Lab 1 Report: Pipe Friction

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Section AB-1

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Results

This section lays out the data tables of measured results from this experiment. Due to equipment limitations and delays, we were unable to collect the extent of data intended. Some aspects were negated due to time constraints.

Water Temperature: 23.2 Celsius
Volumetric Flow Rate:
These tables contain collected and calculated data of flow rate in Liters/Liters per second.

Trial	**Time (Seconds)**	**Volume (Liters)**	**Calculated Flow Rate(Liters per sec)**
1	4.93	2	0.405
2	5.20	2	0.385
3	4.90	2	0.408
Avg	5.01		0.399
S.D.			0.0102
1	10.35	2	0.193
2	10.22	2	0.196
3	10.10	2	0.198
Avg	10.22		0.196
S.D.			0.00205
1	5.08	2	0.393
2	5.10	2	0.392
3	5.03	2	0.398
Avg	5.07		0.394
S.D.			0.00262
1	2.62	2	0.763

2	2.83	2	0.707
3	2.66	2	0.752
Avg	2.70		0.741
S.D.			0.0242

Meter Pressures:
This table contains measured time and pressure data used for calibration: the Orifice and Venturi Meters. The pressure data is in Bar and the time in seconds.

Trial	Time(sec)	Orifice Meter Pressure (Bar)	Venturi Meter Pressure (Bar)
1	4.93	0.006	0.020
2	5.20	0.006	0.022
3	5.03	0.007	0.020
1	10.35	0.001	0.007
2	10.22	0.001	0.007
3	10.10	0.003	0.007
1	5.08	0.007	0.021
2	5.10	0.007	0.021
3	5.03	0.007	0.021
1	2.62	0.030	0.021
2	2.85	0.033	0.021
3	2.66	0.033	0.021

Calibration Curves:

Due to manometer issues, we were also given an existing data set for the same experiment taken by an alternate team. After comparing our calibration data, we opted to use the given data for our calculations.

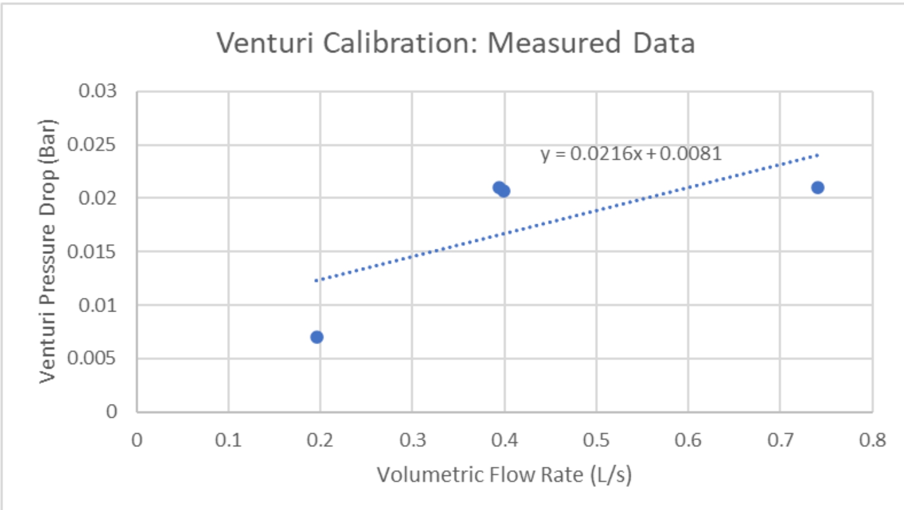

Fig. 1 Venturi calibration curve from our team's data

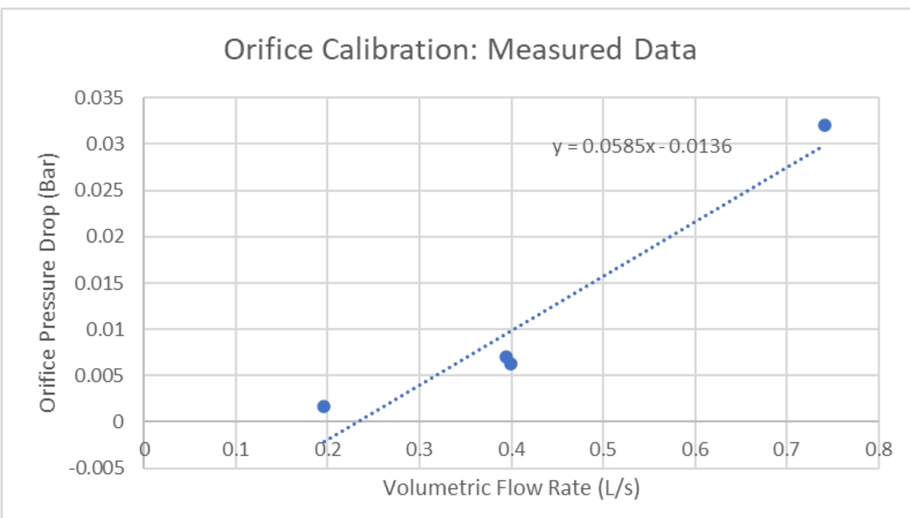

Fig 2. Orifice calibration curve from our team's data

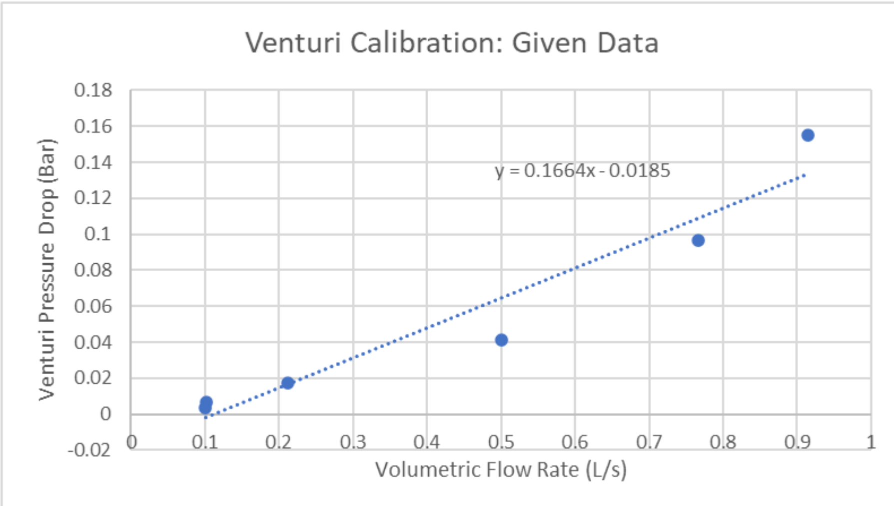

Fig 3. Venturi calibration curve from given data set

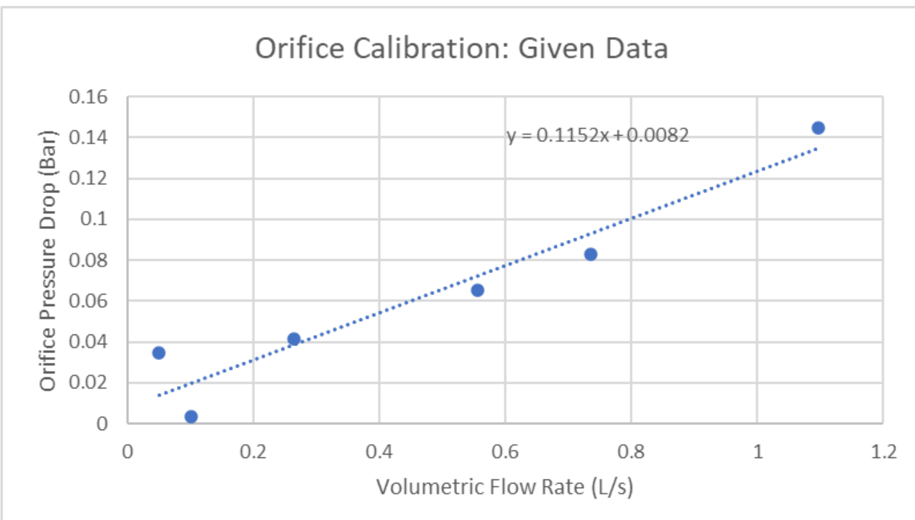

Fig 4. Orifice calibration curve from given data set

Associated Pressure Drops:

This table contains the collected pressure drop data across various bends and inner pipe diameters.

Some data is missing due to lack of time to complete trials.

Inner Diameter(mm)	**Flow Rate L/sec (referenced from calibration curve)**	**Pressure Drop(Bar)**
4.5	4.937	0.577
4.5	4.720	0.552
4.5	4.720	0.552

Average	4.789	0.560
Standard Deviation	0.102	0.0118
4.5 Bend	-0.054	0.002
4.5 Bend	-	-
4.5 Bend	-	-
Average	-0.054	0.002
Standard Deviation	N/A	N/A
7.7	5.845	0.682
7.7	5.719	0.667
7.7	5.875	0.685
Average	5.814	0.678
Standard Deviation	0.0676	0.00787
7.7 Bend	-0.028	0.005
7.7 Bend	-	-
7.7 Bend	-	-
Average	-0.028	0.005
Standard Deviation	N/A	N/A
10.9	2.333	0.277
10.9	2.212	0.263
10.9	2.194	0.261
Average	2.247	0.267
Standard Deviation	0.0617	0.00712

10.9 Bend	0.033	0.012
10.9 Bend	-	-
10.9 Bend	-	-
Average	0.033	0.012
Standard Deviation	N/A	N/A
17.2	5.797	0.676
17.2	5.762	0.672
17.2	5.797	0.676
Average	5.788	0.675
Standard Deviation	0.926	0.00189
17.2 Bend	0.120	0.022
17.2 Bend	-	-
17.2 Bend	-	-
Average	0.120	0.022
Standard Deviation	N/A	N/A
15.2 JPC	3.557	0.418
15.2 JPC	3.540	0.416
15.2 JPC	3.497	0.411
Average	3.531	0.415
Standard Deviation	0.0107	0.00294
15.2 JPC Bend	1.665	0.20
15.2 JPC Bend	-	-

15.2 JPC Bend	-	-
Average	1.665	0.20
Standard Deviation	N/A	N/A

Fanning Friction and Reynolds Graph:

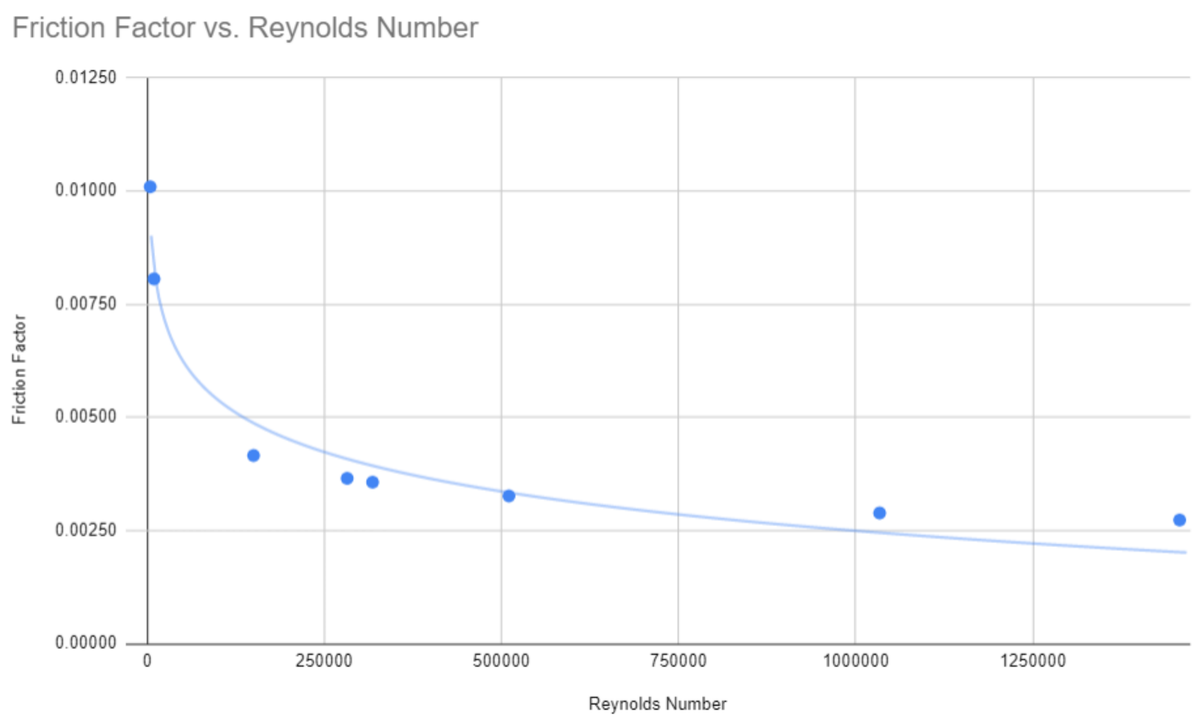

Fig 5. Friction factor / Reynolds number plot for comparison to Perry's Handbook

Pressure Drops across Bends:
These tables show measured pressure drops in Bar across various pipe bends.

Trial	Type	Flow Rate	Pressure Drop (Bar)
1	45 degree elbow	0.293	0.042
2	45 degree elbow	0.319	0.045
3	45 degree elbow	0.354	0.049
Average	-	0.319	0.045
S.D.	-	0.0293	0.00287
1	90 degree long bend	0.007	0.009

2	90 degree long bend	0.007	0.009
3	90 degree long bend	0.033	0.012
Average	-	0.016	0.010
S.D.	-	0.0123	0.00141
1	90 degree elbow	0.554	0.072
2	90 degree elbow	0.493	0.065
3	90 degree elbow	0.658	0.084
Average	-	0.571	0.074
S.D.	-	0.0681	0.00785
1	90 degree short bend	0.120	0.022
2	90 degree short bend	-	-
3	90 degree short bend	-	-
Average	-	0.120	0.022
S.D.	-	N/A	N/A

Pressure drops across valves:
These tables demonstrate the measured pressure drop in Bar across various fittings.

Trial	**Pipe Fittings**	**Flow Rate**	**Pressure Drop(Bar)**
1	Gate Valve (Top)	0.241	0.036
2	Gate Valve (Top)	0.233	0.035
3	Gate Valve (Top)	0.241	0.036
Average	-	0.241	0.036
S.D.	-	0.00377	0.000471
1	Globe Valve (Bottom)	1.934	0.231

2	Globe Valve (Bottom)	1.882	0.225
3	Globe Valve (Bottom)	2.003	0.239
Average	-	1.943	0.232
S.D.	-	0.0496	0.00573

Error Analysis

Standard error calculations are given within the data tables above.

The obtained results may have errors that cannot be described with the standard error. Throughout the experiment, all manometers presented with higher uncertainty than expected due to equipment failure such as the device not being able to read values within range (values would jump from 100 to 1000 within seconds and not stabilize) and the tubes connected to the manometer leaked water. These issues deteriorated the reliability of the measurements collected. Due to this equipment failure, we were unable to collect as much data as we had previously intended in the pre-lab report (5-10 trials for each measurement) due to time constraints. A sample data set was provided and only used for the calibration curves above. All data that is not ours has been highlighted.

Calculations

The first part of the assignment was to evaluate Fanning friction factors over multiple pipes. This example calculation for finding the friction factor of a pipe demonstrates our procedure for doing so. The pipe used in this calculation is the 10.9 mm inner diameter pipe.

In all our calculations, the water is assumed to be a constant 23.2 degrees celsius. We looked up the viscosity of water at 23.2 degrees and found it to be:

$$0.00092777\ \frac{N*s}{m^2},$$

(U.S. Secretary of Commerce, 2023).

as well as the density, which is:

$$997.49\ \frac{kg}{m^3}$$

(U.S. Secretary of Commerce, 2023).

Using the Orifice calibration curve, the formula for volumetric flow given the pressure drop is:

$$(\Delta h\ -\ 0.0082)/0.1152\ =\ Volumetric\ Flow\ Rate\ (L/s)$$

In this case:

$$(0.267 - 0.0082)/0.1152 = 2.2465\ L/s$$

Volumetric data must first be converted into fluid velocity:

$$[L/s] * 1m^3/1000\ L = m^3/s$$

$$\frac{m^3/s}{[\pi(\frac{D}{2})^2]\ m^2} = m/s$$

In this case:

$$[0.0022465\ m^3/s]/[\pi * (0.0109\ m/2)^2] = 24.075\ m/s$$

The Reynolds number calculation is as follows:

$$Re = \frac{997.49\ kg/m^3 * 24.075\ m/s * 0.0109\ m}{0.00092777\ kg/(m*s)} = 2.82137 * 10^5$$

Since the Reynolds number is above 10^4, the flow is thus turbulent, and we can evaluate the Fanning friction factor as follows, with Koo's approximation of the general fanning friction factor equation (Klinzing, 2010):

$$f = 0.0014 + 0.125/Re^{0.32}$$

In this case:

$$f = 0.0014 + 0.125/(282137^{0.32}) = 0.003653$$

Our Fanning Friction factor calculations are summarized here. Note that Reynolds number and friction factor data is graphed in the results section above.

Pipe Inner Diameter	**Calculated Friction Factor**
4.5 mm	0.002732
7.7 mm	0.002887
10.9 mm	0.003653
17.2 mm	0.005427

15.2 mm (JPC)	0.003568

For expected pressure drops across valves and bends, we looked up the k-factors (Plumbing Supply, n.d.) and for common pipe bends (Native Dynamics, 2012), and used the following equation to calculate the expected pressure drop:

$$\Delta h = k * v^2 / 2g$$

(Pipe Flow Software, n.d.)

For example, the expected pressure drop for a 45 degree elbow is calculated as follows:

$$\Delta h = 0.045 * 1.375^2 / 2g$$

Fluid velocity is calculated by referencing the actual pressure drop, and the Orifice calibration, then converted via the same process we used for Fanning friction factors. The table below summarizes our calculations.

Bend/Valve Type	**Estimated Pressure Drop**	**Actual Pressure Drop**
45 degree elbow	0.0337	0.045
90 degree long	0.0017	0.01
90 degree short	0.0102	0.022
90 degree elbow	0.4004	0.074
Gate Valve	0.0094	0.036
Globe Valve	21.378	0.232

For an estimate of lowest pumping energy loss, since the "pumping energy loss is given by the product of pressure drop and volumetric flow rate," we multiplied the pressure drop for each pipe by its volumetric flow rate. Thus, the 10.9 mm pipe has the lowest pumping energy loss.

Pipe Inner Diameter	**Pumping Energy Loss**
4.5 mm	2.682
7.7 mm	3.942

10.9 mm	0.600
17.2 mm	4.791
15.2 mm (JPC)	1.465

Discussion

Results show a variance in the friction factors that roughly support the vendors claims, with the JPC coated pipe boasting the lowest friction factor relative to its internal diameter. However, the claims that their particles produce the lowest friction factors ever measured is patently false, as shown by the lowest energy loss coming from the 10.9mm interior diameter pipe. While the JPC coating does appear to reduce the pumping energy loss through a reduced friction factor, the dominant effect on pipe friction is still internal pipe diameter. Still, comparing the graphs of calculated friction factors literature value shows that the inclusion of the JPC particles does have a slightly lower curve than the literature values, shown in the figure below with our curve superimposed over the graph provided by Fig. 6-9 of Perry's Chemical Engineers Handbook, 8th Ed.

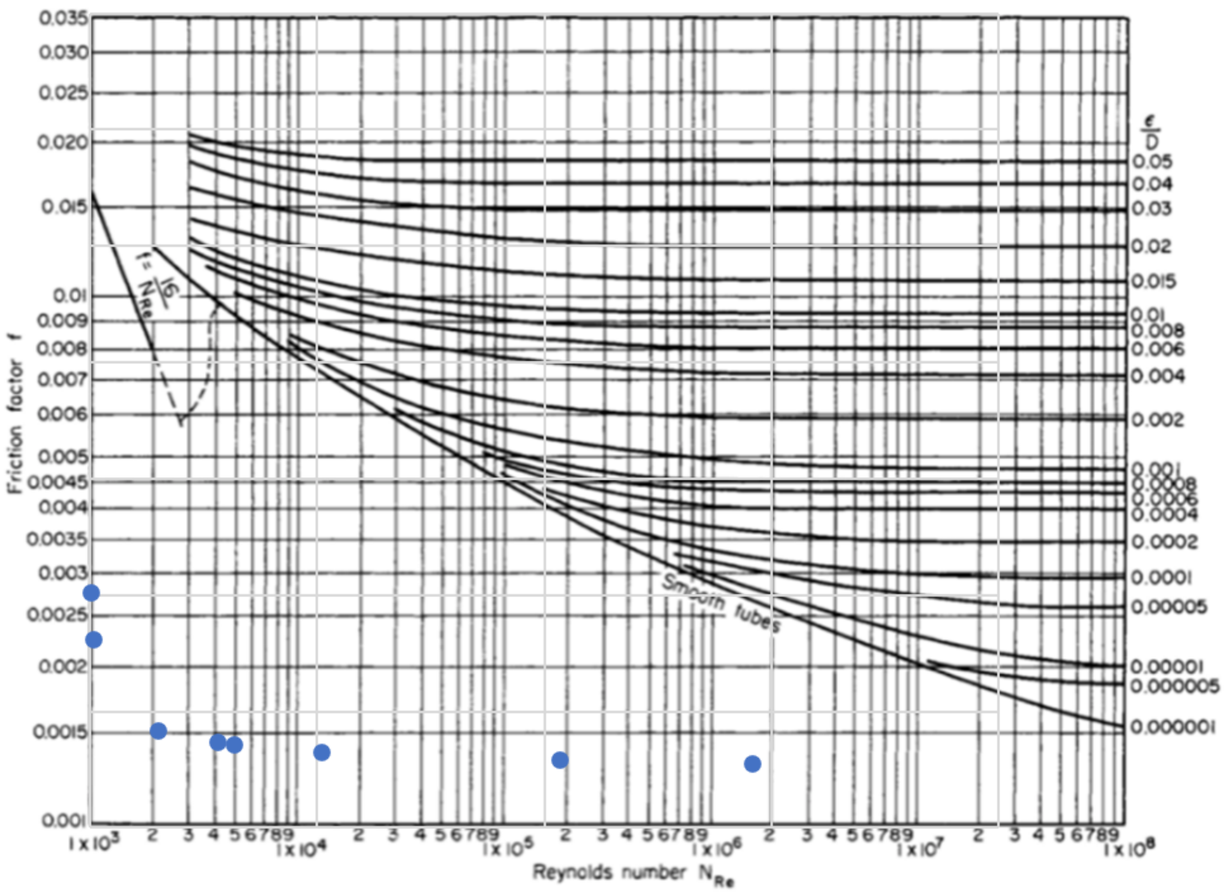

FIG. 6-9 Fanning Friction Factors. Reynolds number Re = $DV\rho/\mu$, where D = pipe diameter, V = velocity, ρ = fluid density, and μ = fluid viscosity. (*Based on Moody*, Trans. ASME, **66**, 671 [1944].)

Graphically, this data supports the expected behavior of the fluid. The left side shows the laminar phase, which quickly splits and levels out with increasing the Reynolds number into the turbulent phase. Considering these results has lead our team to make the following recommendation, expanded on below:

Recommendations

We do not recommend the usage of the 15.2mm JPC pipe in comparison to the available options. It has neither the lowest friction factor nor the lowest energy loss. In fact, the 15.2mm JPC has only the third lowest fanning friction factor of 0.003568, which contradicts the claims made by the new valve supplier. As frictional loss is not recoverable, there are higher operational costs associated with pipes which have high frictional factors, and thus higher associated frictional energy loss. The choice of the 15.2mm JPC pipe would create unnecessary electricity costs in the plant. To further support this claim, we found that the JPC pipe does not have the lowest pumping energy loss.

Instead, we recommend using the 10.9mm pipe. If possible, custom ordering a 10.9 JPC pipe. When comparing the 17.2mm pipe with and without the Janus Particle Coating, it is clear that the particles made a large efficiency contribution. In fact, the fanning friction factor dropped from 0.005427 to 0.003568. The pumping energy loss also underwent a significant drop from 4.791 to 1.465 once the particles were added inside. As the 10.9mm pipe already has the lowest pumping energy loss of 0.600, this trend of significance would be an asset to the plant.

Equal Contribution

Every member of the group completed the agreed upon amount of work. This is the breakdown of what each member contributed.

	Group Members			
Task	Adrian	Liza	Chris	Frances
Safety Incident Report	✔			
Calculations				✔
Data	✔	✔	✔	✔
Presentation of Results	✔			✔
Figures/Tables	✔			
Error Analysis		✔		
Discussion			✔	

Recommendations		✔		
References		✔		
Writing Quality Check		✔		
Equal Contribution		✔		

Data was collected by every group member in the laboratory.
Presentation of results was done by both Adrian and Frances, as they worked together to create tables and graphs.

References

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