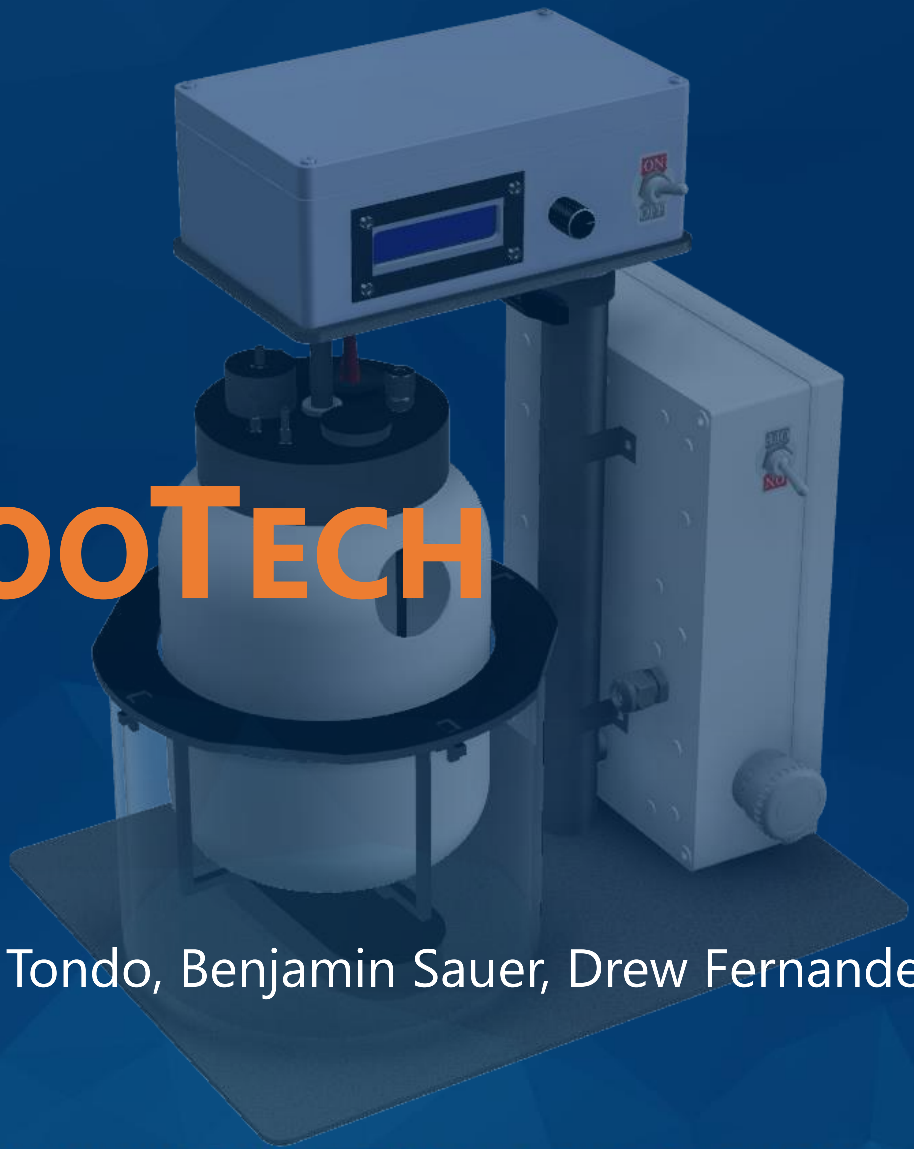
UF Herbert Wertheim College of Engineering
UNIVERSITY *of* FLORIDA

CattlePro By MooTech



EML4502 Mechanical Engineering Design 3
MooTech Final Presentation

Group Number: MT0B-2
Group Members: Jazmine Sandoval, Giuliano Lupica Tondo, Benjamin Sauer, Drew Fernandez, Anissa Mansouri, Nicholas Quach, Brandon Bulnes

Outline

PROJECT BRIEF

FINAL DESIGN

TESTING RESULTS

DESIGN IMPROVEMENTS

DEMO

QUESTIONS

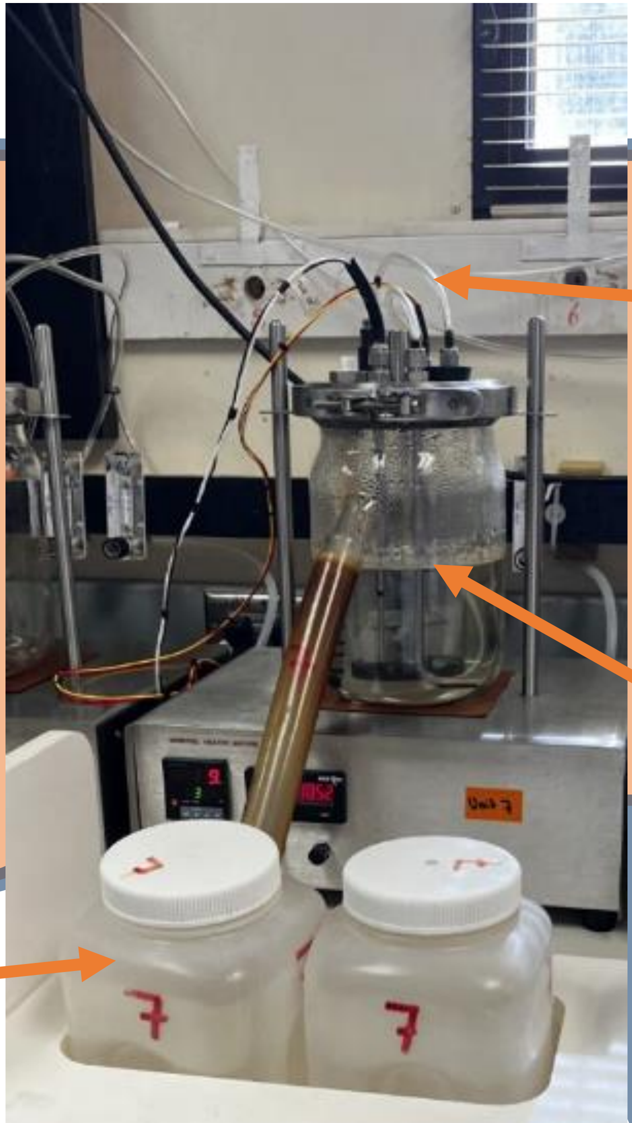
Project Brief

Background

Dual Flow Continuous Culture System

To enhance rumen efficiency by studying microbial populations

Research in meat production, reducing feed waste, and exploring alternative feed sources



Maintains specific liquid inflow and outflow saliva flow rates

Jar holds 1.8L of fluid at 39 ℃ and 100 RPM

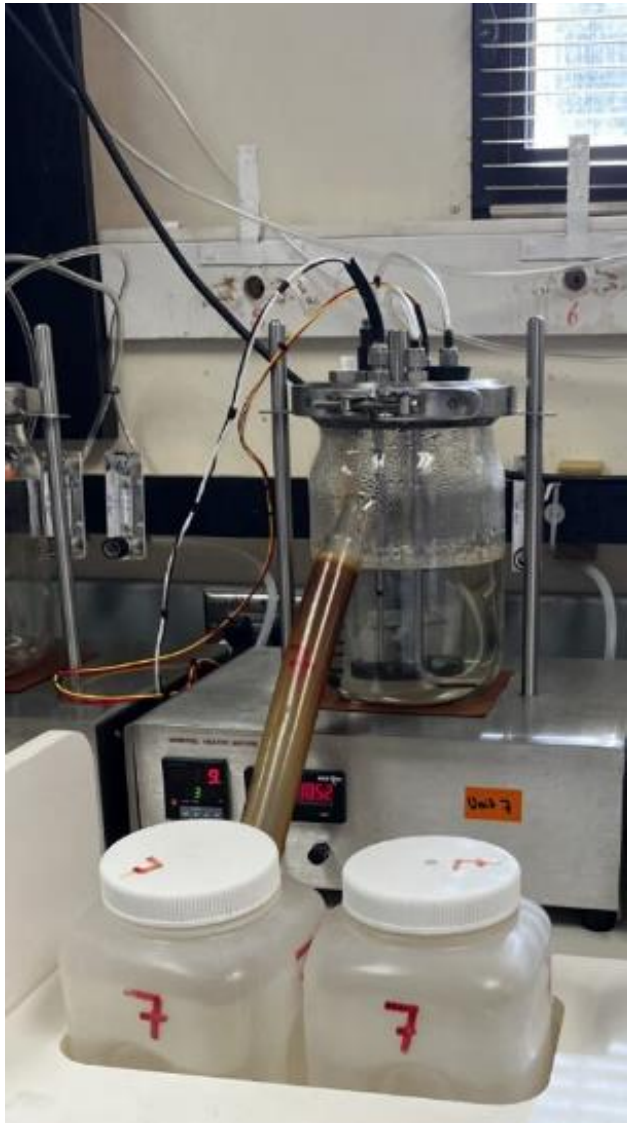
Effluent bottles collect liquid and solid waste separately

Project Brief

Problem

Current is system outdated and unreliable

Impedes research efficiency



Solution

Create sophisticated agricultural research units

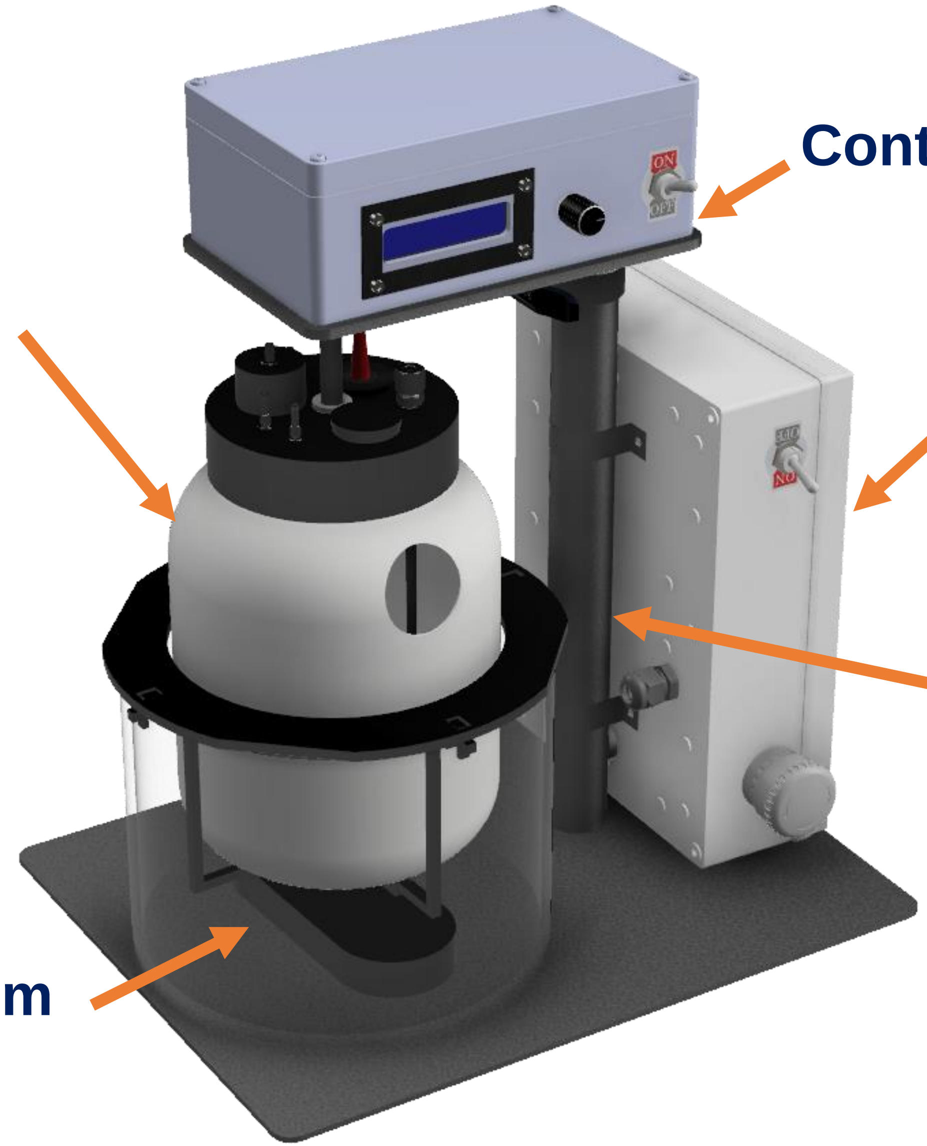
Prioritize the design of user-friendly bench-top lab equipment

Cost-effective, highly efficient solutions

Automated data management functionalities

Final Design

Final Design - CattlePro



Control and Power System

Fermenter System

Structure System

Water Bath Heating System

Structure System

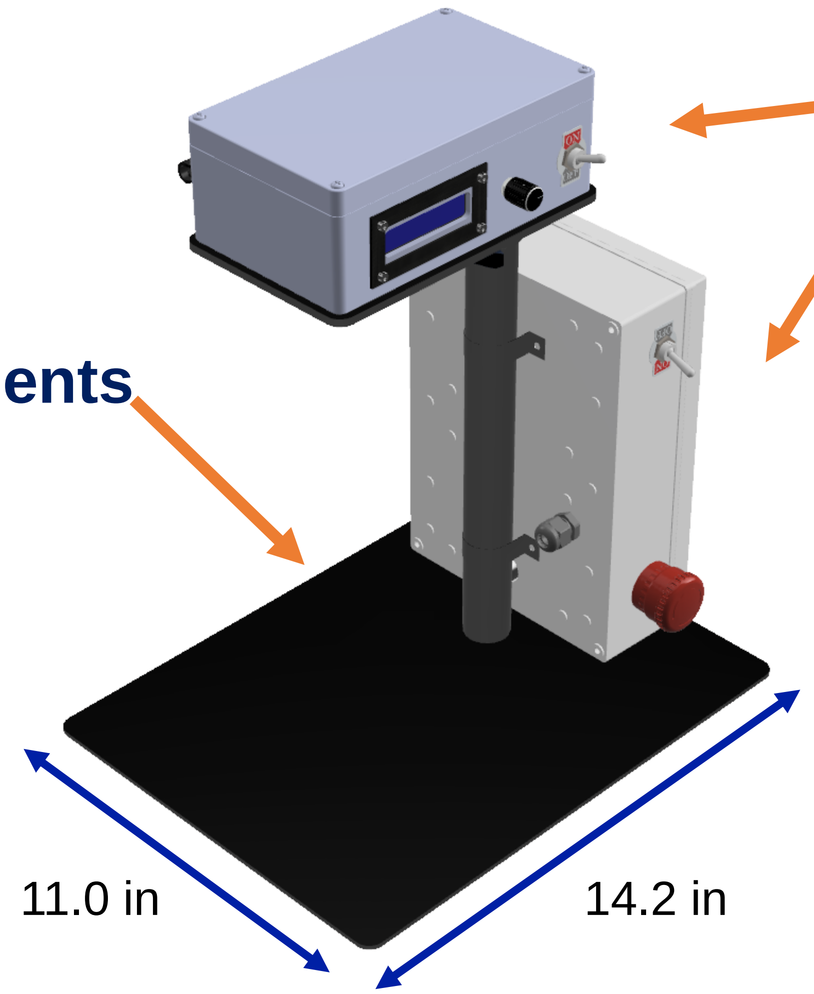
ABS Control Boxes

4130 Steel Metal Components

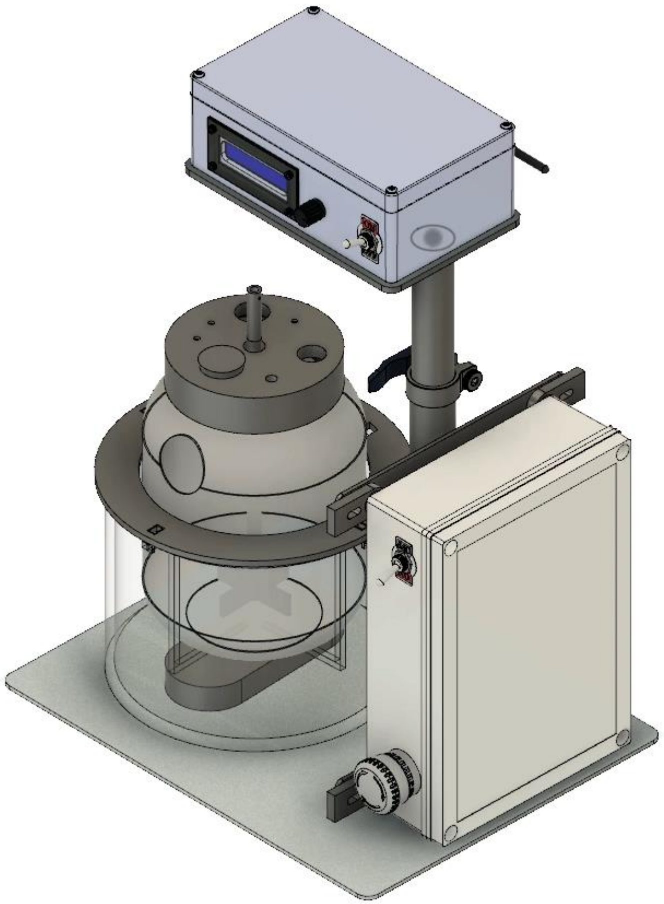
Total Weight: 20 lbs

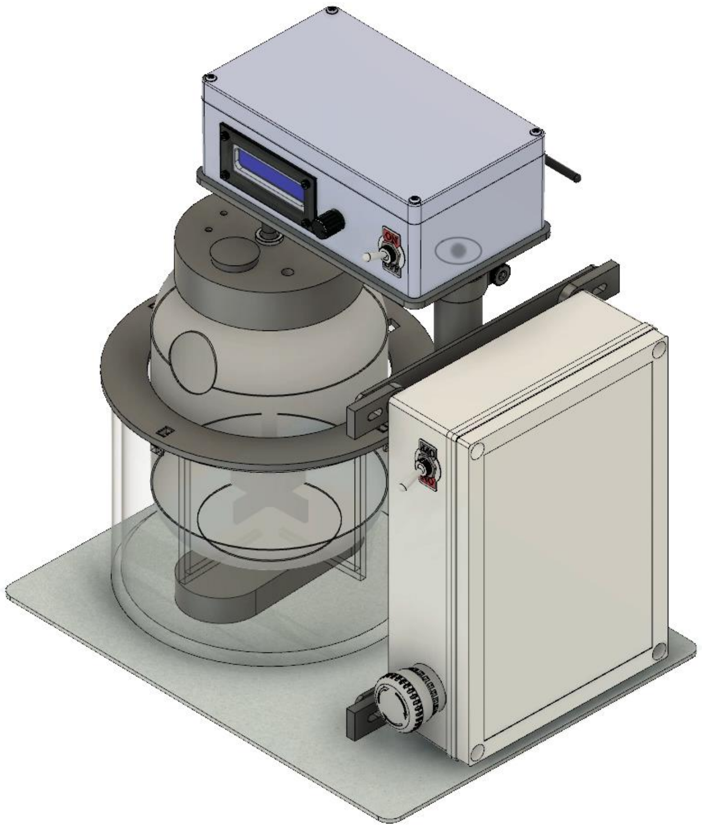
Resting Height: 17 in

Max Height: 19 in



Structure System

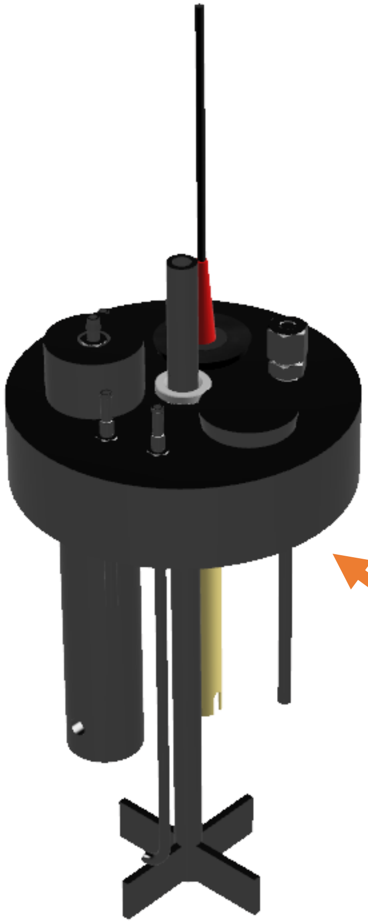




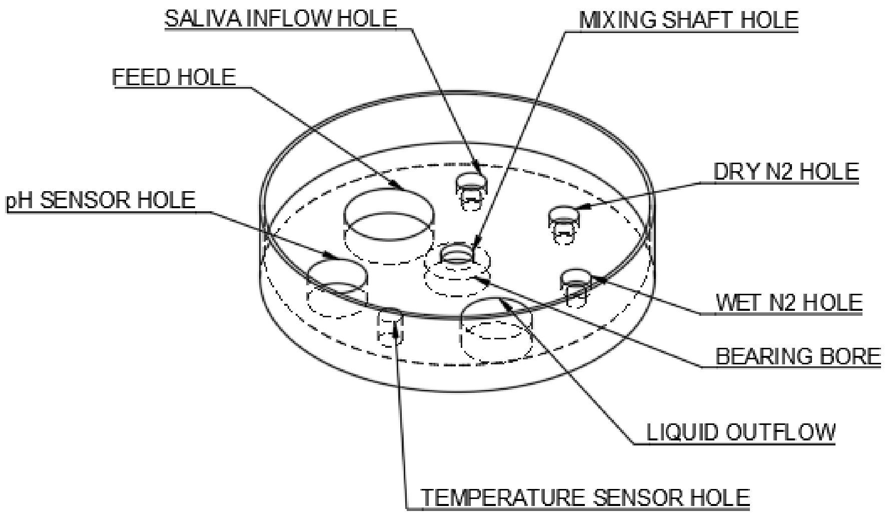
Allows for *vertical* and *rotational* translation

Fermenter System

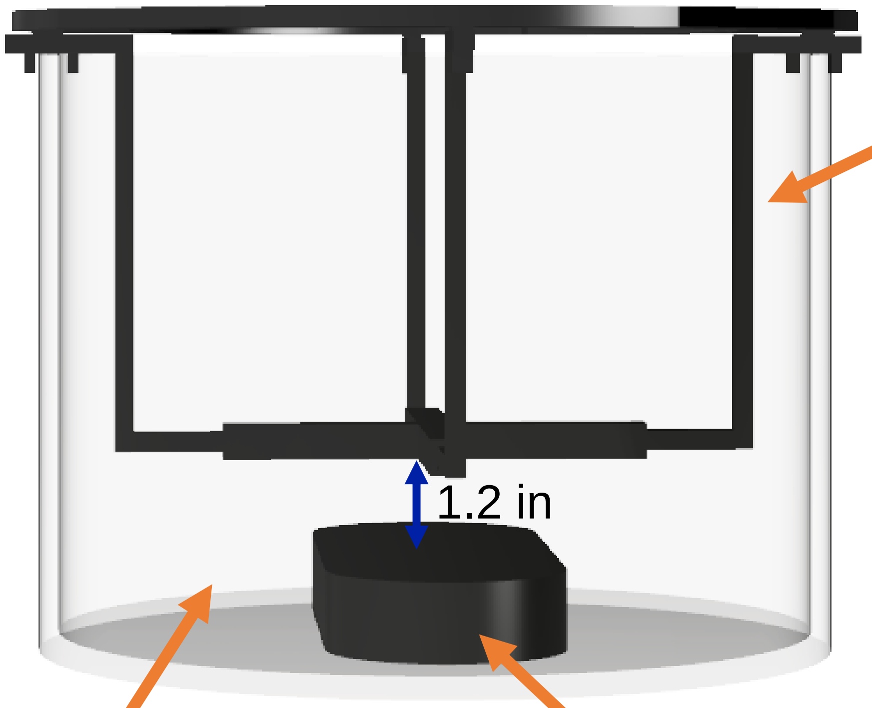
Polyethylene Jar



PETG Lid



Heating System



Glass Jar

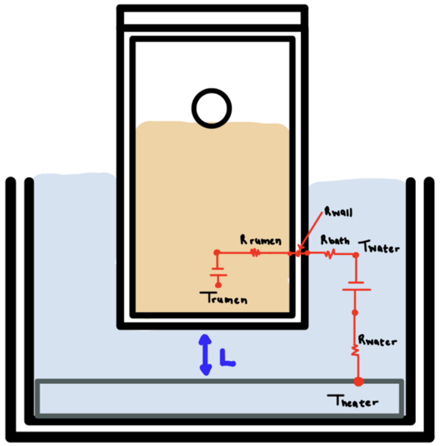
Immersion Heater

PETG Jar Supports

Max Weight: 64 lbs

Weight of Jar and Rumen: ~5 lbs

FOS: 12.8

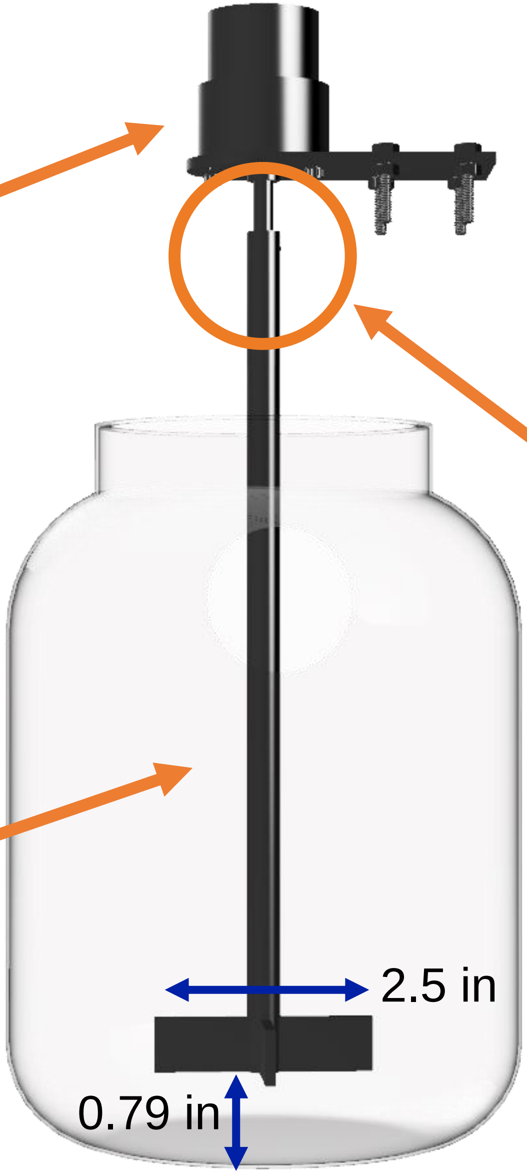


Material	Thermal Conductivity (W/ mK)	Resistance (mK/W)
Jar	0.4	0.00250

Material	Convection Coefficient (W/m²K)	Resistance (m²K/W)
Rumen	169	0.00593
Water	49.6	0.0202
Water Bath	225,580	6.12×10^{-5}

Mixing and Rotation System

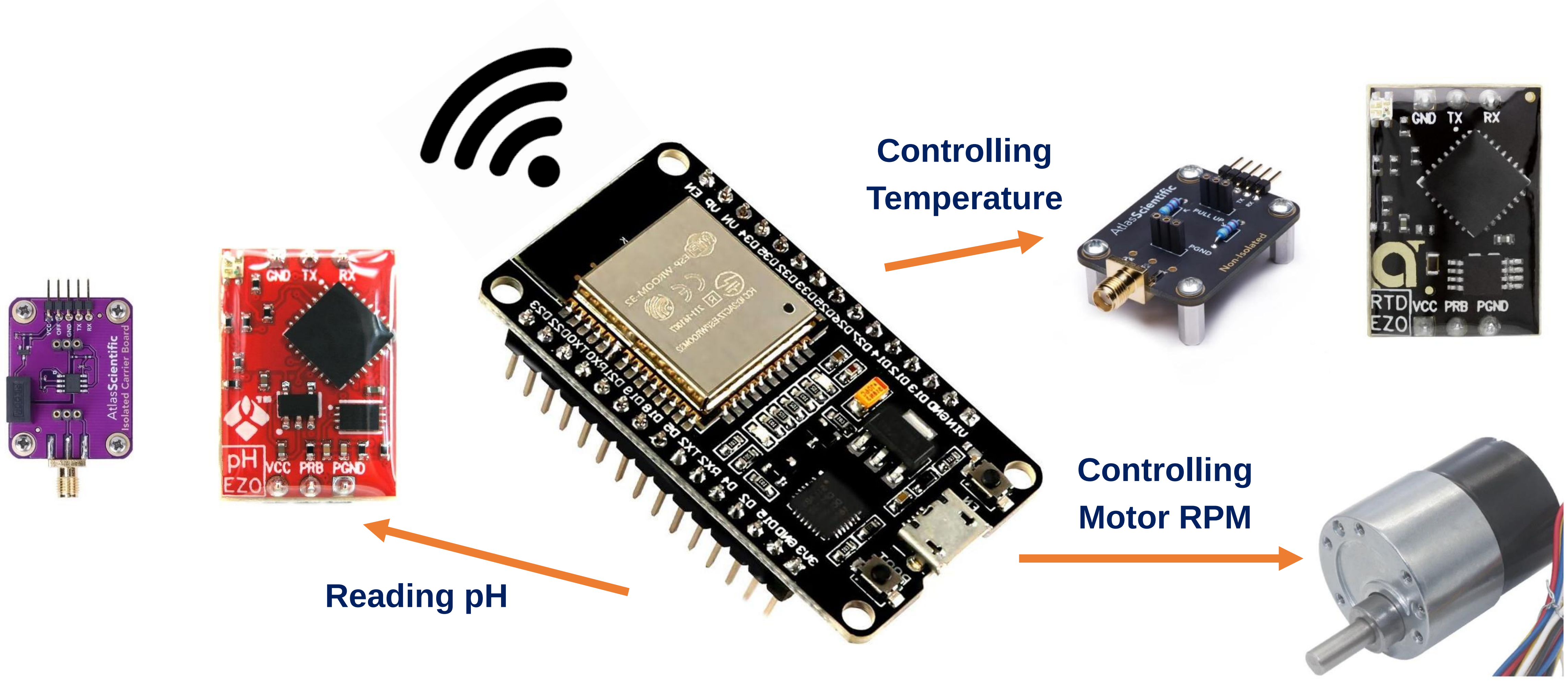
DC Brushless Motor



Stainless Steel Mixing Shaft

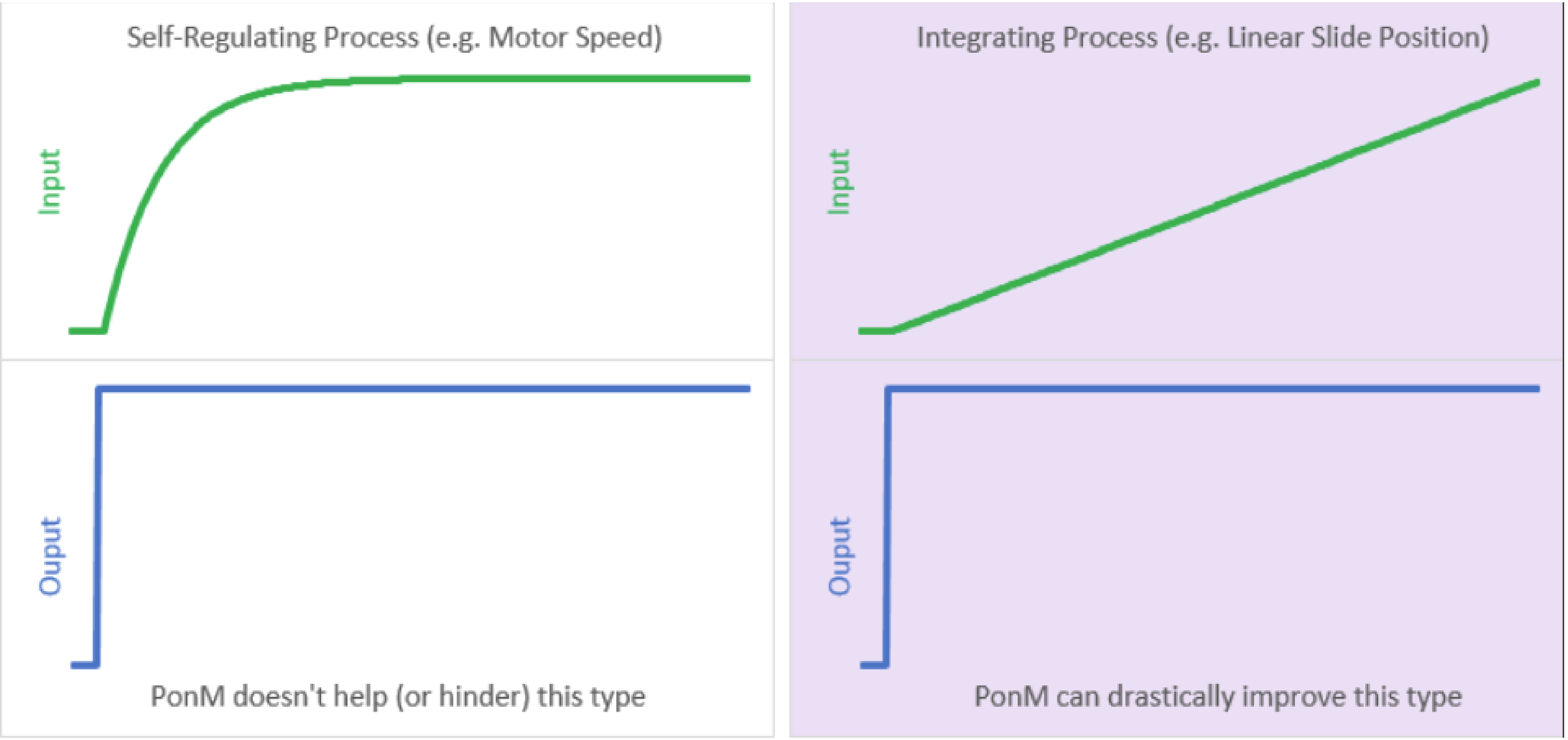
Threaded Removable Mixing Shaft

Control and Power System



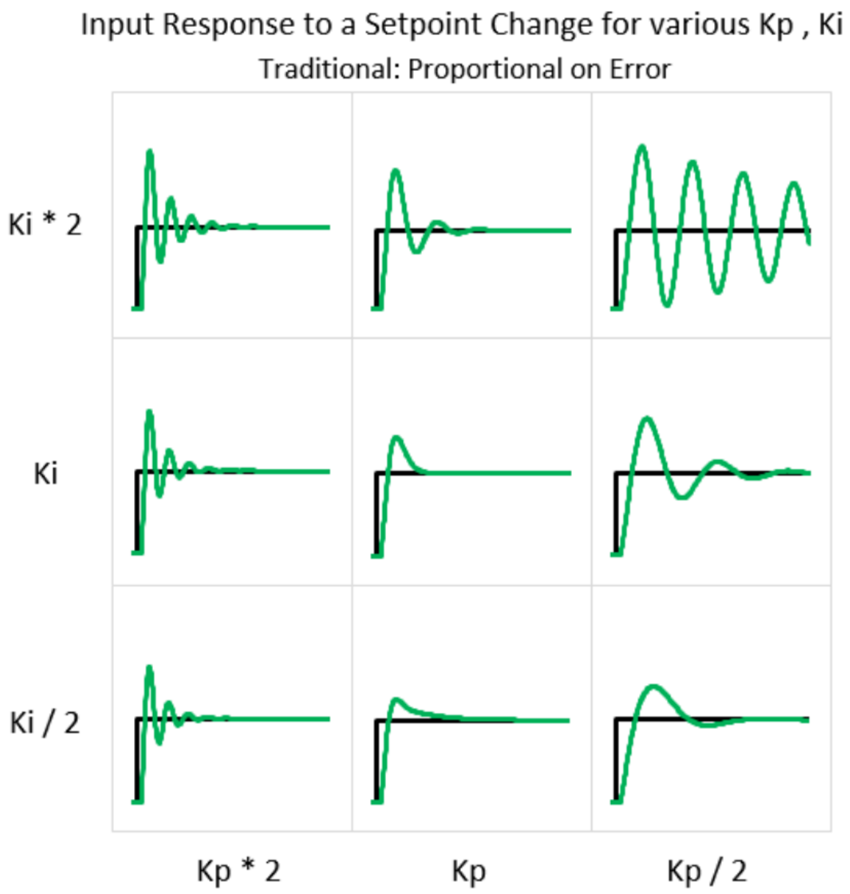
ESP32 Microcontroller

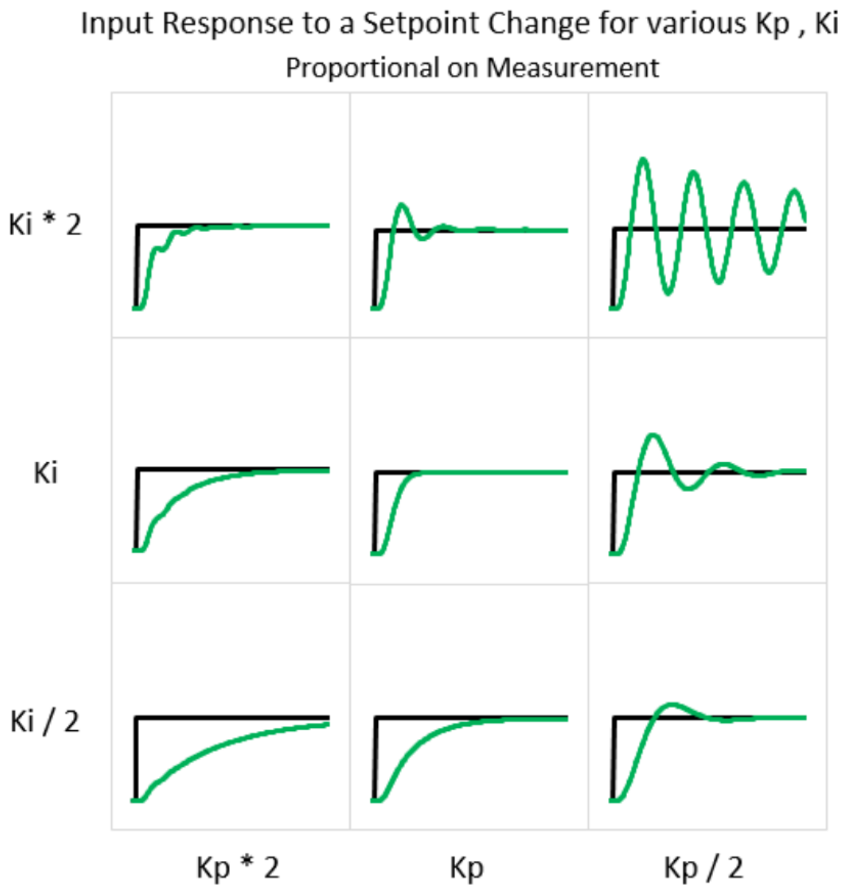
Tuning the Control System



[1] Project Blog, *Introducing Proportional On Measurement*

Tuning the Control System

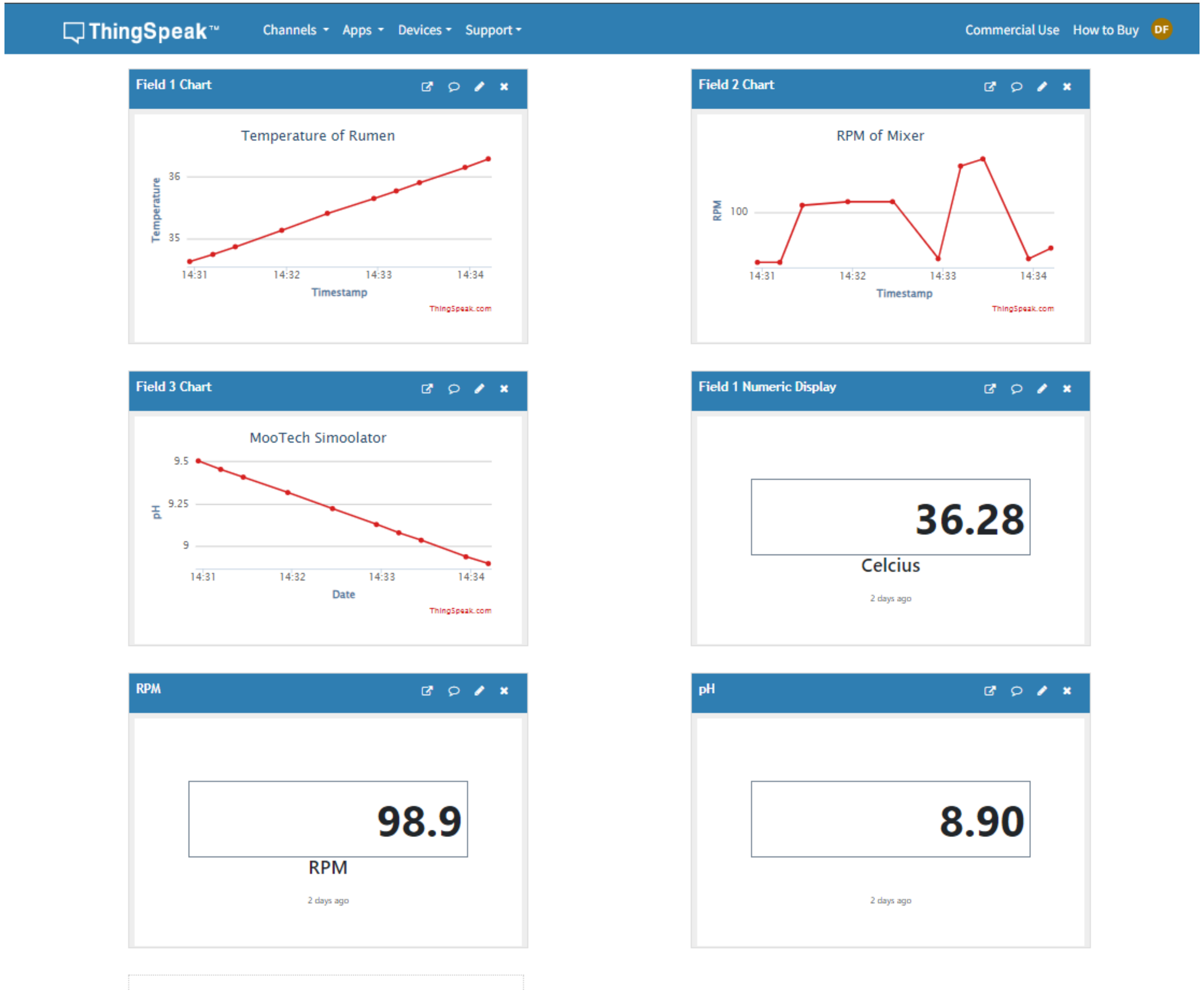




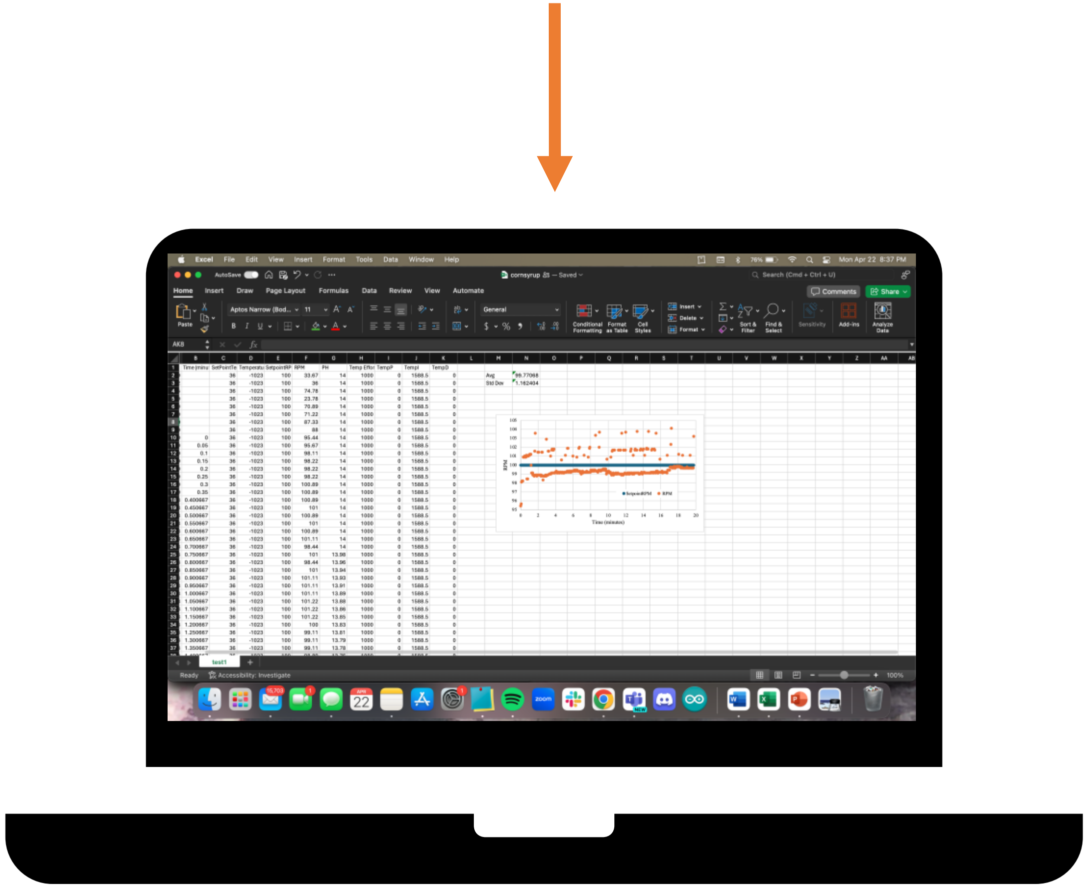
[1] Project Blog, *Introducing Proportional On Measurement*

Data Management

Real Time Monitoring Dashboard

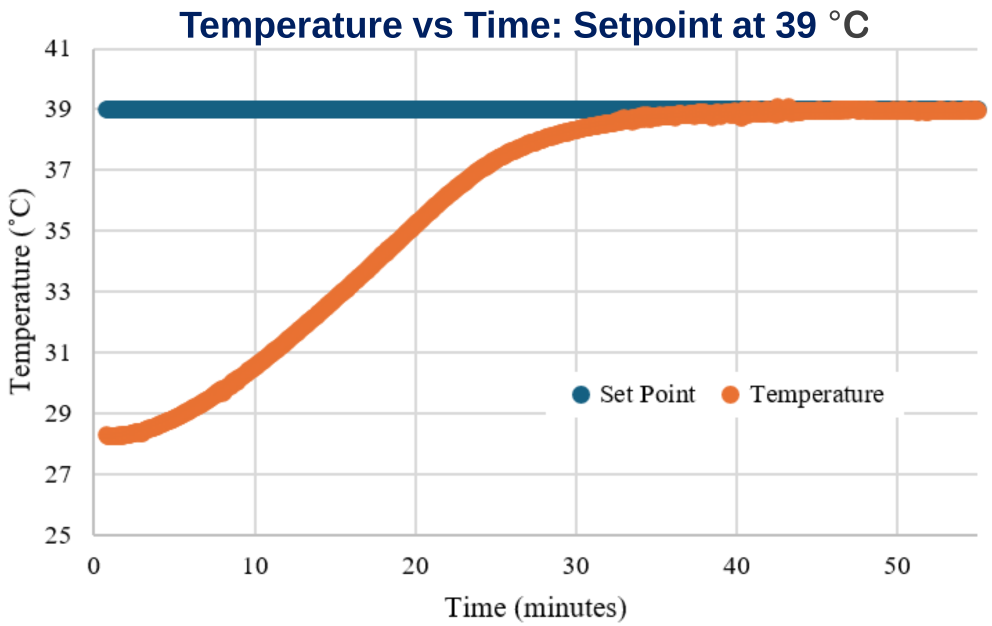


SD Card



Testing Summary – Accuracy of Heater

Setpoint Temperature	36 °C	39 °C	40 °C	Full Throttle (max 40 °C)
Absolute Mean Error (°C)	0.0321	0.0159	0.0397	-
Time to Reach Steady State from Faucet Water ~28 °C (min)	50.3	41.8	51.9	24



Key Takeaways:

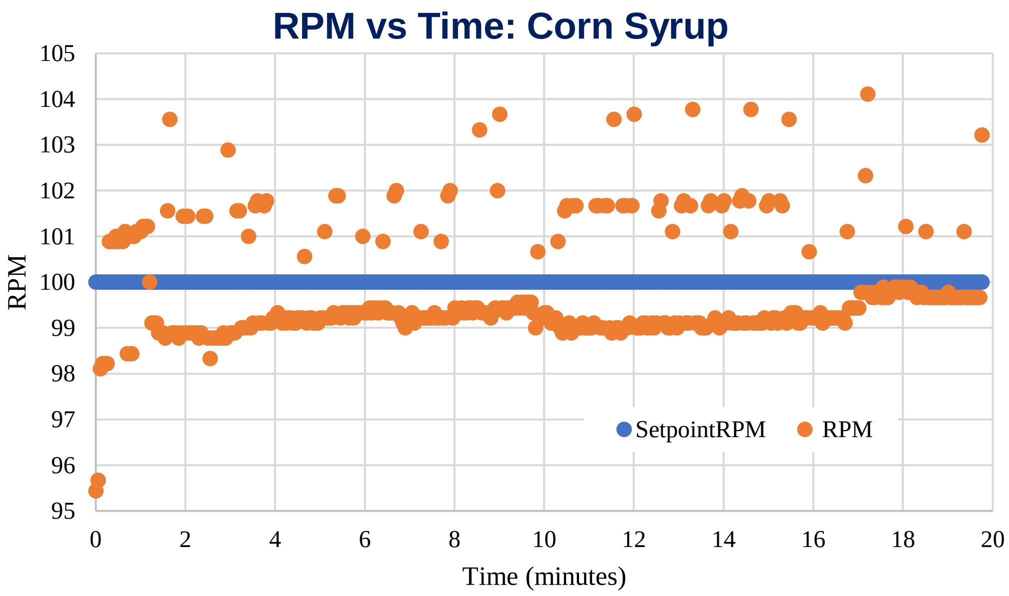
Accuracy within ±0.1 °C

Long heating time

Minimal overshoot

Testing Summary – Viscosity Adaptive Stirring

Liquid	Water (~1 cp)	Chocolate Sauce (~400 cp)	Detergent (~1470 cp)	Corn Syrup (~3,000 cp)
Average (RPM)	99.80	99.82	99.78	99.77
Absolute Mean Error (RPM)	1.19	0.975	1.14	1.16



Key Takeaways:

Accurate motor RPM tracking

Motor can withstand viscosities up to 3,000 cp

Stirring turn over rate is an average 5.25 seconds

Cost Basis

MOOTECH™

Cost basis comparison for production of a single prototype vs. 1000 batch run

Item	Single Prototype Cost	1000 Batch Run Cost
OTS Parts/Raw Material	$1,350.21	$655,567.63
Manufacturing	$117.52	$117,520.00
Assembling	$4.19	$4,190.00
Unit Cost	**$1471.92**	**$777.28**

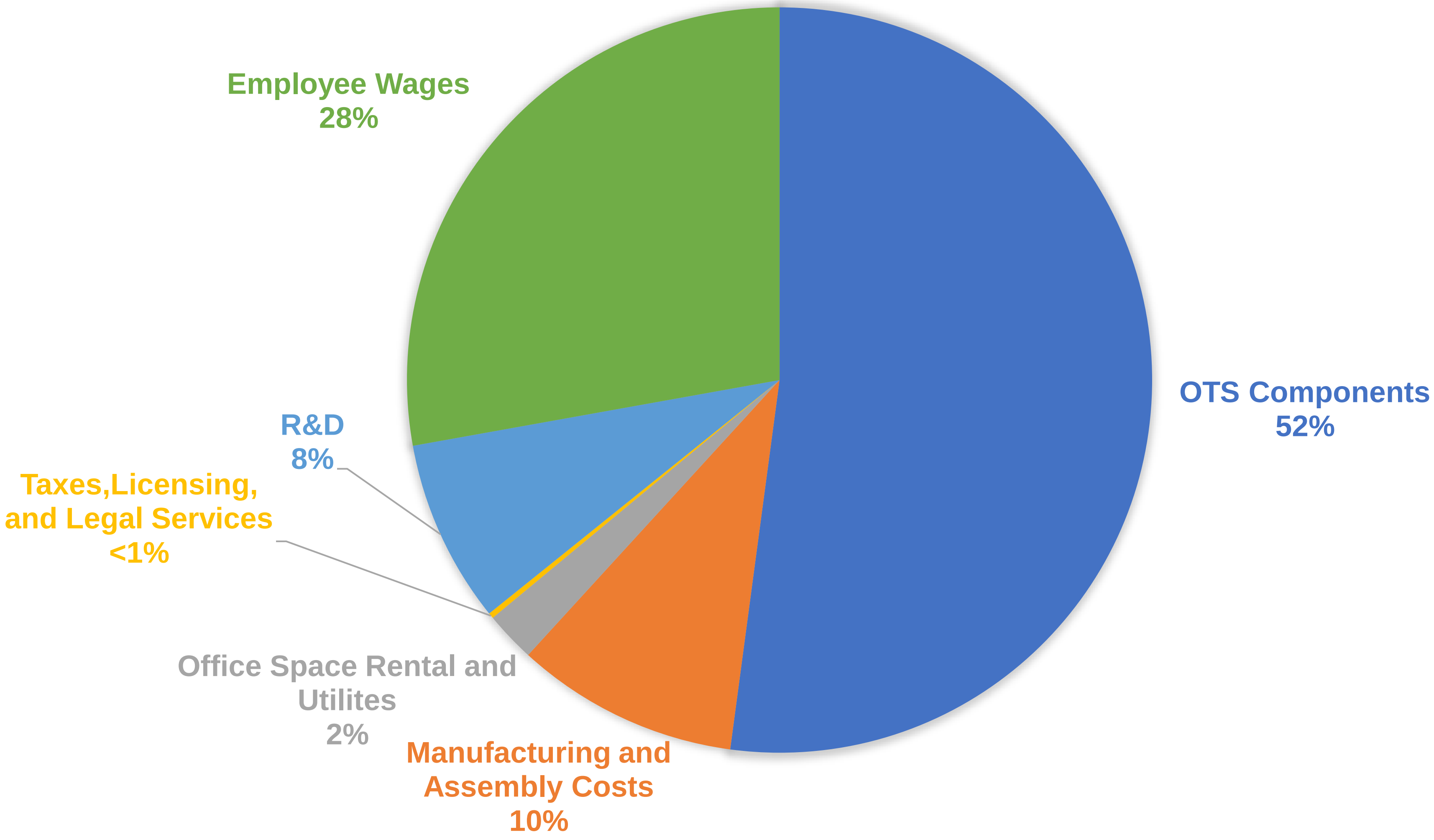
Budget for 1000 Batch Run

Annual Budget:
$1,157,878

Profit Margin:
$150,000

Gross Revenue:
$1,307,878

Price Point for 1000 Unit Batch:
$1,308



R&D [2], Legal Fees [3], Utilities [4], Profit Margin [5]

Improvements

Improvements

Heating Time

Electronic Development

Material Testing

Updated Pumping

Demo and Questions

Scan QR Code for
Live Data Access

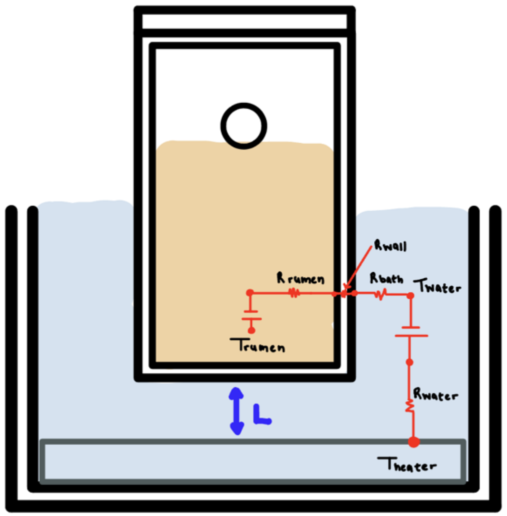
Removing the Fermenter System

Setting Up the Fermenter System

User Interface

Emergency Stop

Heat Transfer – Length Between Heater and Jar



Characteristic Length Between Heater and Jar

Assumptions:

1. 1D lumped capacitance heat transfer model.
   a. Rumen is continuously well mixed mechanically.
   b. Water is well mixed by natural convection.
   c. Therefore, temperature gradients within rumen are negligible.
2. Temperature of the water is regulated so it never boils.
3. Resistance amongst the rumen, rumen jar, and water bath is negligible.
4. All physical properties and equations can be referenced from [1].

Calculations:

To find the characteristic length (L) between the jar and heater to induce buoyancy-driven flow, or natural convection, the Rayleigh number (*Ra)* was used. The Rayleigh number relates the viscosity (ν), thermal diffusivity (α), characteristic length (L), gravity (g), expansion coefficient (β), and the difference between the temperature of the water and heater ($T_w - T_h$). This can be reconfigured to solve for the characteristic length.

$$L^3 = \frac{\nu \alpha Ra}{g\beta(T_w - T_h)}$$

The thermal diffusivity (α) can be found knowing the thermal conductivity (K), density (ρ), and specific heat of water (c_p).

$$\alpha = \frac{K}{\rho c_p}$$

To form the buoyancy-driven flow for an upper surface of cold plate, the Rayleigh number must be greater than 10^4 and less then 10^9. Knowing this and the thermal characteristics of water, the characteristic length can be found.

$$L^3 = \frac{8.56x10^{-4}\frac{Ns}{m^3} * 1.48x10^{-7}\frac{m^2}{s} * 10^4}{9.81\frac{m^3}{s} * 2.87x10^{-4}\frac{1}{K} * (293K - 312K)}$$

$$L = 0.0287\ m = 28.7\ mm$$

The length in the design was rounded to 30 mm to ensure a high enough Rayleigh number, accounting for any uncertainty.

Heat Transfer – Volume of Water

Time to Heat Based on Lumped Capacitance

Assumptions:

1. 1D lumped capacitance heat transfer model.
   a) Rumen is continuously well mixed mechanically.
   b) Water is well mixed by natural convection.
   c) Therefore, temperature gradients within rumen are negligible.
2. The contact resistance is negligible due to an immersion heater.
3. The density of rumen is constant.
4. Resistance amongst the rumen, rumen jar, and water bath is negligible.
5. Temperature of the heater is constant and has reached a steady state.

Calculations:

Using lumped capacitance, the relation between the density of rumen and its volume ($p_r V_r$), density of water and its volume ($p_w V_w$), temperature of the heater (T_H), temperature of the water (T_w), and the resistance of the water (R_w), the time can designate the volume of water needed to reach the customer needs of heating within 10 mins.

$$\frac{T_H - T_w}{R_w} = (p_w V_w + p_r V_r)\frac{dT}{dt}$$

Knowing the temperature difference,

$$\theta = T_H - T_w$$

Recognizing that $\frac{d\theta}{dt} = \frac{dT}{dt}$ and T_H is constant, the equation can be rewritten.

$$R_w (p_w V_w + p_r V_r)\frac{d\theta}{dt} = \theta$$

Setting initial conditions for which $T(0) = T_i$ and $t = 0$, separation of variables can be used.

$$R_w (p_w V_w + p_r V_r)\int_{\theta_1}^{\theta} \frac{d\theta}{\theta} = \int_0^t dt$$

Knowing the temperature difference,

$$\theta_i = T_H - T_i$$

The integral yields the following,

$$R_w (p_w V_w + p_r V_r)\, ln\frac{\theta_i}{\theta} = t$$

This equation can then be rearranged to find the volume of water (V_w)

$$V_w = \frac{t}{R_w\, ln\frac{\theta_i}{\theta} p_w} - \frac{p_r V_r}{p_w}$$

Heat Transfer – Resistance of Water Underneath Jar

To find the resistance in the water (R_w), the Nusselt number can be used for the case of the upper surface of cold plate.

$$Nu = 0.52Ra^{1/5} = 0.52 * 10^{4/5} = 3.28$$

Knowing this, the convection coefficient of the water can be found.

$$h = \frac{Nu \cdot k}{L} = \frac{3.28 * 616 \frac{W}{mk}}{0.03\, m} = 66.5 \frac{W}{m^2 K}$$

Now the resistance of the water (R_w) can be determined through the convection coefficient (h) and the surface area of the heater (A_s). Although the exact of the dimensions of the heater is still being sought out due to testing, it is assumed it is the same diameter as the bottom of the water bath.

$$R_w = \frac{1}{hA_s} = \frac{1}{66.5 \frac{W}{m^2 K} * 0.0285\, m^2} = 0.527 \frac{K}{W}$$

Using this, the volume of the water can be found to heat the rumen within 10 minutes.

$$V_w = \frac{600\, s}{0.527 \frac{K}{W}\, ln \frac{(312.1 - 293)K}{(312.1 - 312)K}\, 993\, \frac{kg}{m^3}} - \frac{1000\, \frac{kg}{m^3} * 3.08x10^{-3} m^3}{993\, \frac{kg}{m^3}}$$

$$V_w = 0.215\, m^3$$

Heat Transfer – Rumen Convection Coefficient

Rumen Convection Coefficient
Assumptions:
Density of rumen is 1000 kg/m^3.
The flow within the jar is estimated as flow over a flat plate.
Viscosity of the rumen is 3000 cp.
Rumen is at a constant speed of 100 rpm.
All physical properties and equations can be referenced from [1].

Calculations:
To find the convection coefficient of the rumen the Reynold's number inside the vessel had to be calculated. The density (ρ), velocity (V). and viscosity (μ) of the rumen were all know. The characteristic length (L) was calculated by dividing the volume over the surface area of the jar. The Reynold's number calculation is shown below.

$$Re = \frac{\rho V L}{\mu} = \frac{1000\ \frac{kg}{m^3} * 0.798\ \frac{m}{s} * 0.0134\ m}{3\ Pa \cdot s} = 3.57$$

This number allows us to determine that the flow is laminar inside the jar. Next the Prandtl number had to be calculated which used the Rumens viscosity (μ), thermal conductivity (k), and specific heat capacity (C_p). The calculation is as follows:

$$Pr = \frac{\mu C_p}{k} = \frac{3\ Pa \cdot s * 3.8 \frac{J}{kgK}}{0.5\ \frac{W}{mK}} = 22.6$$

With these two numbers the Nusselt number can be calculated, which can then be used to solve for the convection coefficient. The Nusselt number equation for a laminar flat plate flow is shown below.

$$Nu = 0.332 * Re^{\frac{1}{2}} * Pr^{\frac{1}{3}} = 0.332 * 3.57^{\frac{1}{2}} * 22.6^{\frac{1}{3}} = 4.5$$

Using the calculated Nusselt number the convection coefficient can be solved, where L is the characteristic length and k is the thermal conductivity of the rumen.

$$h = \frac{Nu * k}{L} = \frac{4.5 * 0.5\ \frac{W}{mK}}{0.0134\ m} = 166.3\ \frac{W}{m^2 K}$$

Heat Transfer – Resistance of Water Bath Sides

Water Bath Resistance
Assumptions:
Density of rumen is 1014 kg/m^3.
The water bath is modeled as free convection over a vertical plate.
Water bath has laminar flow.
All physical properties and equations can be referenced from [1].

Calculations:
To find the resistance due to the water bath, the Rayleigh number must be found. This is found through gravity (g), coefficient of thermal expantion of water (β), the temperature of the surface of the jar (T_s), the temperature of the water (T_∞), the characteristic length (L), viscosity of water (υ), and the thermal diffusivity of water (α). The characteristic length is defined as the amount of water touching the jar.

$$Ra = \frac{g\beta(T_s - T_\infty)L^3}{\upsilon\alpha} = \frac{9.81\ \frac{m}{s^2} * \ 2.87\ x\ 10^{-4}\ \frac{1}{K} * \ (293\ K - 312\ K) * 0.113\ m^3}{8.56\ x\ 10^{-4} * 1.48\ x\ 10^{-7}}$$

$$Ra = 9.35\ x\ 10^6$$

Next, the Prandtl number must be found. This is found by the viscosity of water (υ) and the thermal diffusivity of water (α).

$$Pr = \frac{v}{\alpha} = \frac{8.56\ x\ 10^{-4}}{1.48\ x\ 10^{-7}} = 5764$$

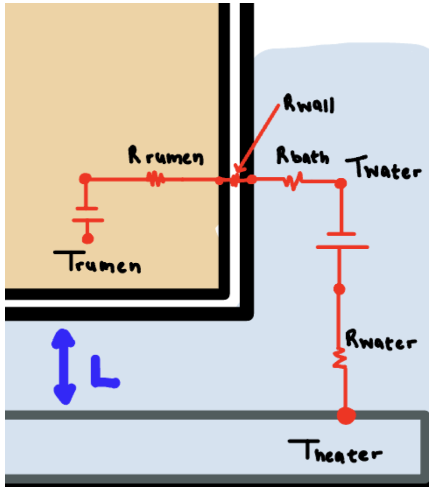
With these two numbers the Nusselt number can be calculated.

$$Nu = \left\{0.835 + \frac{0.387Ra^{1/6}}{[1 + \left(\frac{0.492}{\mathrm{Pr}}\right)^{9/16}]^{8/27}}\right\}^2 = \left\{0.835 + \frac{0.387(9.35\ x\ 10^6\ )^{1/6}}{[1 + \left(\frac{0.492}{5764}\right)^{9/16}]^{8/27}}\right\}^2$$

$$Nu = 41.39$$

Using the calculated Nusselt number the convection coefficient can be solved, where L is the characteristic length and k is the thermal conductivity of the water.

$$h = \frac{Nu * k}{L} = \frac{41.39 * 616\ \frac{W}{mK}}{0.113\ m} = 225{,}580\ \frac{W}{m^2K}$$



Heat Transfer – Wattage Required

Wattage Required

Using the resistances and their respective surface areas or thicknesses, the total resistance can be found. Because the convection coefficient is so high for the side of the water, it can be neglected.

$$Thermal\ Conductivity\ of\ Jar: k = 0.4\frac{W}{mK}$$
$$Thickness\ of\ Jar: 0.001\ m$$

$$Convection\ Coefficient\ of\ Rumen: h_r = 169\frac{W}{m^2K}$$
$$Surface\ Area\ of\ Rumen: 0.0724\ m^2$$

$$Convection\ Coefficient\ of\ Bottom\ of\ Water: h_{w,b} = 49.6\frac{W}{m^2K}$$
$$Area\ of\ Bottom\ of\ Jar: 0.0161\ m^2$$

With this, the total resistance can be found.

$$R_T = \left(\frac{1}{k * L} + \frac{1}{h_r * A_r} + \frac{1}{h_{w,b} * A_{w,b}}\right)^{-1}$$

$$R_T = \left(\frac{1}{0.4\frac{W}{mK} * 0.001\ m} + \frac{1}{169\frac{W}{m^2K} * 0.0724\ m^2} + \frac{1}{49.6\frac{W}{m^2K} * 0.0161\ m^2}\right)^{-1}$$

$$R_T = \left(2500\frac{K}{W} + 0.0820\frac{K}{W} + 1.256\frac{K}{W}\right)^{-1}$$

$$R_T = 0.000399\frac{W}{K}$$

To find the total amount of wattage required, the following can be done.

$$Q = R_T \Delta T$$

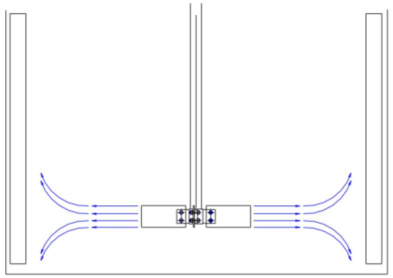
$$Q = 0.000399\frac{W}{K}(39 - 20)K$$

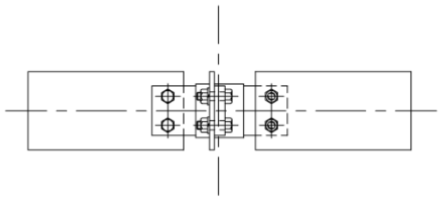
$$Q = 0.008\ W$$

Mixing Fin Calculations

Fluid Mixing Calculations
To determine the impeller type, the diameter of the blades, distance of from the impeller from the bottom, maximum height of the liquid, and the number of impellers mixing standards were used. This will ensure there is minimal vorticity based on the conditions of the slurry.

Assumptions:
1. Radial flow impellers with multiple flat blades mounted parallel to the axis of the mixing shaft.
    a. Impeller style: 4RBT90
    b. Power Number, $N_{p\,=}$ 3.60 (mixing impellers power response)
    c. Pumping Number, $N_{Q\,=}$ 1.10
        i. Applications: High shear, liquid liquid dispersion, low level mixing
        ii. It can run closer to tank bottoms without severe loss in pumping.
        iii. Used in some cases to break up the surface build up in some slurries with floating particles or clumps.
2. Viscosity of 3,000 cp using a liquid-liquid emulsion
3. RBT Blades (Vertical Blade Turbine)
    a. Very high torque as the expense of flow efficiency
        i. Applications: high shear applications, liquid-liquid emulsions
4. Two impellers for a higher allowed maximum height of liquid and to ensure the solid floating solution does not settle.
5. Tank diameter of 152.4 mm.





Calculations:
Based on the customer needs, the system must mix liquid with a viscosity of 3,000 cP. The calculations were based on the following figure dealing with impeller positioning with these assumptions.

Maximum Height of Liquid
Using two impellers and a tank diameter of 152.4 mm (T) the maximum height of liquid (Z) was found using a ratio of 1.5.

$$\frac{Z}{T} = 1.5$$

$$Z = 228.6\ mm = 9\ in$$

Impeller Diameter
The impeller diameter (D) was determined through the viscosity and optimum D/T ratio.

From the graph, the median line was used, giving a D/T ratio of 0.425.

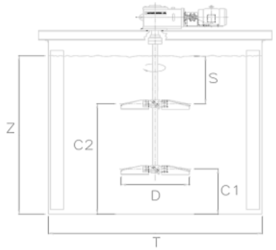
$$\frac{D}{T} = 0.425$$

$$D = 64.77\ mm = 2.5\ in$$

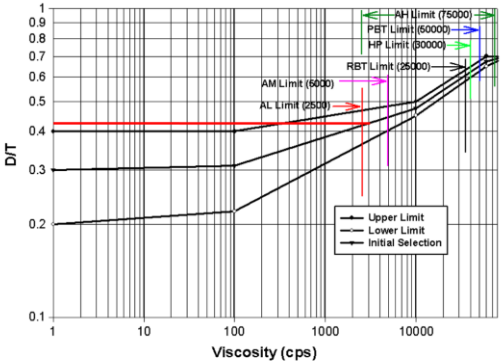
Distance of Impellers
The optimum distance of the first impeller from the bottom (C_1) was given to be 0.3D.

$$C_1 = 0.3D$$

$$C_1 = 19.43\ mm = 0.75\ in$$

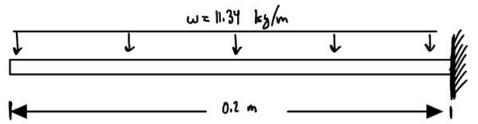


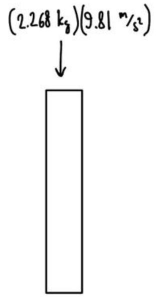
Impeller Style	Number of Impellers	Maximum Z/T	C_1 Optimum	C_1 Range	C_2	Minimum Submergence*
Radial	1	1.0	0.3D	0.16D - 0.5D	---	0.4D
	2	1.5			0.67Z	



Support Rods

Structural Integrity of Support Rods
Assumptions:
1. Cantilever beam assumed with base of 0.12 m and height of 0.006 m.
2. Top box assembly assumed as 5 lb or 2.268 kg. This corresponds to 11.34 kg/m.
3. Length of top structure taken as 0.2 m.





Calculations:

The bending stress of the bar due to the weight of the top box was calculated below.

$$M = \frac{\omega L^2}{2} = \frac{11.34\,\frac{kg}{m} \cdot \left(9.81\,\frac{m}{s^2}\right) \cdot (0.2\ m)^2}{2} = 2.22\ Nm$$

$$I = \frac{bh}{12}(b^2 + h^2) = \frac{0.12\ m \ \cdot 0.006\ m}{12}\left((0.12\ m)^2 + (0.006\ m)^2\right) = 8.66 \times 10^{-7}\ m^4$$

$$S = \frac{Mc}{I} = \frac{2.22\ Nm \ \cdot 0.003\ m}{8.66 \times 10^{-7}\ m^4} = 76{,}891\ Pa$$

From this, the bending stress experienced by top plate is an OOM lower than the yield stress of steel.

Using an OD/ID of telescoping rods taken as 0.0272 m and 0.0261 m, respectively, the axial stress experienced of the rods can be found.

$$A = \pi(r_2^2 - r_1^2) = \pi\left((0.0272\ m)^2 - (0.0261\ m)^2\right) = 1.842 \times 10^{-4}\ m^2$$

$$\sigma = \frac{F}{A} = \frac{2.268\ kg \cdot \left(9.81\,\frac{m}{s^2}\right)}{1.842 \times 10^{-4}\ m^2} = 120{,}790\ Pa$$

The axial stress experienced by telescoping rods is over an OOM less than the yield stress of steel, therefore showing structural integrity within the design.

Pumping Calculations

Liquid Outflow Pumping Calculations

Calculations were done to ensure that the pump selected for liquid byproduct extraction was sufficient. To find the required pumping power, the following equation was used:

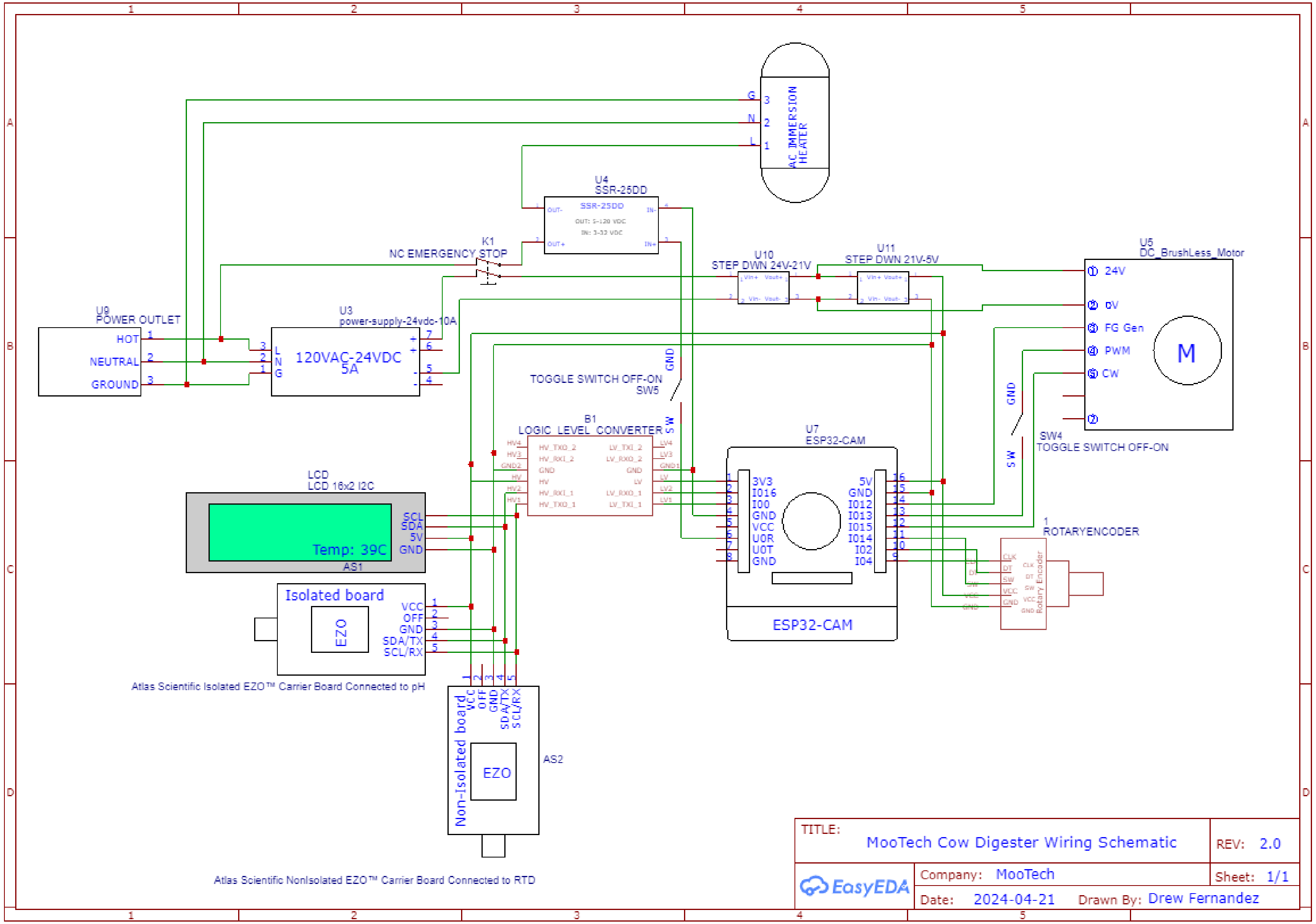
$$P = \rho g Q h$$

In this equation, P represents the pumping power, ρ represents the fluid density, g represents the gravitational constant, Q represents the desired volumetric flow rate, and h represents the head change (the vertical distance the liquid must travel). The fluid density was assumed to be the same as water at 39º C, which is 992.6 kg/m^3. The gravitational constant was assumed to be 9.81 m/s^2. The customer has specified the desired volumetric flowrate as 3 mL/min, or 5E-8 m^3/s. The head change in the liquid outflow filter is 5.8 in, or 0.147 m. These values were all inserted into the pumping power equation:

$$P = \left(992.6 \frac{kg}{\cancel{m^3}}\right)\left(9.81 \frac{m}{s^2}\right)\left(5 \times 10^{-8} \frac{\cancel{m^3}}{s}\right)(0.147\ m) = 7.157 \times 10^{-5}\ W$$

Thus, the pumping power required is 7.157 x 10^{-5} W, which is well under the rating of the pump used in the design.

Electrical Schematic



MOOTECH™

UF | Herbert Wertheim College of Engineering
UNIVERSITY *of* FLORIDA

POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

References

- [1] http://brettbeauregard.com/blog/2017/06/introducing-proportional-on-measurement/
- [2] https://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/R&D.html
- [3] https://lawteam.com/how-much-does-a-florida-business-attorney-cost/
- [4] https://www.gru.com/MyBusiness/YourService/BeforeYouStart.aspx
- [5] https://fullratio.com/profit-margin-by-industry