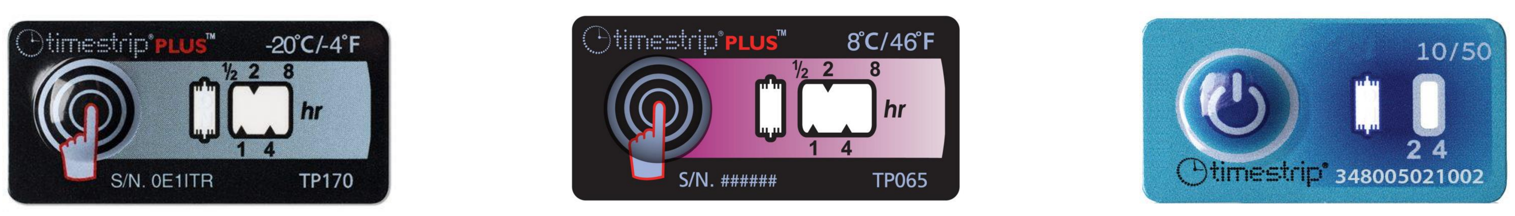
UET CENTENNIAL DAY/WORLD ENGINEERING DAY

Simulating Fluid Flow in Porous Media for the Development of Time-Temperature Indicator for Food Quality Control

ADVISOR: Dr. Muhammad Salman Abbassi (m.salman@uet.edu.pk)
Shahzil Raza[1] (18-ME-402), Saad Saeed[1] (18-ME-404), Gulzar Ali[1] (18-ME-415)
Department of Mechanical Engineering, Rachna College of Engineering and Technology, Gujranwala

Abstract

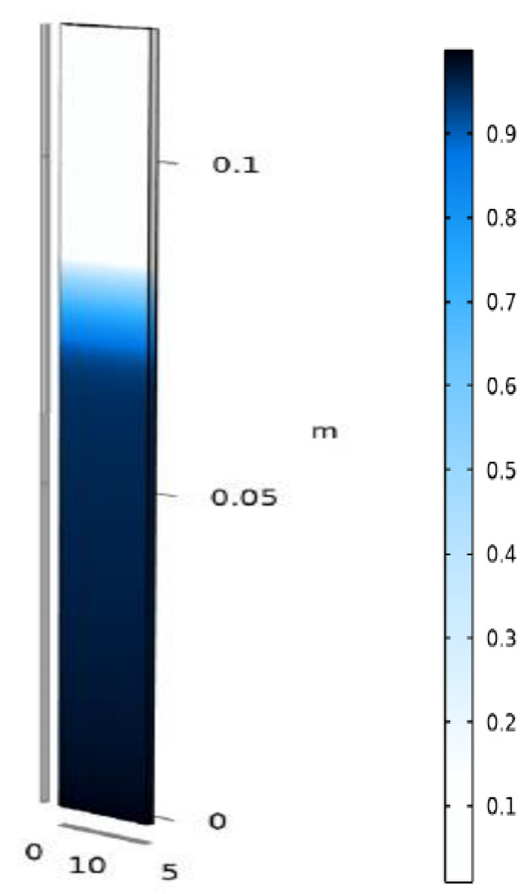
Shelf life is the time period for which an item may be stored without decaying, becoming unfit for use. The shelf life of food items is highly dependent on its stored temperature. Monitoring of safe temperature is crucial for cold chain food items being transported across Pakistan. Biggest challenge in our agriculture-based country is lack of modern storage and efficient transport techniques, due to which significant number of organic goods especially fruits and vegetables deteriorate before reaching the retailers. In order to assure food quality throughout the supply chain, there is a need for a sensor to monitor the time and temperature to determine its shelf life. This indicator is called a flexible time-temperature indicator (FTTI).



Objectives

The objectives of this project are oriented to the modeling process of the imbibition through porous media, and analysis through experimental simulations which were done on different geometries and parameters of porous material used in FTTIs.

- Initially we validate the wash-burn Equation with simulation results
- Then we do simulation by varying porosity and width of paper
- Last of all we compare experimental results of fluid *(Castor Oil and Water with sugar)*



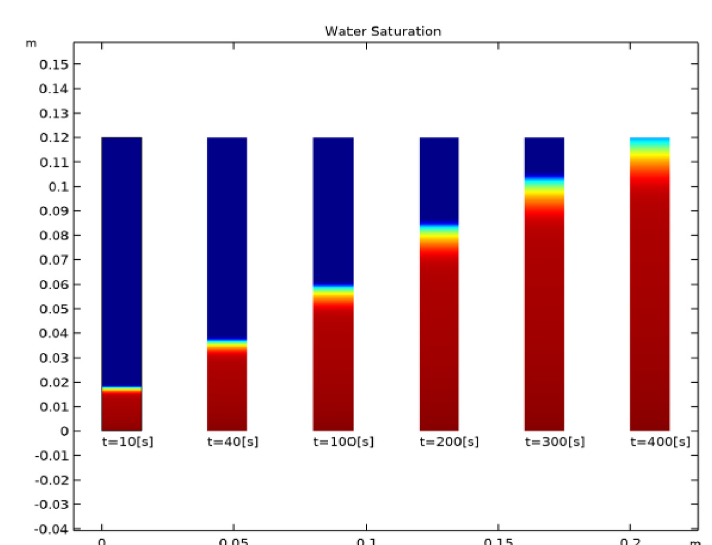
3D Water Saturation at *200s*

Methodology

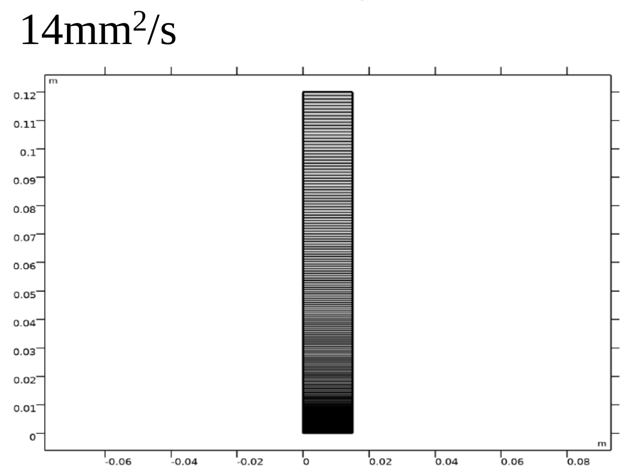
Basic simulation model is developed using porous media and sub-surface flow model in COMSOL multi-physics. Then Simulations are done using time-dependent study with Two Physics

- **Phase and Porous Media**
- **Darcy's Law**

The model is set up as a 2D model of a paper strip with a rectangular geometry of 12 cm length and 1.5 cm width. The thickness of the strip is defined as 1 mm. While the porosity and pore size is 0.5942 and 8 micrometer respectively. And Density and Kinematic Viscosity of Castor Oil is 915 kg/m^{3}and 14mm^2/s

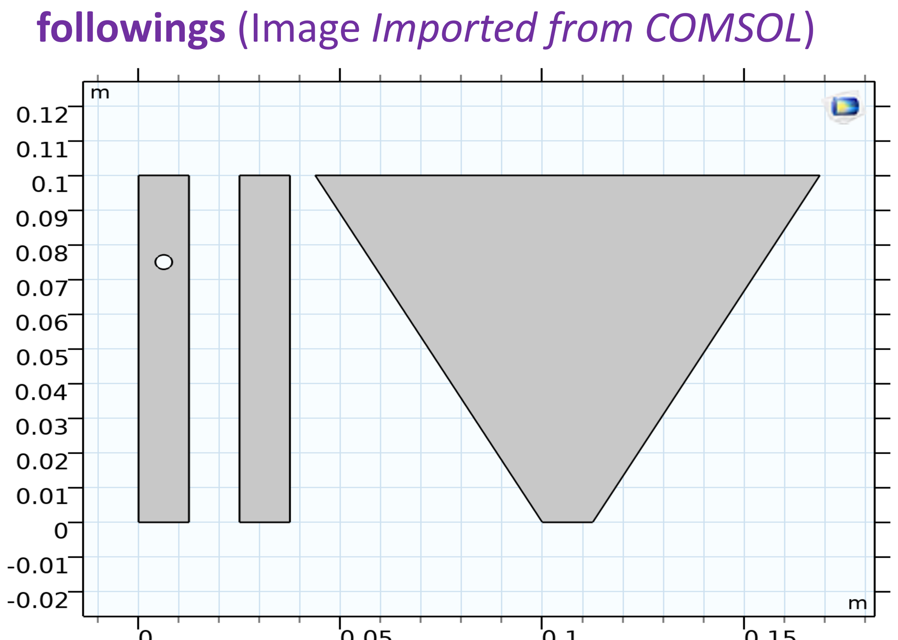


Water Saturation in the paper strip after *10, 40, 100, 200, 300,* and *400 s.*



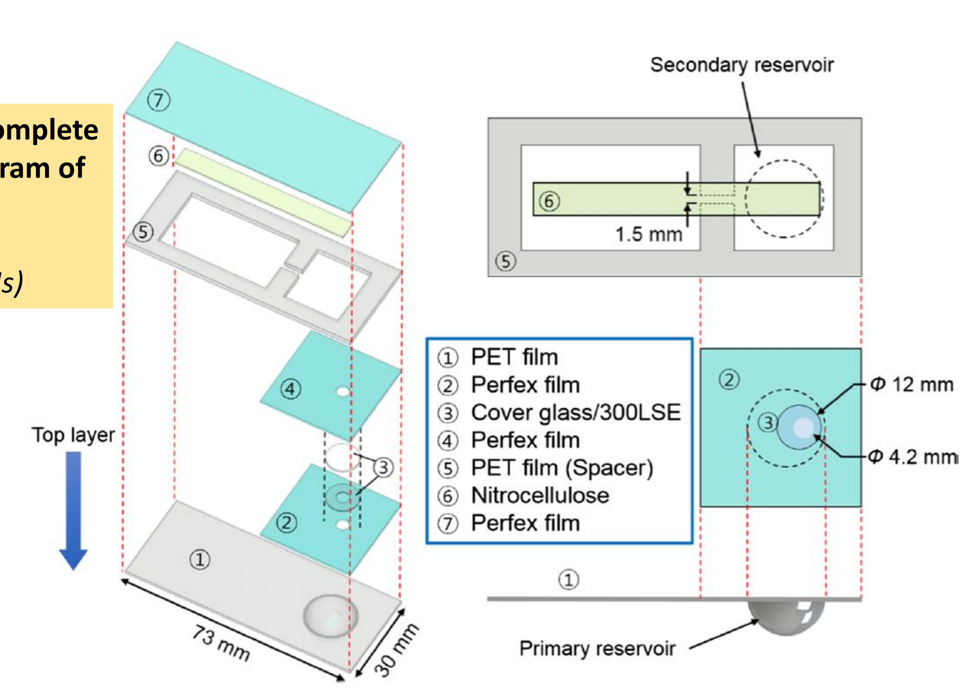
The dense mesh at the bottom is needed to resolve the very steep saturation gradient in the initial phase of the process.

Geometries we used in our Simulations are followings (Image *Imported from COMSOL*)



- Then we simulate the model for Castor Oil solution and Water Solutions
- We solve the model for 30% and 40% by volume sugar solution with Water and Castor Oil
- And also solved it for Vertical and Horizontal Wicking Setups
- We validate our simulation results with the Experimental results performed by GIK students
- Lastly, we analyze all the results gathered by experiment and propose the most optimum parameters and geometries for FTTIs

Following is complete assembly diagram of Flexible Time-Temperature Indicator *(FTTIs)*



Numerical Domain

The **Phase Transport in Porous Media** interface follows separate equations for the volume fraction s_i of the wetting or nonwetting fluid i:

$$\frac{\partial}{\partial t}(\varepsilon_p \rho_i s_i) + \nabla \cdot \left(-\rho_i \kappa \frac{\kappa_{ri}}{\mu_i}(\nabla p_i - \rho_i \mathbf{g})\right) = Q_i = 0$$

Sum of the volume fractions of the two phases is 1, the remaining volume fraction is computed from

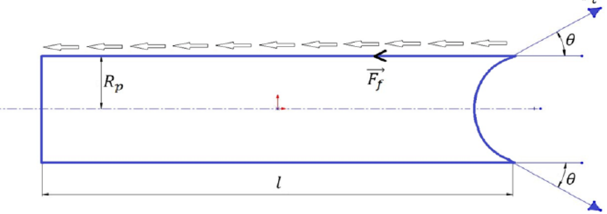
$$s_1 = 1 - s_2$$

The capillary pressure pc is calculated as a function of the saturation of the wetting phase s_w (which is s_2 in the model) and the entry capillary pressure p_{ec}. By using the Brooks and Corey model, the capillary pressure is given by:

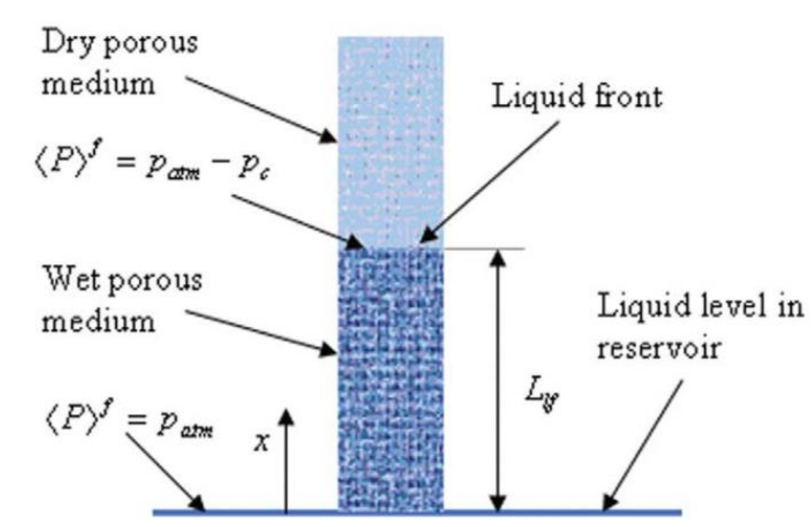
$$p_c = p_{ec} \frac{1}{(\overline{s_w})^{1/\lambda_p}}$$

where **λp** is the pore distribution index. The relative permeabilities for the wetting and nonwetting phases, based on the Brooks and Corey model, are given by

$$\kappa_{rs_w} = (\overline{s_w})^{(3+2/\lambda_p)} \qquad \kappa_{rs_n} = \overline{s_n}^2 (1 - (1 - \overline{s_n})^{(1+2/\lambda_p)})$$



Horizontal Setup Theoretical Model



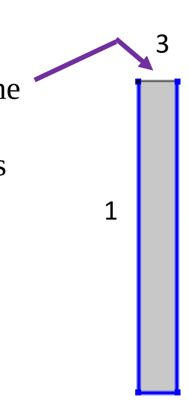
A schematic 0f the vertical wicking setup and wicking (or liquid-front) height in a porous wick

The **Darcy's Law** interface combines Darcy's law with the continuity equation:

$$\frac{\partial}{\partial t}(\rho \varepsilon_p) + \nabla \cdot \rho\left[-\frac{\kappa}{\mu}(\nabla p)\right] = 0$$

Boundary Conditions

In this model, the top boundary condition for the Phase Transport in Porous Media interface is a mass flux condition where the mass flux results from the pressure gradient computed using Darcy's Law using **weak Constraints.**(Using Langrangian Multiplier)
And No flow condition at **1** and **4** Boundaries.
And **P = 0** *(Initial Condition)* at **2.**

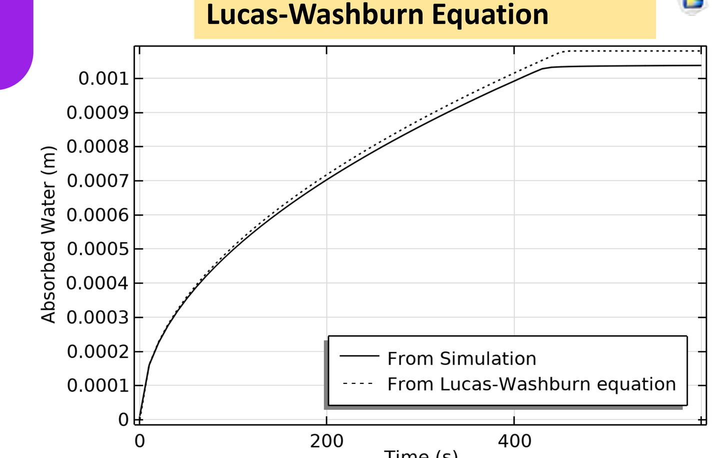


Results And Calculations

The simulation values (solid line) are compared with those calculated from the analytical expression given by the Lucas-Washburn equation (dashed line), where H_{lf} is defined as

$$H_{lf} = \sqrt{\frac{\gamma R_c \cos\Theta}{2\mu_w}}$$

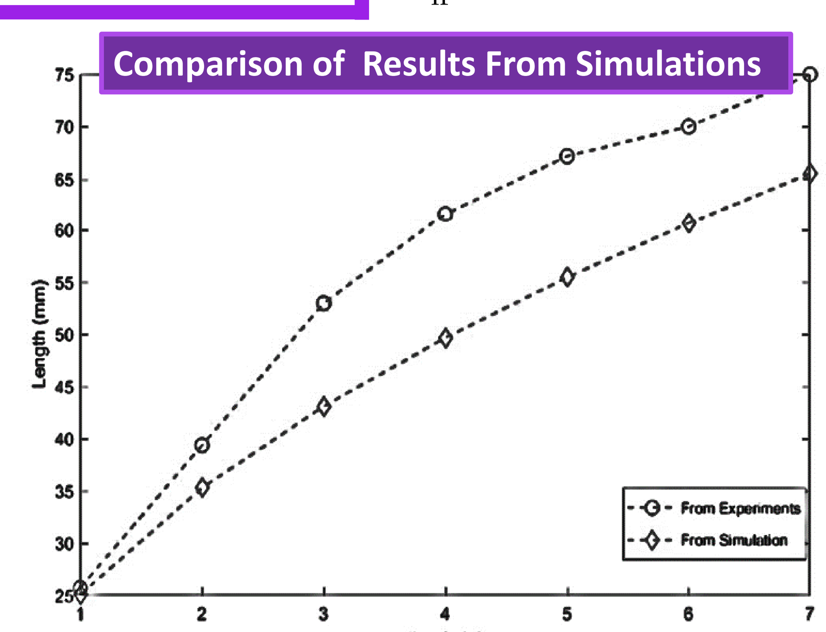
Validation of Simulation with Lucas-Washburn Equation

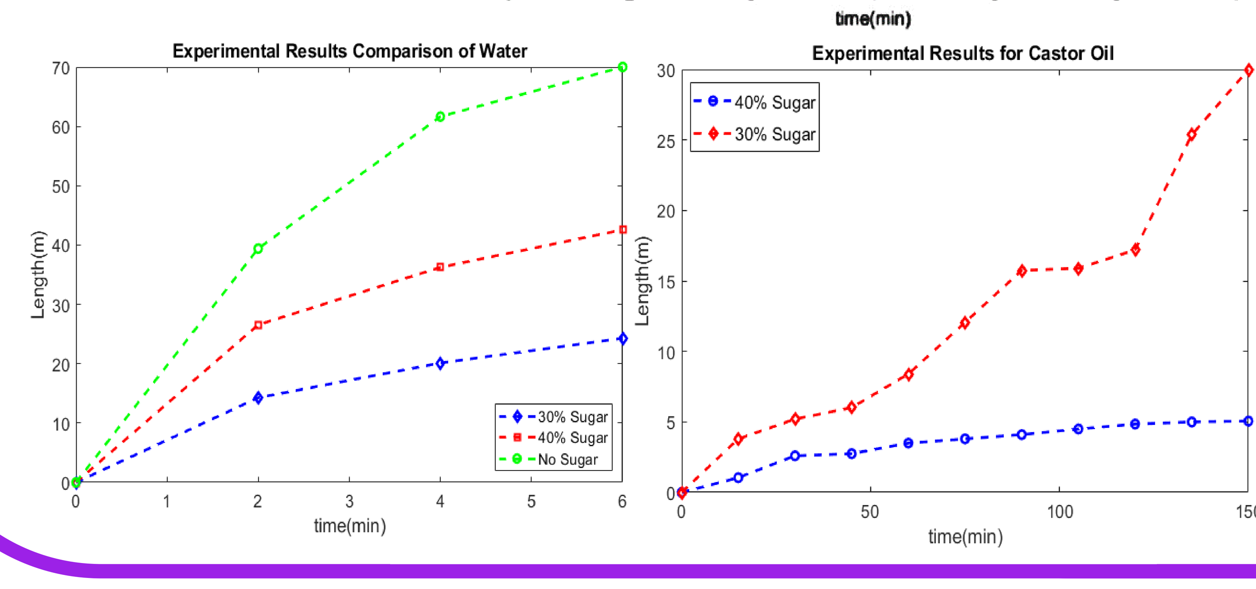


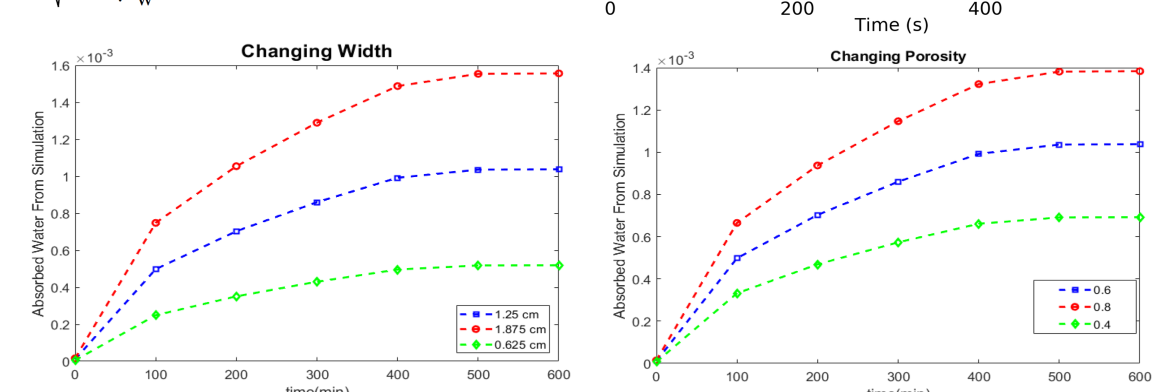
The result from experiment shows slight variation between 3- 5 min interval. We can assume the trend of experimental curve is same as calculated in Simulation.

Following Below graphs shows the experimental variations used in our study.

Comparison of Results From Simulations







Difference in curve by changing Width(LEFT) and Porosity (RIGHT)

Conclusions

- Validation of Washburn Equation shows that numerical Model is *~90-95%* accurate
- The simulation results of Varying width and porosity shows that with increase in width and porosity water Uptake increases So these results help us to estimate, what strip lengths we should use in our FTTIs
- Castor Oil with 30% sugar is more effective in reducing the liquid front in porous paper than water-sugar solution

References

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