Objective
Red blood cells donated for transfusion expire after 30 days in the refrigerator. Storing and transporting refrigerated blood is costly and inconvenient. The objective is to explore spray drying red blood cells as a means of storing cells at room temperature to improve the logistics of storage.

Background
Red blood cells are contained by fragile phospholipid membranes and can lyse or fold in conditions shown below. An external gas atomizer nozzle uses a high velocity nitrogen gas source to atomize liquid media. Spraying increases the surface to volume ratio. Droplets, approximately 10 μm in diameter, experience mass transfer from the liquid phase into the gas phase, resulting in dried blood. Dried product is extracted from the exhaust gas.

Modeling
Terminal Velocity via Stokes’ Law
\[ v = \frac{2}{9} \frac{\rho_g - \rho_l}{\rho_l} \frac{d^4}{18 \mu \rho_l} \]
Reynolds Number
\[ Re = \frac{d u \rho_l}{\mu} \]
Froude’s Equation
\[ Fr = \frac{d u^2}{g \rho_l} \]
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Diffusion Coefficient Relationship
\[ D = \frac{k}{\rho \mu} \]
Change in Diameter with Respect to time
\[ \frac{d D}{dt} = \frac{2 D \mu (2 d + 5 S)}{d^3} \]

Methods
Red Blood Cell Suspension

Red Blood Cell Viability Testing

Spray Dry Testing

Red Blood Cell Drying Tests Results
Red blood cells in phosphate buffered saline were placed on standard microscope slides to allow evaporation to occur. Half of the cells lysed during drying due to the increase in salt concentration. After rehydration, 40% of original cells remained intact.

Spray Dry Test Results
Temperature was taken at different points in the system during testing. An 80 °C nozzle output temperature was used instead of room temperature because it kept cells intact, while increasing the mass transfer. Drying efficiency was tested by varying gas flow rates and saline concentrations (Figure 1). Red blood cells were sprayed through the nozzle with humidified nitrogen to differentiate the death due to spraying from the death due to drying. Hemoglobin is released when red blood cells lyse and can be quantified by spectrophotometry (Figure 2). The absorbance spectrum of oxygenated and deoxygenated hemoglobin indicated that 430 nm is the best wavelength to take measurements for both. Cell death at nitrogen flow rates of 10 L/min are significantly lower than at 20 L/min regardless of blood flow rate.

Analysis and Conclusions
More than 50% of red blood cells lysed in phosphate buffered saline during microscopy slide drying. An additional 10% lysed during rehydration. The current system removed up to 80% of water from salt solutions. Lysing of red blood cells is reduced with a gas and liquid flow rates of 10 L/min and 10 mL/min, respectively. The viscosity and density of the red blood cell solutions sprayed are similar to those of water, which suggests water can be used to model spraying properties.

Looking Forward
Further testing should be conducted with human rather than equine red blood cells because the cell size varies significantly. Drying does not occur at the gas and liquid rates tested. A second drying stream should be investigated.

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Spray Drying for Long-Term Storage of Red Blood Cells
Meehe Kim, Mary McLean, John Simeles, Dr. Adam Higgins (Sponsor)
School of Chemical, Biological, and Environmental Engineering