Surface Area to Volume Ratio and Diffusion

**Background information:**

The surface area to volume ratio is a fundamental concept used by biologists to explain the rate of diffusion in all living organisms. The surface of a cell, known as the cell membrane, is the outer structure of the cell where diffusion into and out of the cell occurs. Diffusion in cells is the process when molecules move from an area of high concentration to an area of low concentration in or out of the cell membrane (Allott & Mindorff, 2014). As cell size increases, the surface area and volume both increase however the rate of increase of surface area decreases compared to the rate of increase of volume this is because the volume is cm3 and the surface area is cm2. Therefore, diffusion becomes a less effective method for transportation of materials in and out of a cell as there is more materials needed. The smaller the cell is, the less volume compared to surface area it has and therefore the more effective diffusion will be to transport materials in and out of the cell (Miller & Levin, 2005). This experiment tests the surface area to volume ratio by diffusing cubes of different sizes. The formula to calculate the surface area of a cube is length x width x number of faces and the formula to calculate the volume of a cube is length x width x depth. To try to answer the research question, Sodium Hydroxide solution will be diffused in four cubes of agar (sizes 10mm2, 20mm2, 30mm2, 40mm2 and 50mm2) and each cube will be measured for % of diffusion.

**Research question:** How does increasing the size of an agar cube, and in turn decreasing its SA:Vol ratio, affect the rate of diffusion of 1M sodium hydroxide?

**Hypothesis:** If the cube gets bigger then the rate of diffusion will decrease because the SA:Vol ratio will decrease meaning that the volume increases at a quicker rate than the surface area leading to less diffusion in relation to its size (Allott & Mindorff, 2014).

**Variables:**

**Independent:** Size of the agar cubes

How will this be controlled?

The cubes will be cut to the following size 1, 2, 3, 4, 5cm3 using a rules and a scalpel.

**Dependent:** Amount of sodium hydroxide diffused/Percentage diffused

How will you measure this? Using a vernier caliper and the following equation

% diffusion = volume of diffused ammonium hydroxide X 100

total volume of cube

**Controlled variables**

|  |  |  |
| --- | --- | --- |
| **What?** | **Why?** | **How?** |
| Same amount of Sodium hydroxide 1M | Different amounts, substances and moles may have different rates of diffusion | Use 300ml 1M sodium hydroxide |
| Time the agar cubes are in the solution | More or less time will impact the amount of diffusion | Use a stopwatch to make sure the cube is in the solution for only 3mins |
| Type of agar and concentration of agar | Different types or concentrations of agar could change the rate of diffusion | Make sure all the cubes come from the same batch of agar solution. This will ensure the same type and concentration of agar. |
| Same vernier calipers | Different calipers may have different scales | Use the same calipers |
| Same size beaker | Different sized beakers could lead to different levels of sodium hydroxide leading to different pressure changing the rates of diffusion | Use a 300ml beaker |

**Materials (with quantities):**

* Different sized cubes of agar impregnated with phenolphthalein (1, 2, 3, 4, 5cm3)
* Razor blade
* Metric ruler (±0.5mm)
* Sodium hydroxide (1M ±0.1M) 300ml
* Beaker (400ml ±50ml)
* Paper clips
* Vernier callipers
* Stopwatch

**Method:**

1. Calculate the surface area, volume and SA:Vol ratio of each of the different cubes of agar.
2. Place a cube 1cm3 into the beaker with 300ml of ammonium hydroxide solution (1M) and start the timer, remove it after 3 minutes.
3. Cut the cube in half and use the Vernier callipers to measure the amount of diffusion of the ammonium hydroxide in the cube by the change of colour. Record results
4. Repeat Steps 2 & 3 four time for 1cm3 agar cubes
5. Repeat steps 2-4 for other cube sizes.
6. Collate the class set of data.

**Qualitative Data**

**Table 1:** A table showing the observations collected for each cube size during the experiment

|  |  |
| --- | --- |
| Cube (mm) | Qualitative |
| 10 | * Smooth cut * Floated in sodium hydroxide solution * Turned dark pink when dropped in solution * Variation in color from light pink to dark pink when agar was cut in half |
| 20 | * Rough cut * Floated in solution * Turned dark pink when dropped in solution * Variation in color from light pink to dark pink when agar was cut in half |
| 30 | * Rough cut * Half sunken in solution * Turned dark pink when dropped in solution * Variation in color from light pink to dark pink when agar was cut in half |
| 40 | * Rough cut * Half sunken in solution * Turned dark pink when dropped in solution * Agar broke apart while trying to take it out of the solution * Hard to distinguish between dark and light pink when agar was cut in half |

**Quantitative Raw Data**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Amount of Soduim Hydroxide Diffused in Agar (mm) (+/- 0.1mm) | | | | | | |
| Cube (mm) +/- 5mm | Surface Area: Volume Ratio | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 | Group 6 | Group 7 |
| 10 | 3:5 | 3.5 | 3.4 | 3.4 | 3.7 | 5.2 | 3.8 | 3.4 |
| 20 | 3:10 | 2.3 | 2.5 | 2.5 | 4.5 | 3.3 | 2.2 | 3.0 |
| 30 | 1:5 | 3.2 | 2.2 | 2.1 | 2.4 | 3.5 | 2.4 | 2.0 |
| 40 | 1:5:1 | 2.4 | 1.9 | 2.0 | 2.5 | 2.5 | 2.7 | 2.7 |

**Table 2:** A table showing the raw data collected in the experiment from 7 groups, without processing

\*Anomalous results are highlighted in blue, this is will be removed from the processing of the data.  
\*The cube was poorly cut, therefore, the uncertainty is +/- 5mm

\*A ruler was used to measure the amount of diffusion; therefore, the uncertainty is +/- 0.1mm

The raw data collected will be processed in order to find the mean, standard deviation and, the percentage of the sodium hydroxide diffused in the agar. The raw data will be processed through a number of mathematical calculations.

Average and standard deviation will both be calculated using excel.

A correlation will also be calculated to see if there is a relationship between the size of the cube and the percentage diffusion. Excel will also be used to calculate this value.

To find the percentage of diffusion, I need to calculate the volume of the light pink and the whole cube. To do so, I multiply the mean of the cube size by 2 and subtract the number from the cube size. Now, I have the length, width, and depth of the light pink cube. When I cube the answer I get the volume. Additionally, I cube the cube size. I subtract the volume of the light pink from the volume of the cube size. I divide the answer by the volume of the cube size and multiply by 100. The percentage of diffusion is found.

**Percentage of Diffusion exemplar calculation**

Example using 10mm cube:

* **Length of Light Pink Cube:** Size of Cube – (2 x Mean) = 10mm – (2 x 3.5mm) = 3mm
* **Volume of Light Pink Cube:** (Length of Light Pink Cube)3 = (3mm)3 = 27mm3
* **Volume of Dark Pink Cube:** (Length of Dark Pink Cube)3 = (10mm)3 = 1000mm3
* **Percentage of Diffusion =**(Volume of Dark Pink Cube) – (Volume of Light Pink Cube)   
   =1000mm3 – 27mm3

= 973 mm3

= 973mm3/1000mm3

= 0.973

= 0.973 x 100

= 97.3%

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Cube (mm) +/- 5mm | Surface Area: Volume Ratio | Mean distance of Sodium Hydroxide Diffused into the Agar cube(mm) (+/- 0.1mm) | Standard Deviation  mm | Diffused Volume (%) |
| 10 | 3:5 | 3.5 | 0.2 | 97.3 |
| 20 | 3:10 | 2.9 | 0.8 | 64.2 |
| 30 | 1:05 | 2.5 | 0.6 | 42.1 |
| 40 | 1:5:1 | 2.4 | 0.3 | 31.9 |

**Quantitative Processed Data**

**Table 3:** A table showing the processed data including mean, standard deviation, and the percentage diffused.

**Graph 1:** A scatter graph showing the relationship between the amount of sodium hydroxide diffused in agar and different sizes of cubes.

\*The error bars represent standard deviation, which shows the reliability of the results.

**Graph 2:** A scatter graph showing the relationship between the percentage of diffusion and the different sizes of cubes.

**Conclusion**

The purpose of this lab was to investigate how increasing the size of an agar cube, and in turn decreasing its SA:Vol ratio, affect the rate of diffusion of 1M sodium hydroxide. The hypothesis was that if the cube gets bigger then the rate of diffusion will decrease because the SA:Vol ratio will decrease. The data from the lab supports this hypothesis, this can be seen in graph 2. As the cube increases in size the percentage of diffusion reduces this is a strong negative correlation with a correlation value of -0.97. The reason for this strong negative correlation is due to the fact that even though both the volume and surface area are increasing as the cube gets bigger the volume increases at a faster rate so reducing the ratio between the two (Allott & Mindorff, 2014) The rate of diffusion will decrease, as the cubes get bigger because surface area doesn’t increase as fast as volume, therefore, the diffusion of sodium hydroxide is no longer an efficient way to transport materials or waste. So as organisms get bigger their surface area/volume ratio gets smaller. A bacterium is almost all surface with not much inside, while a whale is all insides with not much surface. This means that as organisms become bigger it becomes more difficult for them to exchange materials with their surroundings… materials simply cannot diffuse fast enough to support the reactions needed for life (Miller & Levin, 2005). As can be seen in graph 1 the standard deviation for the 10cm3 cube was small so it had a high level of reliability. The 20cm3 and 30cm3 had reduced reliability as the spread of results (standard deviation) was larger. In Graph 1, the line of best fit was able to pass through all the error bars, which represents standard deviation. This shows us the accuracy of our data. Despite the involvement of human errors, the data is still reliable because the relationship found matches the results of other research (Miller & Levin, 2005).

**Evaluation**

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| --- |
| **Problem:**  Size of the Cube  **Explanation of the problem:**  The cubes were poorly cut and the sides were not even. The cube not being the size wanted can affect the accuracy of data because the surface area is affected. Diffusion will not be constant throughout the experiment. This human error can cause both higher and lower scores than expected.  **Improvement:**  Set the agar in specially made plastic containers according to the size of cube being tested.  **Explanation of the improvement**  Once the agar has set, the cube can be taken out of the container. Since the container has the dimensions of the cube needed, the agar will equal the same dimensions. As a result, the agar will be equal in size and have a smooth cut. |
| **Problem:**  Amount of time the cube was inside the solution  **Explanation of the problem:**  When trying to take the largest cube out of the solution. It began to break into smaller pieces. Due to the difficulty of taking out the largest cube, the cube was left in a lot longer than it should have been. This error leads to the next error.  **Improvement:**  Pour out the solution in the sink a couple of seconds before the time limit. Then the beaker can be tipped over the chopping board, letting the cube slip out.  **Explanation of the improvement**  Pouring out the solution is an easier way to take the cube out. If the solution was kept, then the cube has to be taken out by a tool, which isn’t efficient as the cube can keep slipping back in. Without the solution, the beaker can be tipped over. This saves a lot of time and now the cube can be taken out in time. |

# Works Cited

Allott, A., & Mindorff, D. (2014). *Biology: Course companion.* Oxford: Oxford.

Miller, & Levin. (2005). *Biology.* Cambridge: Presscott.