

DESIGN AND CONSTRUCTION OF A CLINOSTAT TO SIMULATE MICROGRAVITY

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Project Objective

This project was focused on designing and constructing a clinostat to simulate microgravity. The project began with extensive literature review on the design and function of clinostats, as well as clinostats specifically used in cell culture studies. From here, the project group organized into four functions; first function is design a theoretical model, the second function is to design and construct the physical apparatus, the third function is working to develop a code and electrical system for the clinostat, and the final function is working on verifying the clinostat design via cell experimentation.

Theoretical analysis

The theoretical step in the design process of a clinostat is determining the rotational speed necessary to overcome particle sedimentation due to gravity, but to also limit the speed so as not to cause centrifugal forces. By working through these calculations, rotational values used in literature were verified.

The first step was to calculate the sedimentation speed (V_{sed}) of a cell in cell culture media under normal gravity.¹ This is given in **Equation 1**, which is derived from a force balance between the velocity of the fluid and the buoyancy, drag, and gravitational forces felt on the particle.

$$V_{sed} = \left(\frac{2}{9}\right) * (\rho_{particle} - \rho_{fluid}) * \left(\frac{g}{\mu}\right) * a^2 \quad \text{Equation 1}$$

Where $\rho_{particle}$ is the density of the cell tested, ρ_{fluid} is the density of the media, g is the gravitational force, μ is the dynamic viscosity of the media, and a is the effective Stokes radius of the particle.

The diffusion coefficient (D_{AB}) of a cell was estimated. After the sedimentation speed of a cell and the diffusion coefficient has been calculated, the radius that a particle would travel during clinorotation was calculated. This radius accounts for sedimentation that would occur while this particle is traveling in a circular path, as well as the random dispersion from Brownian motion.

The period of rotation is then calculated. This is the estimated time that it will take for the cell to complete one full rotation under the conditions of clinorotation and Brownian motion. From this value, the angular velocity (ω) was calculated, and this was converted into the minimum RPM by **Equation 2**.

$$RPM_{minimum} = \frac{60\omega}{2\pi} \quad \text{Equation 2}$$

Table 1: The table below gives the calculated values for a red blood cell and a bacterial cell.

	V_{sed} (cm/s)	D_{AB} (cm ² /s)	ω (radius/s)	RPM (Rev/min)
Bacterial Cell	3.45E-05	2.00E-11	4.73	45.161
Red Blood Cell	2.57E-04	7.85E-10	6.68	63.750

Physical Design

There are two types of clinostat designs: 1D and 2D. For the purposes of this project, a 1D clinostat was designed. Only one rotational speed is necessary for a 1D clinostat. It has been observed that experiments with 1D clinostats at the proper rotational speed have produced comparable results to microgravity space flights.² One of the major parts of the physical design is the frame. Based on the result of the thermal analysis it must be stable enough to support the weight of the motor used to induce rotation up to speeds of 65 RPM for long periods of time. In addition, the weight of the cell culture flasks must be accounted. The next step in the design process was to design a carriage for holding the cell culture flasks during rotation. The carriage design was altered to accommodate four Corning 12.5 cm² cell culture flasks, which holds 43 mL of cell culture media.³



Figure 2: Assembled clinostat

Coding and Electrical Components

A stepper motor was chosen as the motor to operate the clinostat. Stepper motors are robust, reliable, and provide high torque at low speeds. The durability of stepper motors provides assurance that the device will operate efficiently in an incubator. The electronic portion of the clinostat was accomplished using an ARDUINO unit, a driver, and the stepper motor. The programming section involves the development of a graphic user interface (GUI), and the ARDUINO code, which sends a signal to the motor. The GUI was developed using MATLAB.

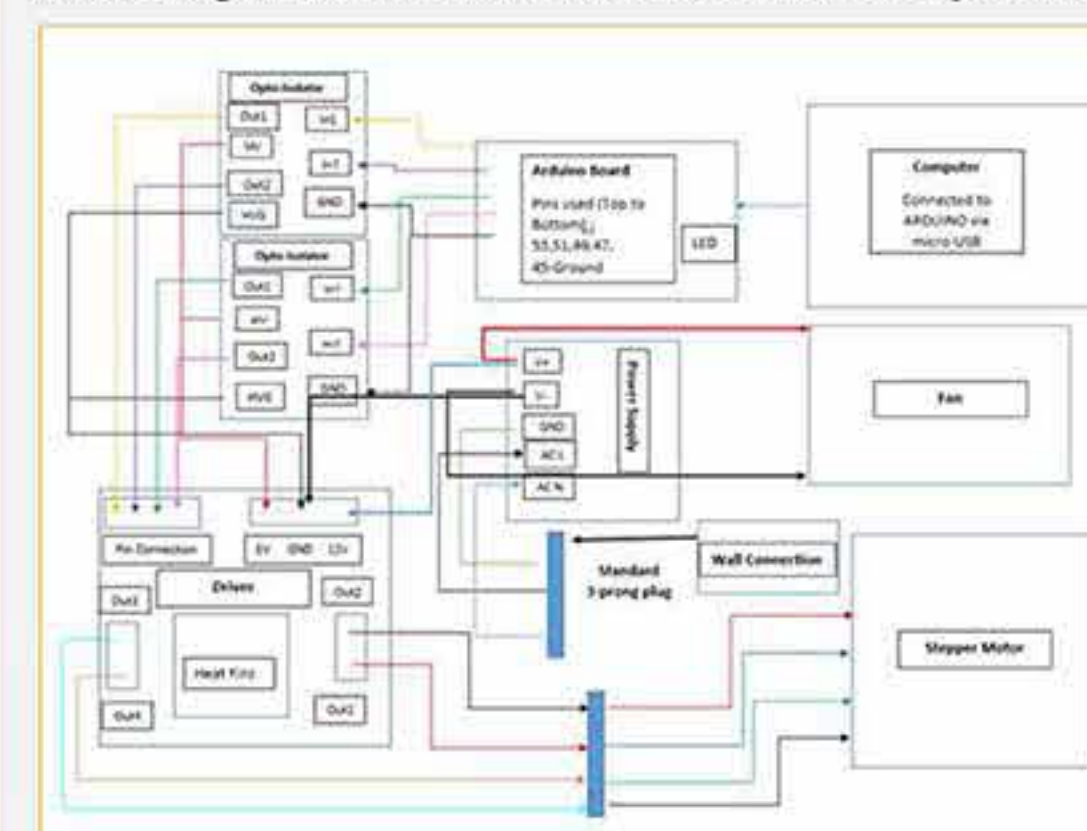


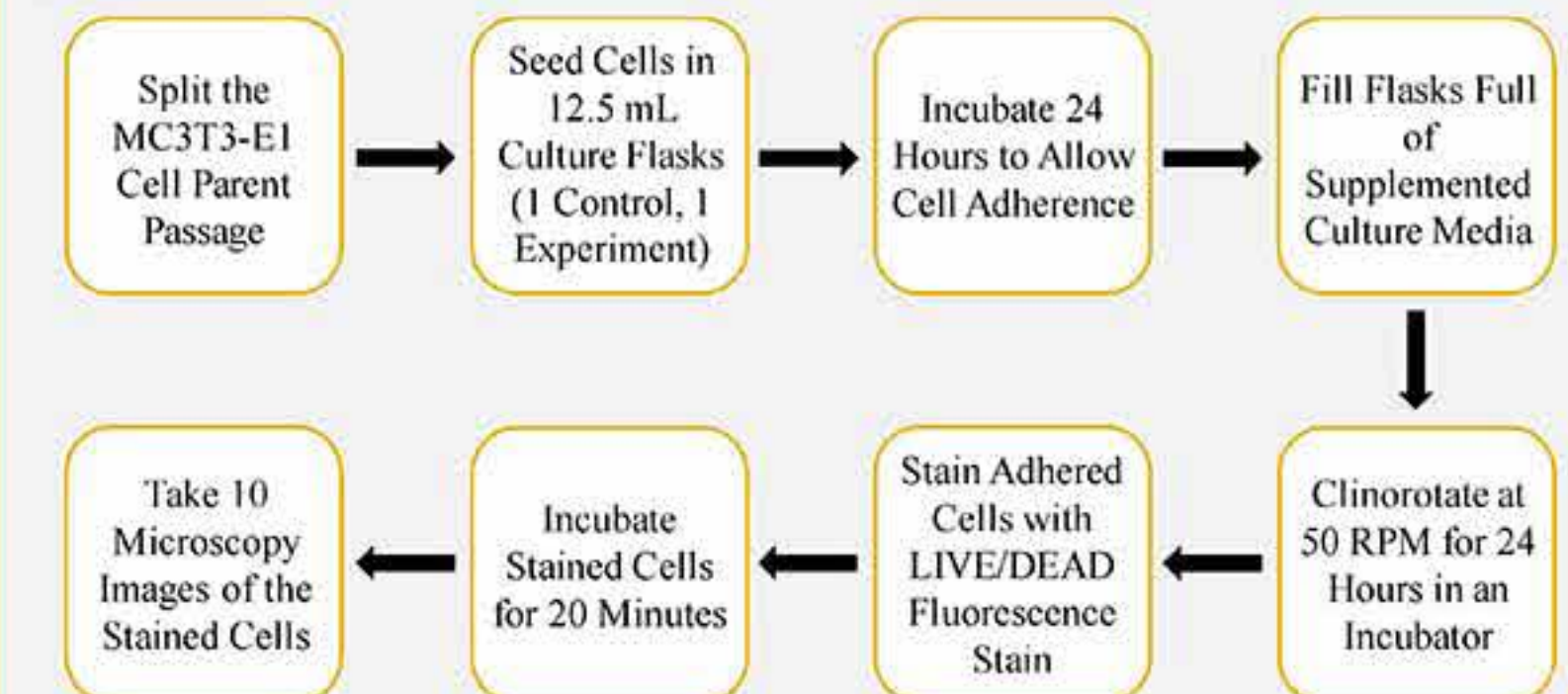
Figure 3: Wiring diagram of the electrical assembly for the operation of this clinostat.



Figure 4: Electronics housing Assembled

Clinostat Design Validation

In order to evaluate the effectiveness of the clinostat designed in this project, an experimental plan was developed. This experiment will validate the design by replicating the results of Sarkar et al. and their experiment with ROS 17/2.8 (rat osteosarcoma cells) in clinorotation.² The process for validating the design is shown below.



Unfortunately, due to the outbreak of COVID-19, work on this project was halted before any cell experimentation could be done. However, this experimental procedure should be tested before use of the clinostat in order to evaluate its construction and effectiveness.

Economic Analysis

There are two paths that were considered in the economical analysis. The actual expenses that were spent during this project, and the cost estimated to manufacture this device to sell it to public. Both considerations can be viewed below:

Table 2: The actual costs expended during the project.

Elements	Material	Electronics	Labor	Experimental	Shipping	Total
Cost	\$256	\$87	\$1710	\$446	\$18	\$2517

Table 3: The estimated costs and profits if this design were commercially manufactured.

Units Year	Cost Unit	Total Cost Year	Selling Price Unit	Profit Unit	Profit Year
5	\$5,082	\$25,410	\$6,000	\$918	\$4,590

Conclusion

- The theoretical model provided a strong foundation for the project based on reviewed literature.
- The design was finalized and assembled.
- Electronics were assembled and secured in a housing.
- Validation of the clinostat was prepared, but due to the COVID-19 pandemic the experiment was not accomplished.
- Considering costs of labor and materials it would take 8.41 years to gain profit on this clinostat design.

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Scientific Instrument Maker: Charles Cornwall – Department of Chemical and Materials Engineering.
 Brian Petty – Department of Chemical and Materials Engineering.
Operator: Stephanie Haag – Department of Chemical and Materials Engineering.

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