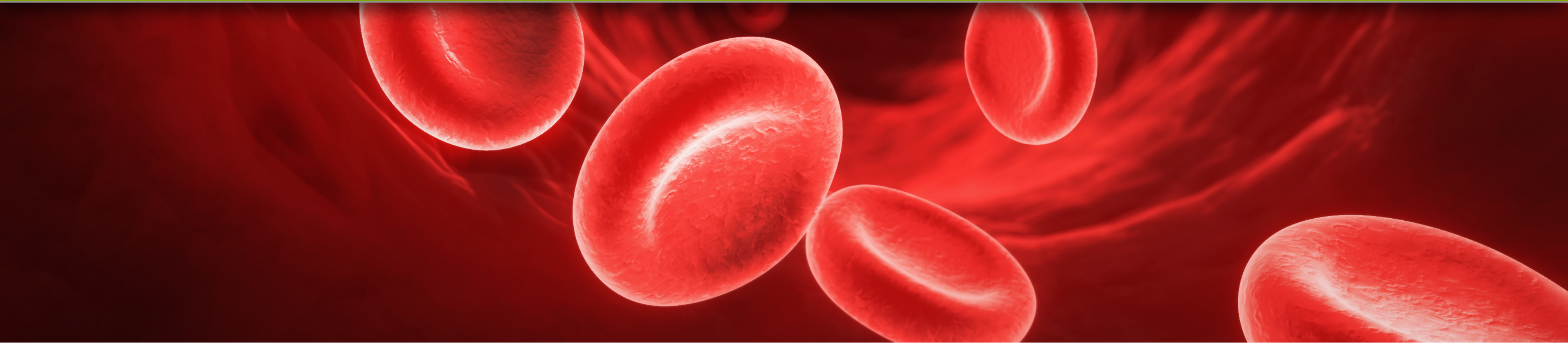

AUTOMATED COUETTE VISCOMETER

MEM493-PR33 Spring 2015

TEAM
Austin Farber (BS-MEM / BS-ECE)
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ADVISOR
Dr. Young Cho (Drexel MEM)

Presentation

Overview

I. Introduction
   a. Problem
   b. Stakeholders

II. Theory
   a. Couette Flow
   b. Buoyancy
   c. Eddy Current

III. Assembly
   a. Rotational Assembly
   b. Coaxial Fluid Tester
   c. Temperature Control
   d. Housing
   e. Data Acquisition
   f. Demo

IV. Verification
   a. Standards
   b. Testing
   c. Baseline

V. Results
   a. Baseline
   b. Viscosity
   c. Hemolysis

VI. Discussion
   a. Context & Impact

VII. Management
   a. Organization
   b. Budget
   c. Gantt Chart
   d. Future Work

Introduction

Problem

High Viscosity[2][3]

- Measurement correlated with Cardiovascular Disease (CVD)
- Flow impaired at bifurcation → plaque collection
- Microvasculature flow impaired → microangiopathy
- High shear blood flow → plaque rupture

#1[1]
KILLER

58%[1]
NO EFFORT

25 SEC[1]
PER EVENT

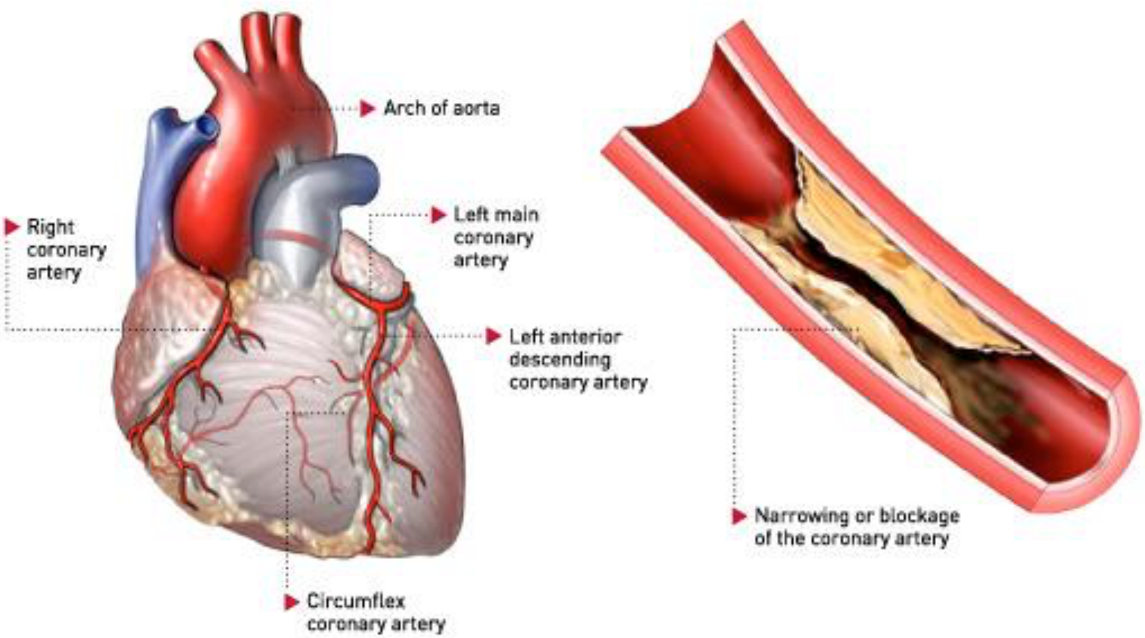


Image: http://www.webtrainer.ca

Introduction

Problem

Goal: Design Couette blood viscometer capable of physiologically relevant shear rates for medical research and diagnostics.

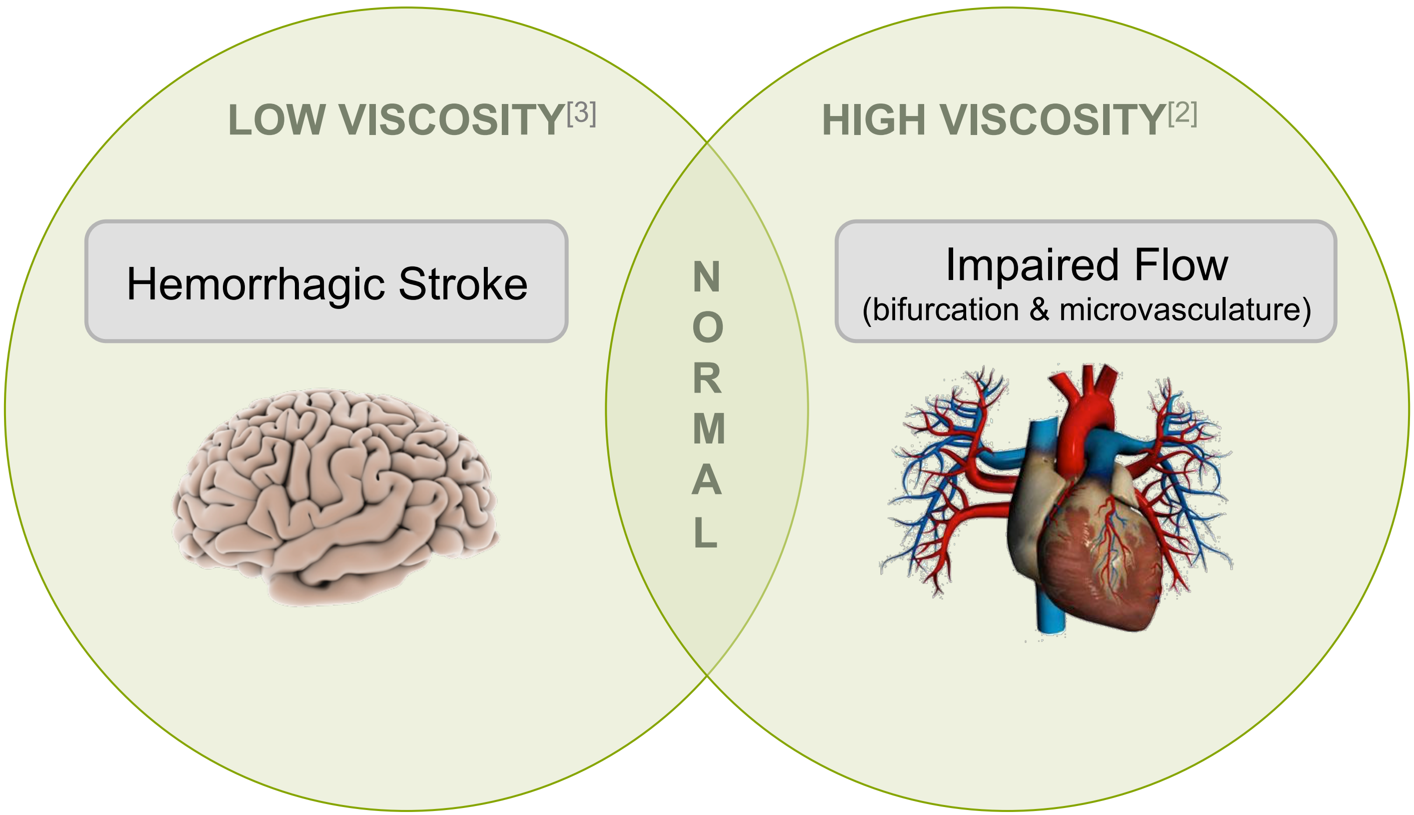


Image: http://mediad.publicbroadcasting.net
Image: http://www.cybersurgeons.net

Introduction

Stakeholders

Stakeholder	Need	Priority	Specification
Senior Design Group	Automated Coasting Action	1	2 minutes
Patient	Reading Accuracy	1	> 95% accuracy
Senior Design Group	Speed Range	1	0-20 RPM
Senior Design Group	Rotation Measurement	1	95% accuracy
Senior Design Group	Manufacturability	1	100% completion
Senior Design Group	Temperature Regulation	1	36.9°C
Senior Design Group	Temperature Accuracy	1	± 0.1°C

Hospital

Patient

Doctor

Group

Scientist

Theory

Couette Flow [4]

1 Torque | Shear

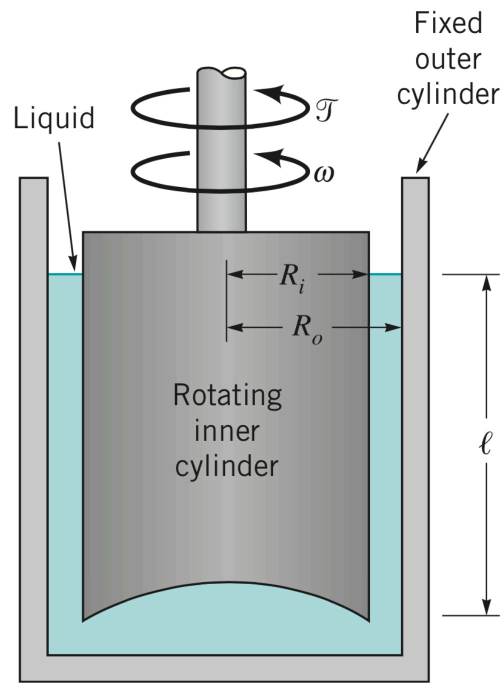
$$T = 2\pi R^2 L \tau_R$$

$$2\tau_R \frac{d\Omega}{d\tau_R} = f(\tau_R) - f(s^2 \tau_R)$$

2 Transformation

$$f(\tau_R) = 2\Omega \sum_{p=0}^{\infty} s^{2pm} m(s^{2p}\tau_R)$$

$$f(\tau_R) = \frac{\Omega}{-\ln(s)}[1 - m\ln(s) + \frac{1}{3}(m\ln(s))^2]$$



$$\eta = \frac{\tau}{\gamma}$$ $$T = \frac{2\pi R_i^3 l \mu \omega}{R_0 - R_i}$$ → $$s = \frac{r_i}{r_o}$$ $$\tau = \mu \frac{s\omega}{1-s}$$ $$\gamma = \frac{2\omega}{1-s^2}$$

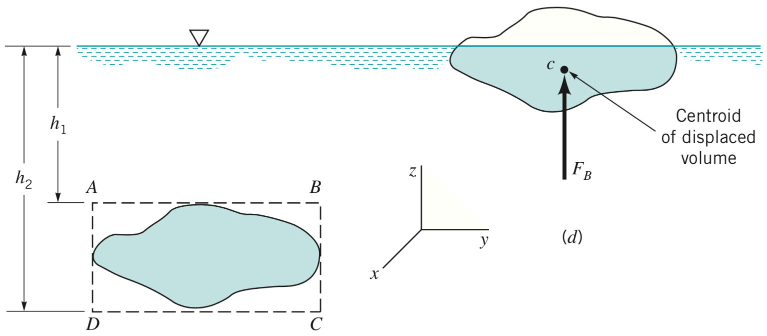
Image: Munson (2009)[4]

Theory

Buoyancy [5]

1 Gravitational Force

$$F_g = g(\rho_{rotor})(V_{rotor})$$



2 Buoyancy Force

$$F_b = g(\rho_{fluid})(0.25\pi)(D_{rotor})^2(h_{final} - h_{initial})$$

$$\boxed{F_b > F_g}$$

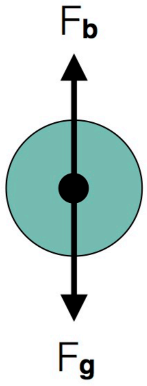


Image: Munson (2009)[4]

Theory

Eddy Current [6]

1 Faraday's Law of Induction

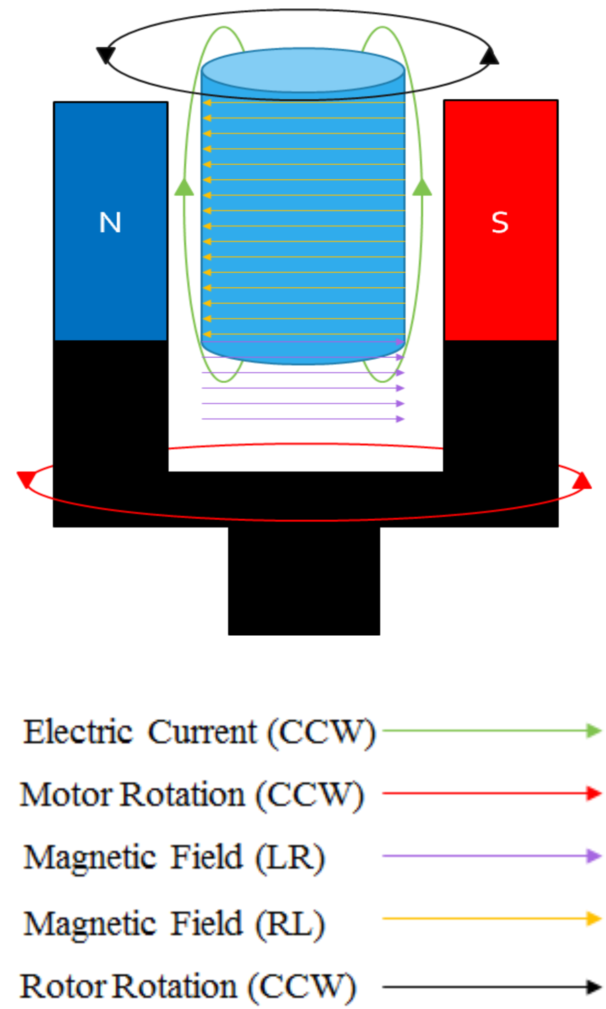
$$V = -\frac{d\Phi_B}{dt} = I * R$$

Lenz's Law

Ohm's Law

2 Magnetic Flux

$$\Phi_B = B \cdot A$$



Concept:

- Changing magnetic field induces current
- Induced current generates magnetic field
- Attraction between induced and rotating field results in rotor rotation

Assembly

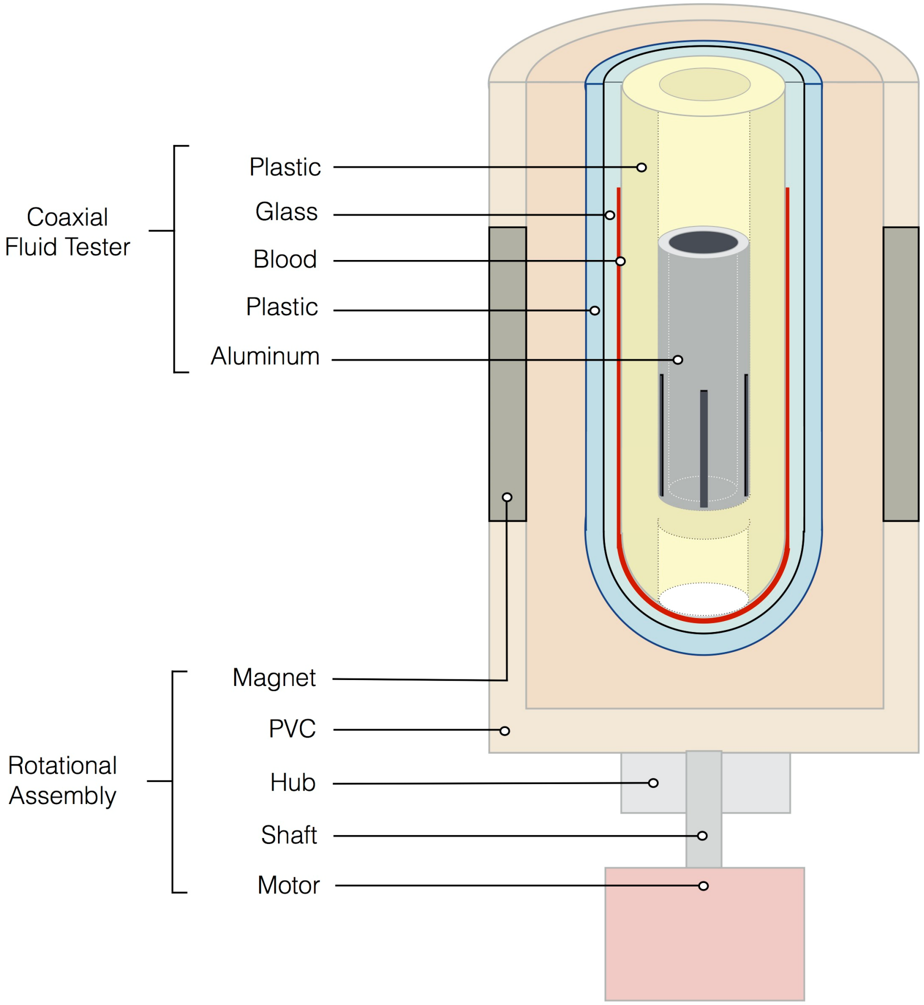
Rotational Assembly

Component Overview

Purpose: Interaction with rotor through influence of rotating magnetic field.

Details:

- PVC embedded with four neodymium magnets
- Motor speed 200-1000 RPM
- Precision-milled screw hub joining motor and PVC



Assembly

Coaxial Fluid Tester

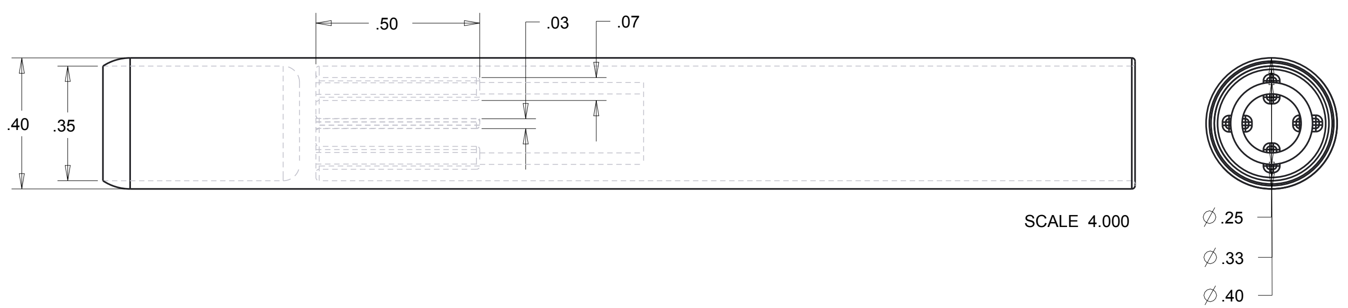
Plastic Rotor & Aluminum Inserts

Hybrid Rotor:

- 7075 aluminum insert
- 3D printed photopolymer resin (PPR)
- Buoyant in 1mL of fluid

Dimensions:

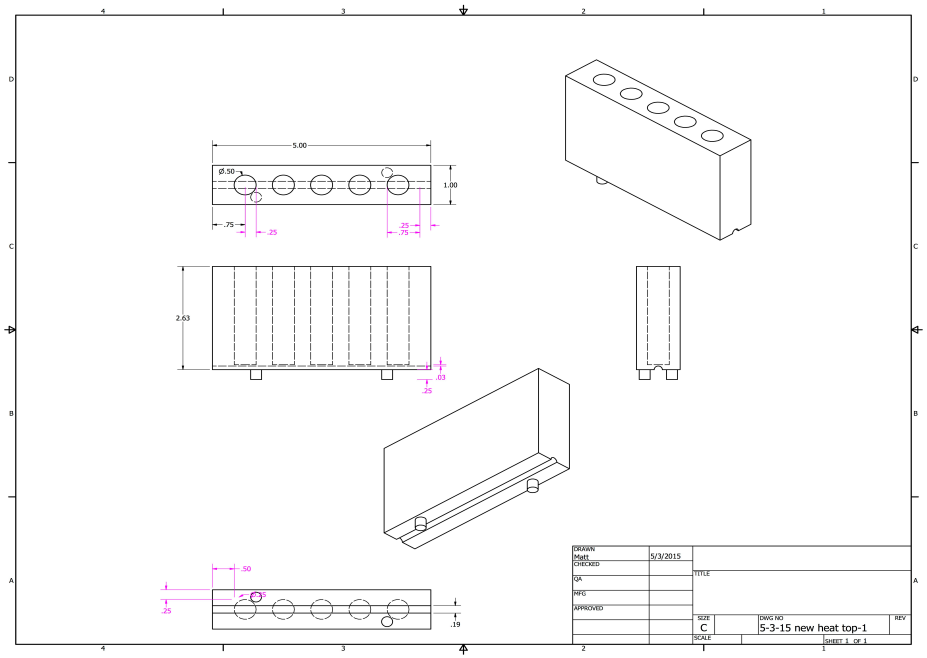
- 3.129” length
- 0.4” outer diameter
- 0.421” vacutainer inner diameter



Assembly

Temperature Control

Pre-heated Sample



Purpose: To pre-heat sample prior to viscosity test in order to maintain 37°C during test.

Procedure:

- Heat for 30min prior to testing
- Set-point slightly above desired temperature to retain heat for test duration

Details:

- Aluminum used for conductivity
- Wood used to insulate
- Heating strip fed through bottom channel

Assembly

Housing

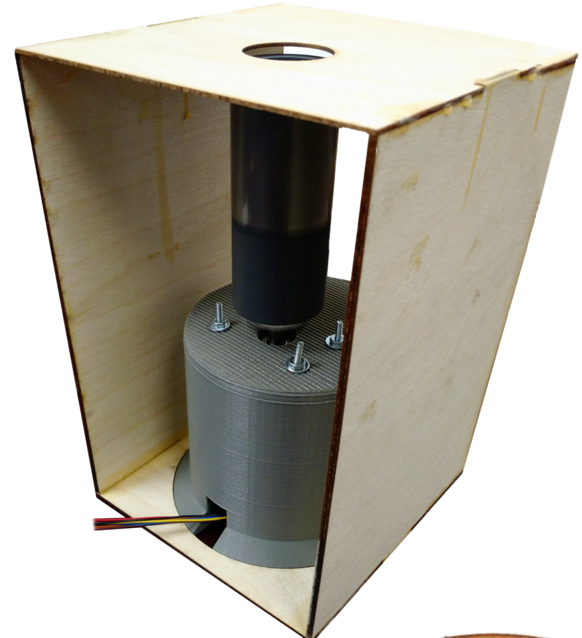
Inner & Outer Enclosures

Inner Enclosure:

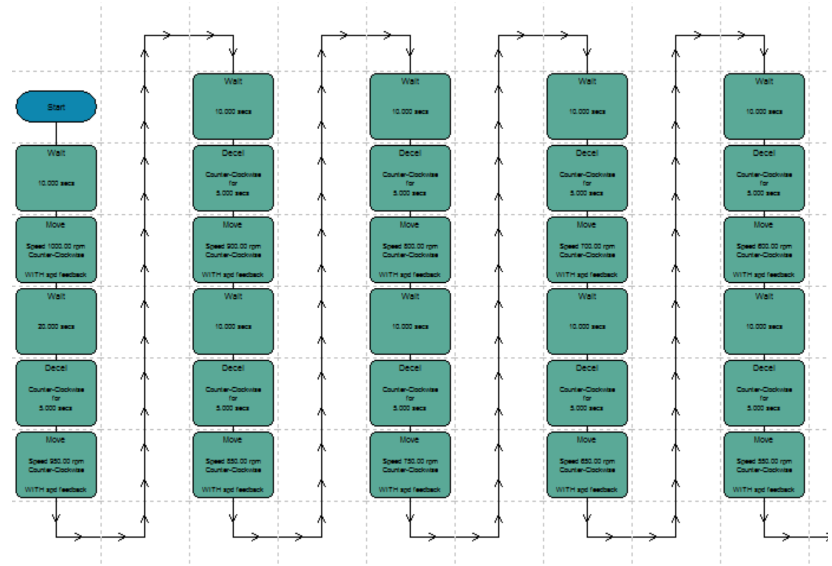
- Stability and protection
- Provides support for vacutainer suspension
- Controlled motor placement

Outer Enclosure:

- 3mm thick medium-density fiberboard (MDF)
- Scored with laser cutter to increase flexibility
- Maintains inner housing stability



Assembly
Data Acquisition
Programming Scheme

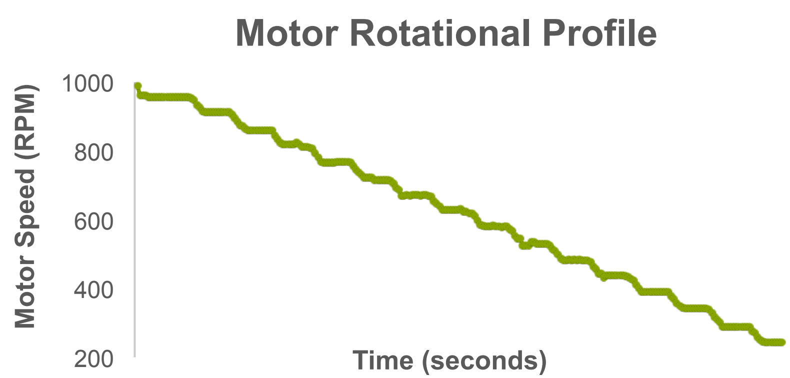


Controller / Programming:

- Block-based user interface
- Controller interfaces with motor
- Verify motor speeds with tachometer

Procedure:

- Initiate viscosity test at highest rotational speed
- Transition to lower speeds in steps with time to stabilize
- Motor gradually stops

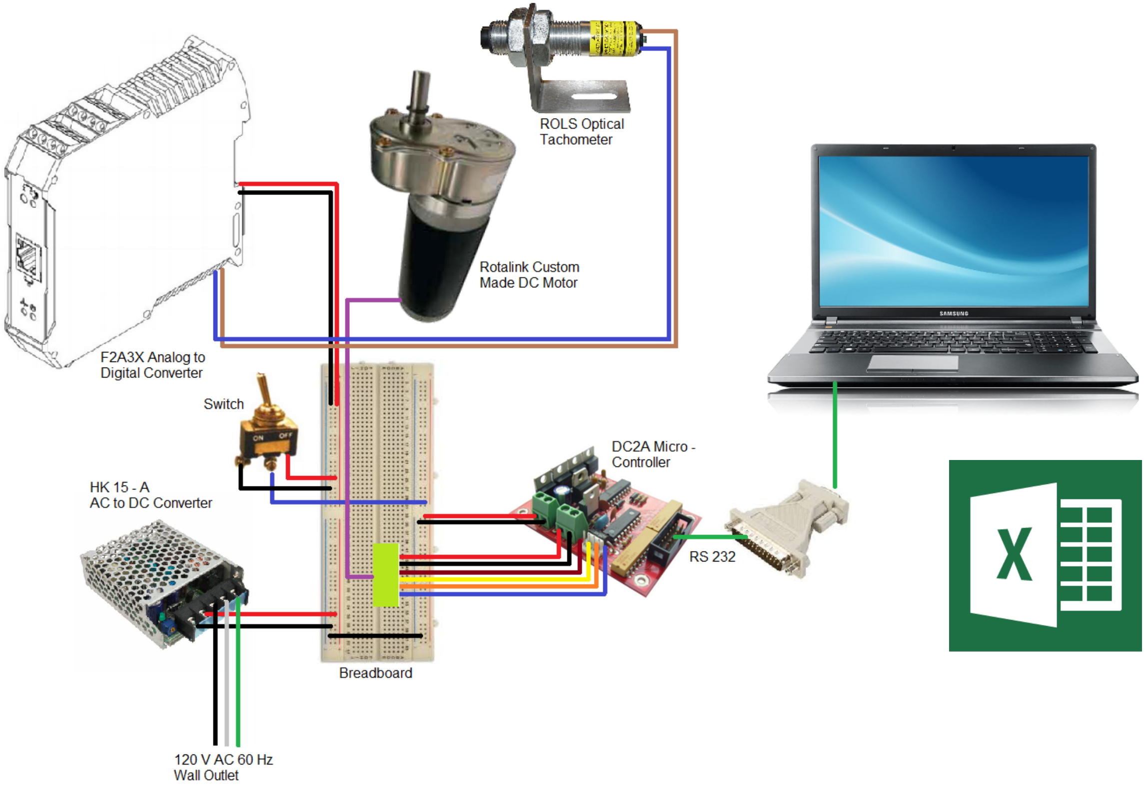


Assembly

Data Acquisition

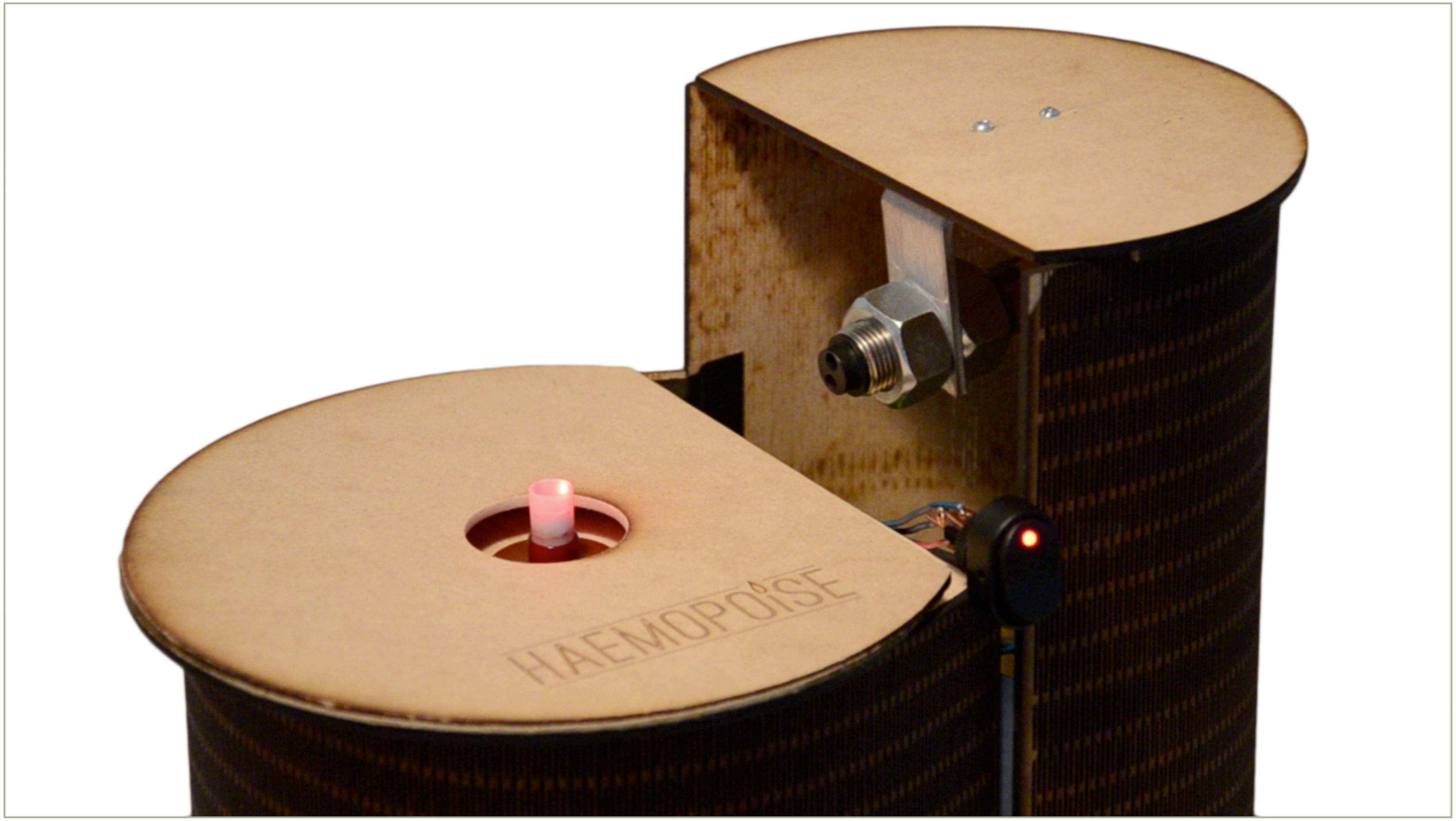
System Intercommunication

- Motor Control
- Eddy Current
- Rotor Rotation
- Tachometer
- Data Analysis
- Viscosity



Assembly

Demo



Verification

Standards

ASTM D445-14

Kinematic Viscosity of Transparent & Opaque Liquids[8]

- Test method for determination of kinematic viscosity with metric for repeatability and reproducibility.

  Method: Differences from mean value are 0.35% (repeatability) and 0.7% (reproducibility).

ASTM F756

Standard Practice for Hemolytic Assessment of Materials[9]

- Test method for determination of sample hemolysis quantified by the concentration of hemoglobin.

  Method: Spectrophotometer data comparison to negative control yields relative hemolytic index.

Image: http://www.astm.org

Verification

Testing

Primary Testing

Viscosity

- Standard Viscosity → use known values to create predictive model

Hemolysis

- Hematocrit → measure RBC/plasma before and after testing

Secondary Testing

Magnetic Field

- Interference → measure strength as a function of distance

Heat Retention

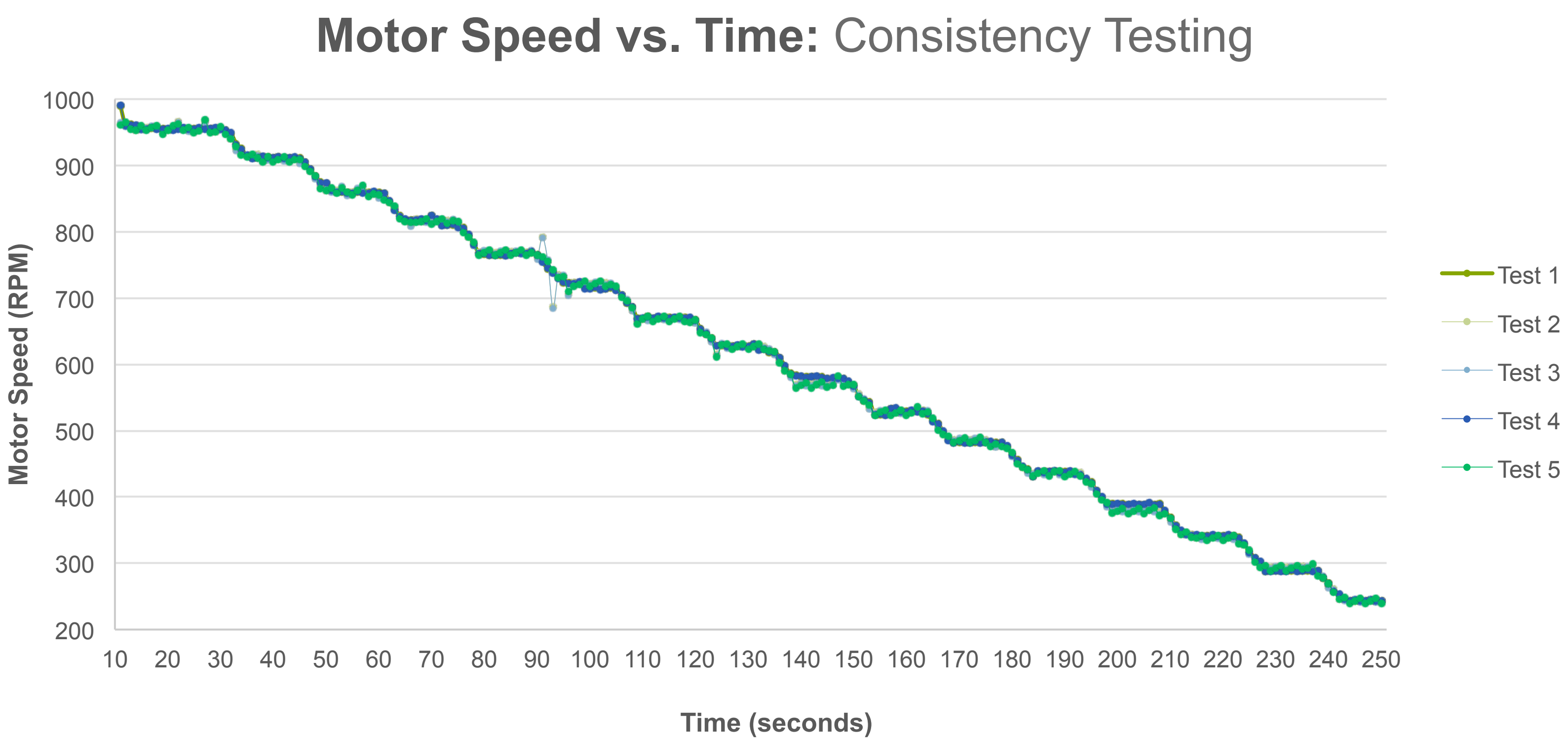
- Vacutainer → verify duration of heat retention

Dimensions

- Tolerance → measure and compare many samples

Verification

Baseline

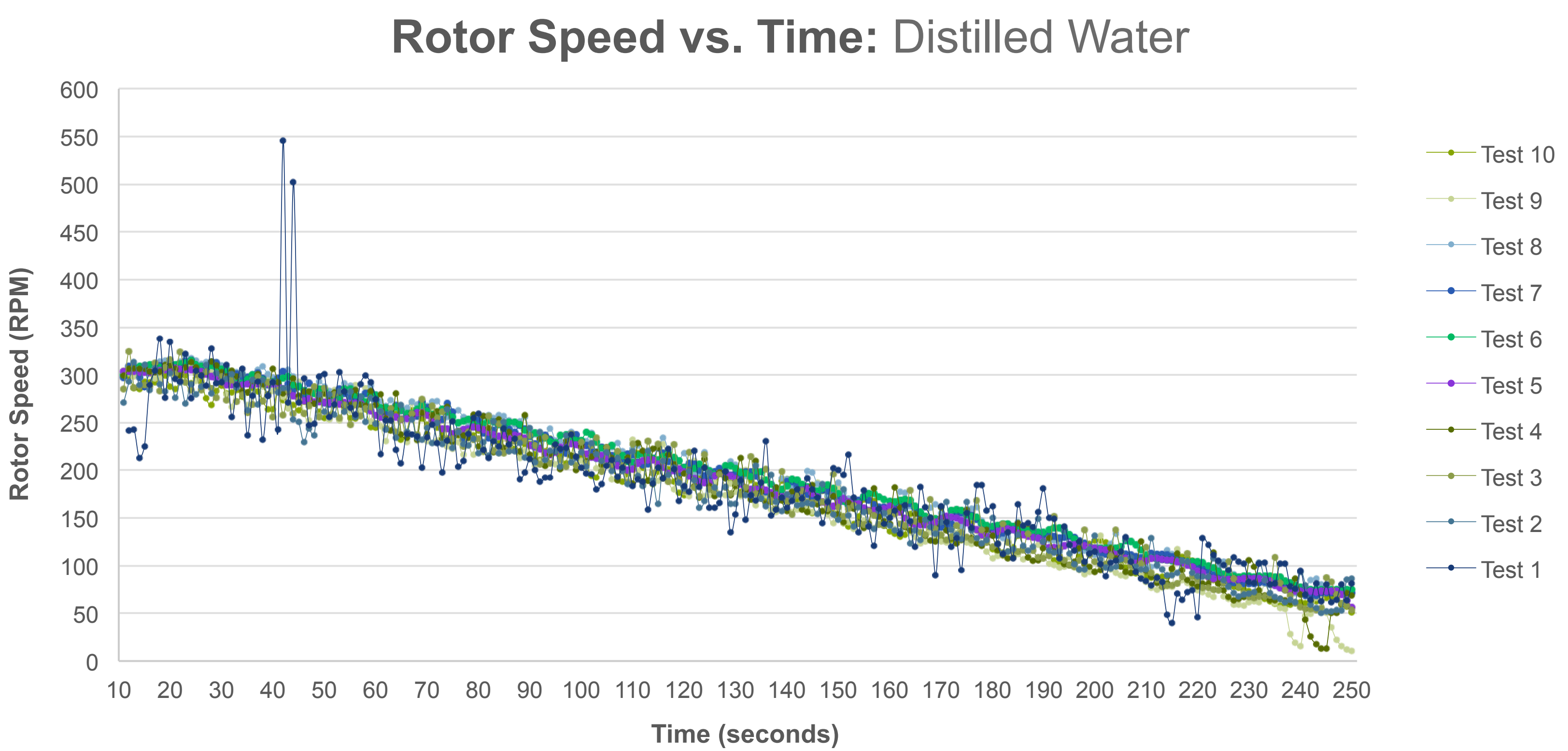


Results:

- Consistent, repeatable speeds achieved over multiple tests
- Tested over 16 speed regions

Verification

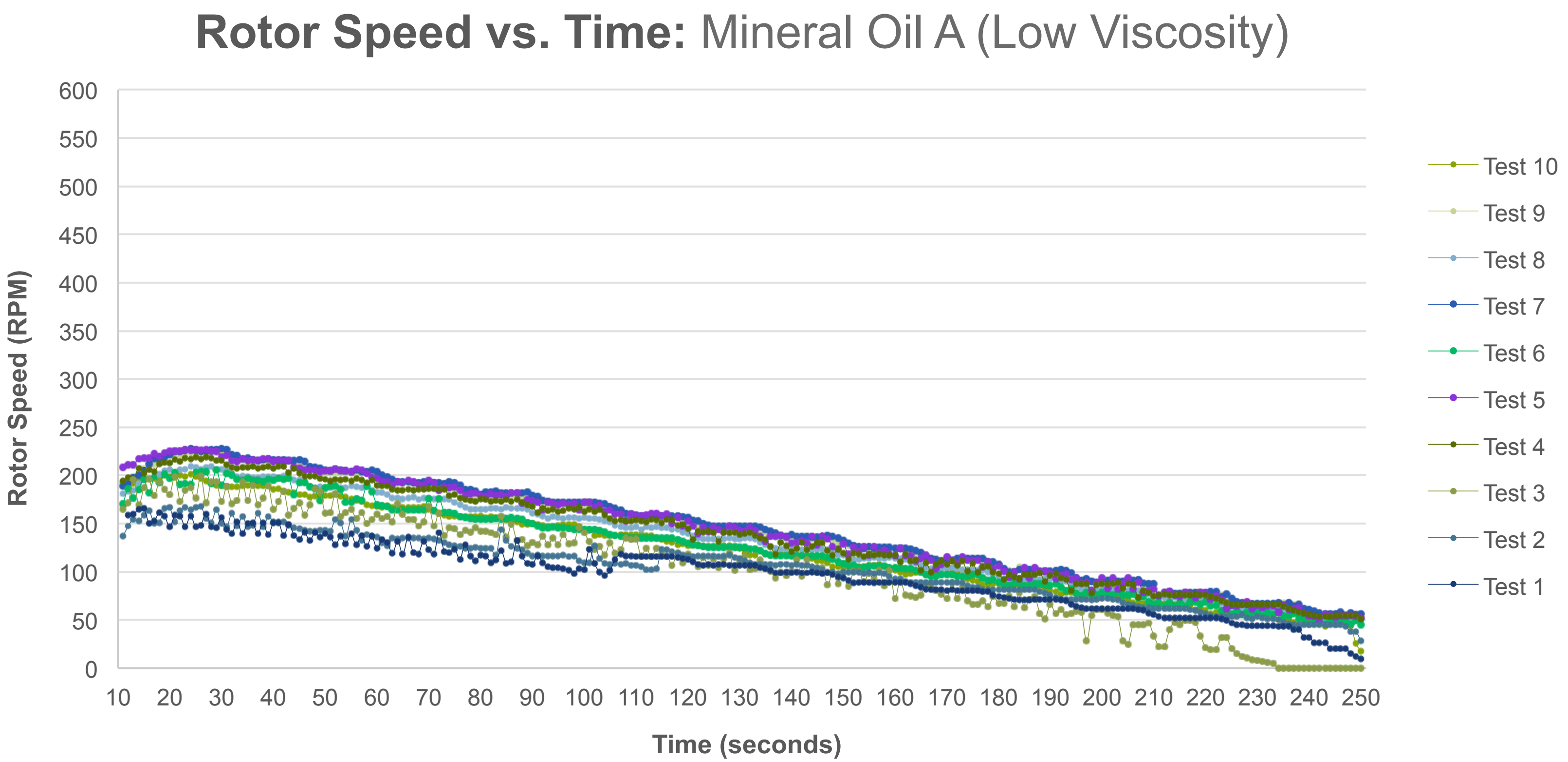
Baseline



Results:

Standard Deviation = 9.75

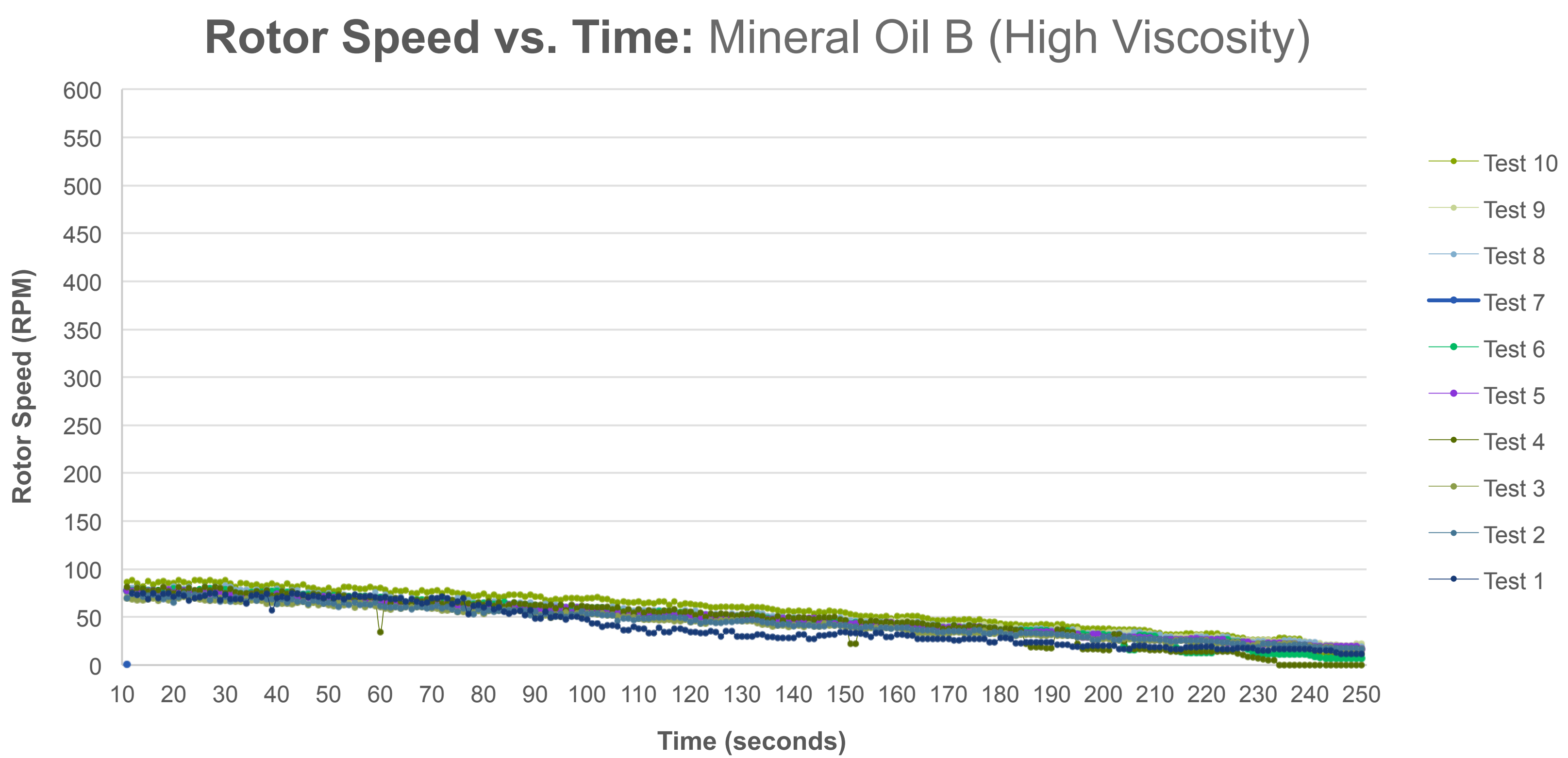
Verification
Baseline



Results:
Standard Deviation = 18.8

Verification

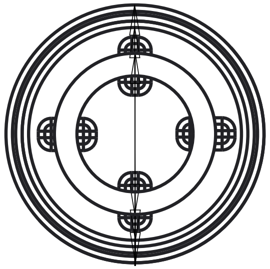
Baseline

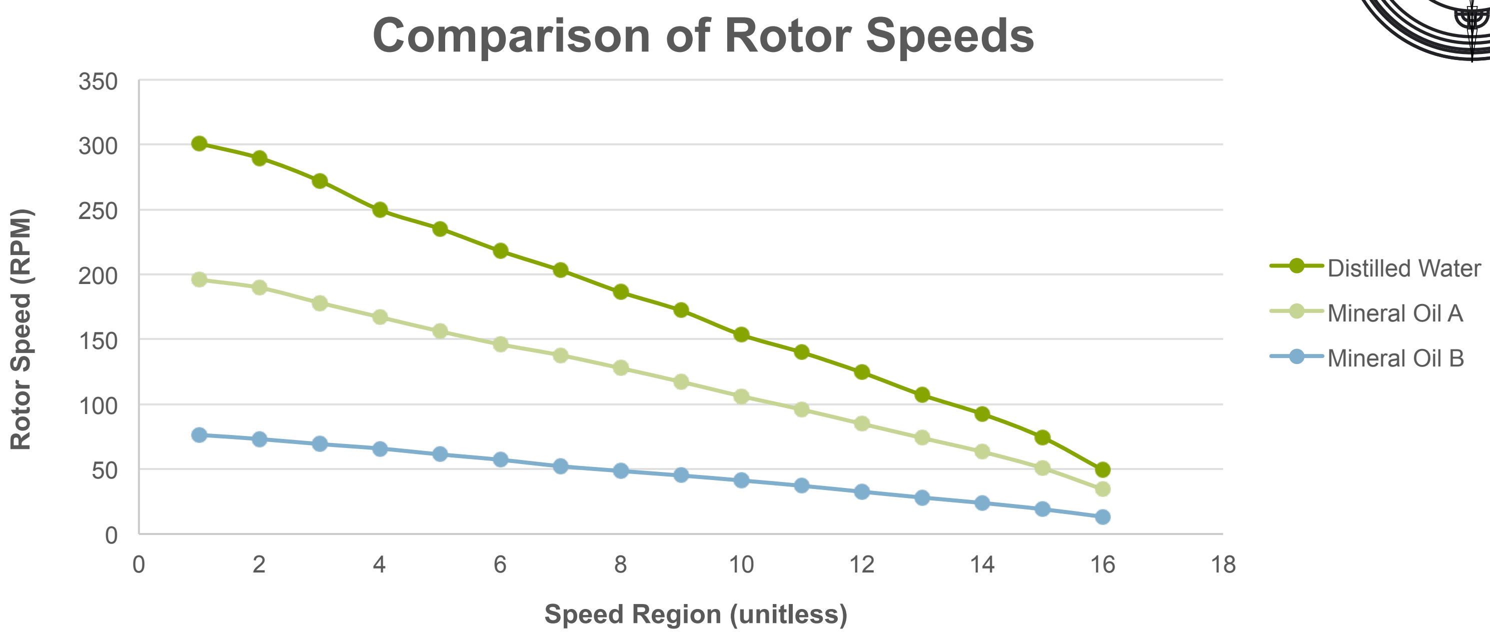


Results:
Standard Deviation = 5.78

Results

Baseline





Repeatability:

- Distilled Water = 6.8%
- Mineral Oil A = 3.8%
- Mineral Oil B = 4.6%

r_i = outer rotor radius (m)

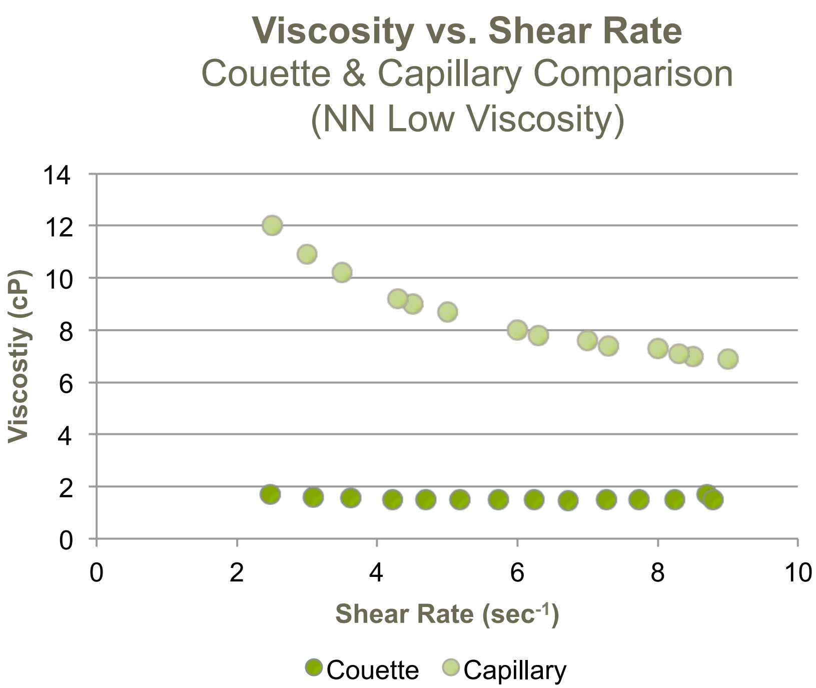
r_o = inner vacutainer radius (m)

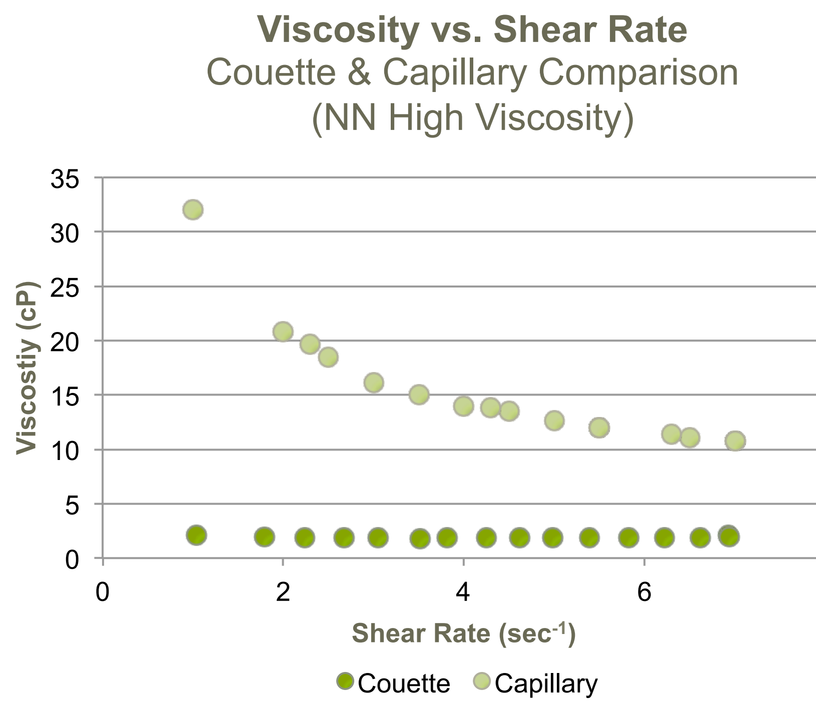
ω = angular velocity (rad/s)

$$\frac{\mu_{MO}}{\mu_W} = \frac{\omega_{W,r}}{\omega_{MO,r}}$$

Results

Viscosity





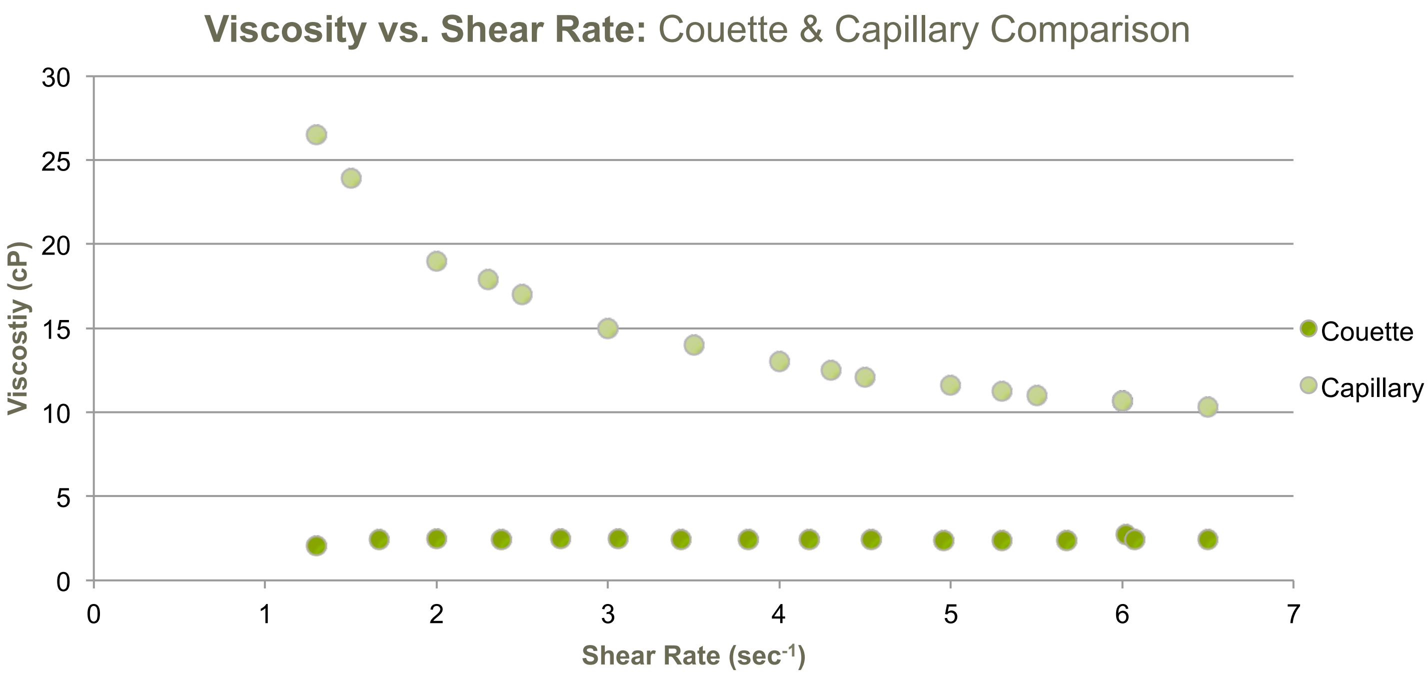
Sample: Non-Newtonian Standard Viscosity Fluid (Low/High)

Correction Factor: 5.81 (Low Viscosity) | 6.85 (High Viscosity)

*divided capillary tube blood viscometer at 5 sec^{-1} shear rate by measurement to obtain correction factor.

Results

Viscosity



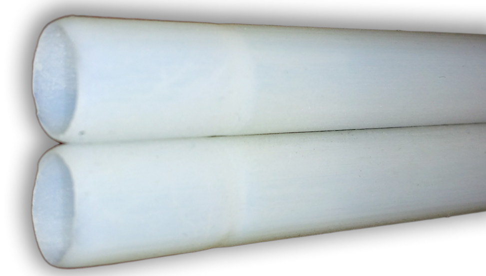
Sample: Human Blood | Hematocrit = 46

Results: Correction Factor = 4.89

*divided capillary tube blood viscometer at 5 sec^{-1} shear rate by measurement to obtain correction factor.

Results

Limitations



Primary issue is rotor resistance during rotation.

Rotor:

a) Gap between rotor and vacutainer too tight
b) Prone to warping due to environmental conditions
c) Fluid pull-away during rotor placement
d) Imperfectly circular rotor geometry
e) Rotor porosity leads to fluid retention
f) Non-uniform surface texture

Temperature:

a) Temperature not monitored/maintained 37°C during rotation

Results

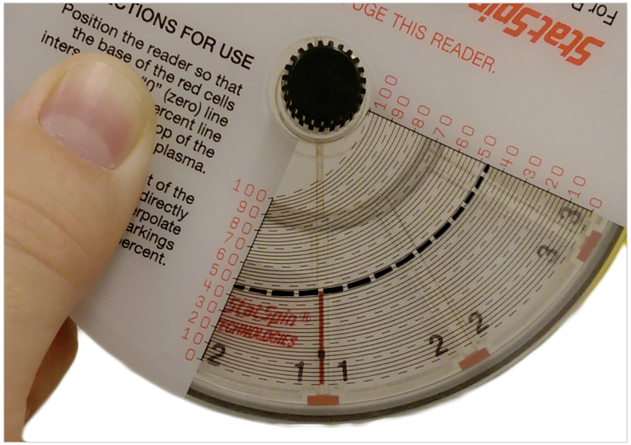
Hemolysis

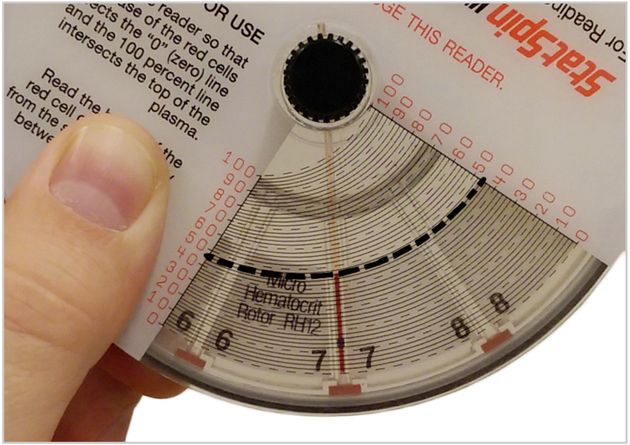
Hematocrit

Measurement of RBC/Plasma

- **Method(s):** Beckman-Coulter (cell counter) | Haematokrit 210 (centrifuge)
- **Results:** Comparison of pre- and post-test values to assess percent difference.

*centrifuged capillary tube of sample and conducted test at Drexel Plasma Institute.





Pre-test Hematocrit: 48

Post-test Hematocrit: 48

No significant change in hematocrit, thus no significant hemolysis.

Discussion

Context / Impact

Economic

- Typical medical devices are costly but offset by benefits

Upstream: R&D, BOM, testing

Downstream: Manufacture of final product and distribution

Environmental

- Few environmental concerns
- Minimize disposable volume
- Powered solely by electricity
    - No hazardous by-products

Social Impact

- Direct social impact
- Improve longevity of life
- Assist with quality of life
- Generally new territory

Ethical Analysis

- No direct patient interaction
    - Incorporates existing technology
- FDA approval not required
- Minimal ethical concern

Management

Organization

Team Member	Roles and Responsibilities
Rich Hanna	Team Management Project Coordination
Austin Farber	Data Acquisition Feasibility Programming Logic Power Supply
Mike Sinisi	Coaxial Fluid Tester Design Rotational Assembly Design
Matt Lorenz	Temperature Control Housing Design Rotational Assembly Design
Dan Nguyen	Data Acquisition Feasibility Verification Testing

Management

Budget

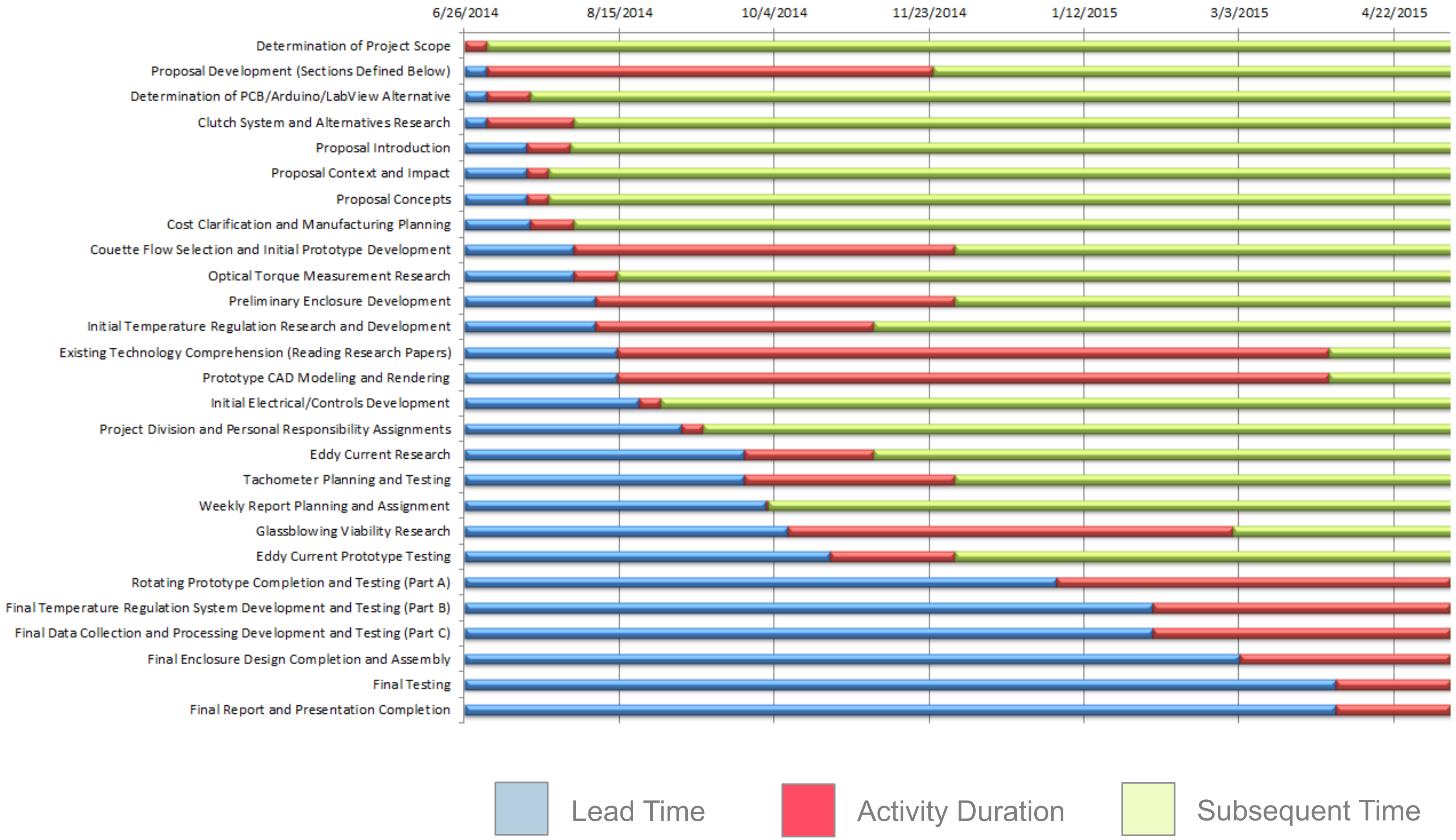
Internal Funding: Dr. Young Cho

- Current Expenditures

Device Component	Total Expenses to Date
Coaxial Fluid Tester	$118.43
Rotational Assembly	$327.27
Thermal Control System	$316.06
Housing	$14.69
Data Acquisition	$789.21
Power Supply	$79.09
TOTAL	**$1645.20**

Management

Gantt Chart*



*subject to change

Future Work

Improvements:

① Analyze and optimize the effect of smaller rotor diameter

② Change rotor material and improve manufacturing process

③ Optimize rotor weight to eliminate pull-away

④ Integrate thermal control/monitoring into rotational system

HAEMOPOISE

References

[1] American Heart Association. Matters of Your Heart, (2012) Infographic.

[2] Blood Viscosity: The Unifying Parameter In Cardiovascular Disease Risk (Blood Flow Online) http://bloodflowonline.com/commentary/blood-viscosity-unifying-parameter-cardiovascular-disease-risk

[3] J. Martini et al. (2006) Mechanotransduction and the homeostatic significance of maintaining blood viscosity in hypotension, hypertension and haemorrhage, *J of Int Med* 259: 364–372.

[4] S. Middleman, (1968) *The Flow of High Polymers* Jon Wiley & Sons.

[5] Munson, Bruce. Fundamentals of Fluid Mechanics. 6th Edition. Wiley, 2009.

[6] J. Walker et al. Fundamentals of Physics 8th Ed. Wiley, 2009.

[7] Giancoli, Douglas C. (1998). Physics: Principles with Applications (5th ed.) p.624.

[8] ASTM D445-14e2, Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity), ASTM International, West Conshohocken, PA, 2014, www.astm.org

[9] ASTM F756, Standard Practice for Hemolytic Assessment of Materials, ASTM International, West Conshohocken, PA, 2012, www.astm.org

Q / A