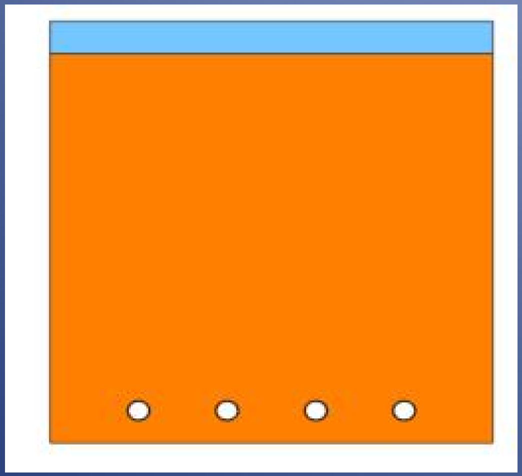
- Due to computation limitations two sets of 2-dimensional models were used for each mash tun configuration in lieu of a single 3-dimensional model

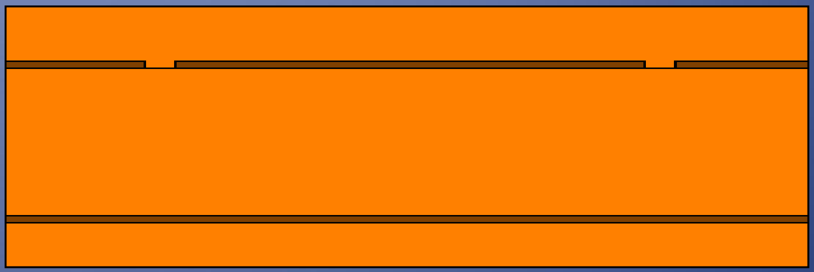




Modeling

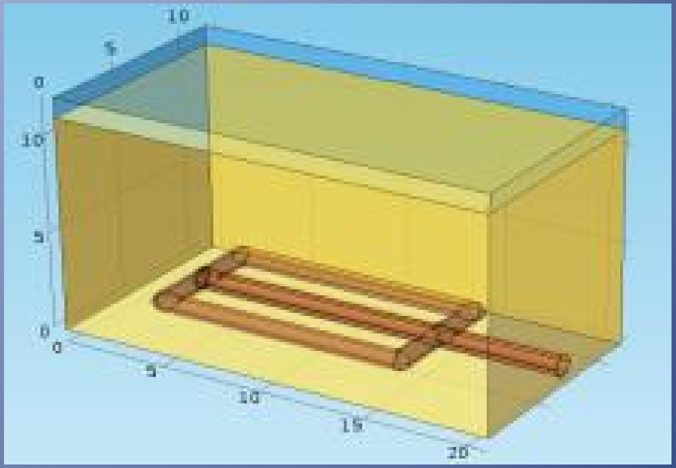
- The 2-dimensional models were constructed by taking various planar cuts, which were evaluated separately. In aggregate they approximate the 3-dimensional parameter modification such that the results can be combined to develop an ideal mash tun design.

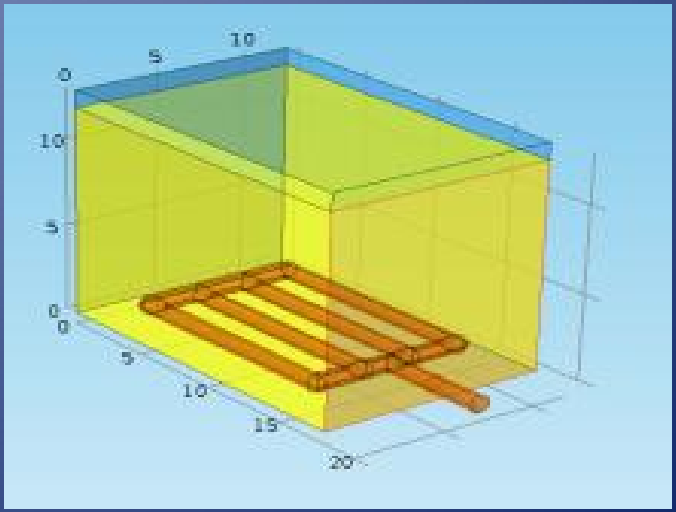




Design Parameters

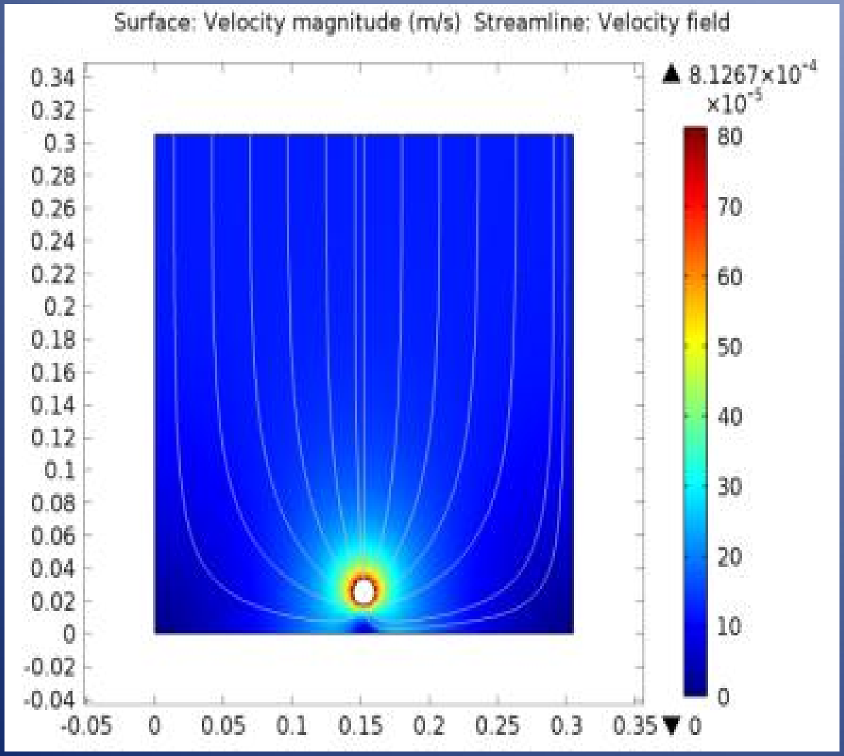
- Various mash tun design parameters were varied in order to evaluate their effects on performance:
  - Number of manifold legs
  - Diameter of pipe
  - Size of manifold slots
  - Number of manifold slots
  - Level of water above grain bed

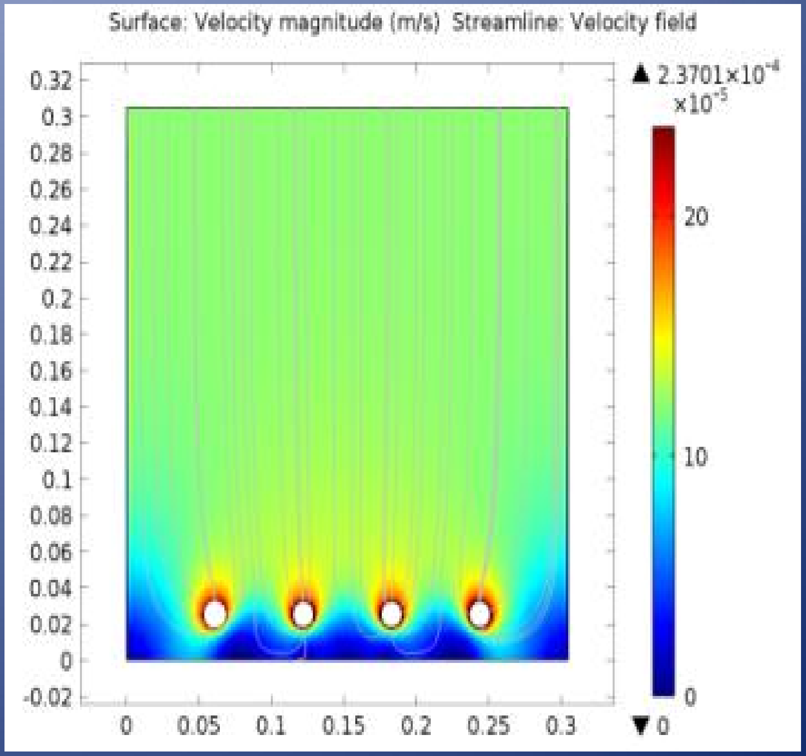




Results

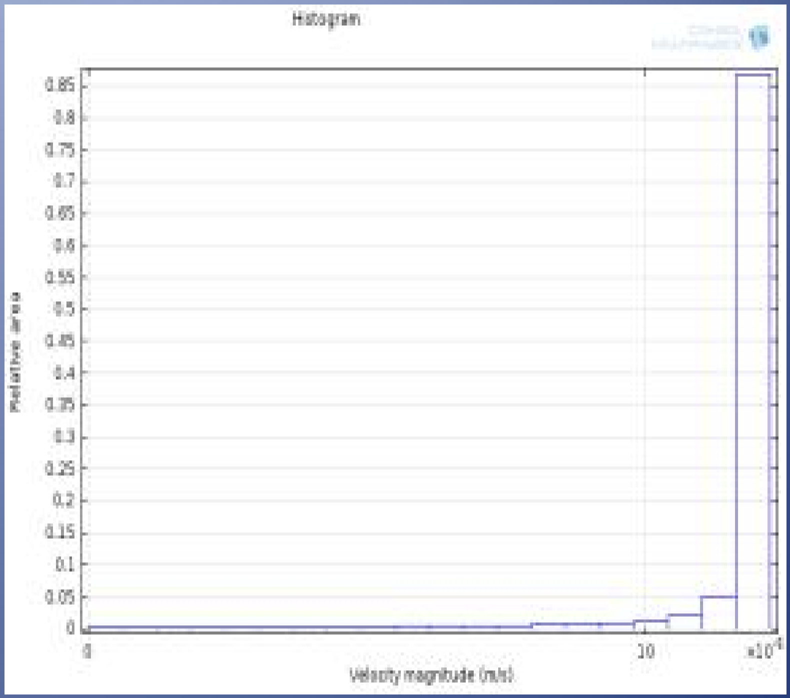
- Velocity throughout the grain bed was calculated for each mash tun configuration





Results

- The 1D plot feature was used to create histograms in order to quantify the percentage of each grain bed experiencing specific velocity levels
- These histograms were used to calculate **efficiency** of the particular configuration as well as predict the resulting **wort quality**



Pipes	Efficiency (%)	Oversparged (%)
1	89.9	45.8
4	91.2	42.4
8	88.4	28.5

Conclusions

- COMSOL Multiphysics provided a convenient and easy to use environment to carry out computer experiments designed to compare the effectiveness of various proposed mash tun reactor designs
- Together with some basic empirical understanding of the brewing process, finite element modeling with COMSOL allowed the testing of ideas and intuition and helped generate insight and know-how useful to the home brewer