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EFFECT OF TEMPERATURE ON THE GROWTH OF A SUPERABSORBENT POLYMER (ORBEEZ BALLS) IN WATER

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ABSTRACT

In this paper we experimentally study the growth of orbeez balls made of a superabsorbent polymer, with time and its relation to temperature, by growing them in water kept at three different temperatures. Variation of size of orbeez balls with time is plotted for three cases and the curve is studied. Finally, a mathematical function is given which approximately represents it.

KEYWORDS: Orbeez balls, Superabsorbent polymer (SAP), sodium polyacrylate, size of orbeez balls, temperature of water, Brillouin function.

I. INTRODUCTION

Orbeez balls is a very popular scientific toy. These balls are made of a material called Superabsorbent polymer abbreviated as SAP. The IUPAC definition of superabsorbent polymer is, a polymer that can absorb and retain extremely large amounts of liquid relative to its own mass. Superabsorbent polymers are now commonly made from polymerization of acrylic acid blended with sodium hydroxide to form sodium polyacrylate. These are long chain molecules enabling the material to absorption. Orbeez balls are manufactured and designed to absorb water and grow in size.

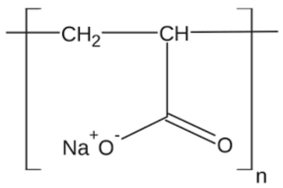

Fig 1: Chemical formula of sodium polyacrylate [2]

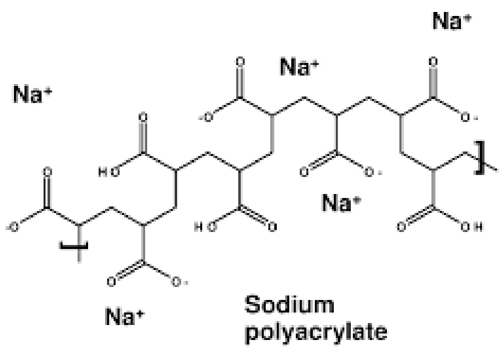

Fig 2: Partial structure of sodium polyacrylate [2]

Initially, the orbeez balls are only a few millimeters. After placing them in water for several minutes, they absorb and grow up to a few centimeters, which are almost spherical.

We experimentally determine how the growth of Orbeez balls in water is varied with temperature.

II. METHODOLOGY

We now write the procedure of the experiment which was performed.

Experimental Procedure

1. Orbeez balls of approximately the same size are selected and the very big and very small ones are taken away.

2. We do the experiment in three different conditions/cases:

Using

a) Water at room temperature

b) Hot water

c) Cold water

3. We place all the Orbeez balls of approximately the same size in a bowl containing water (normal/hot/cold).

4. A clock is used to measure time. For every five minutes two orbeez balls are taken out. Their diameters are measured and their average size is calculated. In this experiment we measure its diameter using a ruler with a least count of 0.05cm and can measure in the steps of 0.05cm.

5. The experiment is continued this way for about 100 minutes.

6. The size balls are measured and tabulated for corresponding time.

7. A graph of size of orbeez balls versus time elapse is plotted for the three cases mentioned above.

III. MODELING AND ANALYSIS

- Initially, it is observed that as the orbeez balls grow in water with time, they are not quite spherical. Their shape is a distorted sphere. With time they all become spherical.
- The orbeez balls grow a few millimeters for every five minutes.
- Their size does not indefinitely increase, they reach a constant value after growing to a certain size.

Case 1: For water at room temperature

Table 1: Shows the data of size variation of Orbeez balls with time placed in water at room temperature (~21^{0}C)

Time (min)	Trail 1: Size of Orbeez balls (cm)	Trail 2: Size of Orbeez balls (cm)	Average size of Orbeez balls (cm)
0	0.20	0.20	0.200
5	0.3	0.35	0.325
10	0.45	0.45	0.450
15	0.45	0.5	0.475
20	0.55	0.45	0.500
25	0.65	0.5	0.575
30	0.75	0.6	0.675
35	0.7	0.75	0.725
40	0.85	0.5	0.675
45	0.95	0.6	0.775
50	0.9	0.65	0.775
55	0.9	0.85	0.875
60	0.8	0.85	0.825
65	0.85	0.75	0.800
70	0.85	0.8	0.825
75	0.85	0.85	0.850

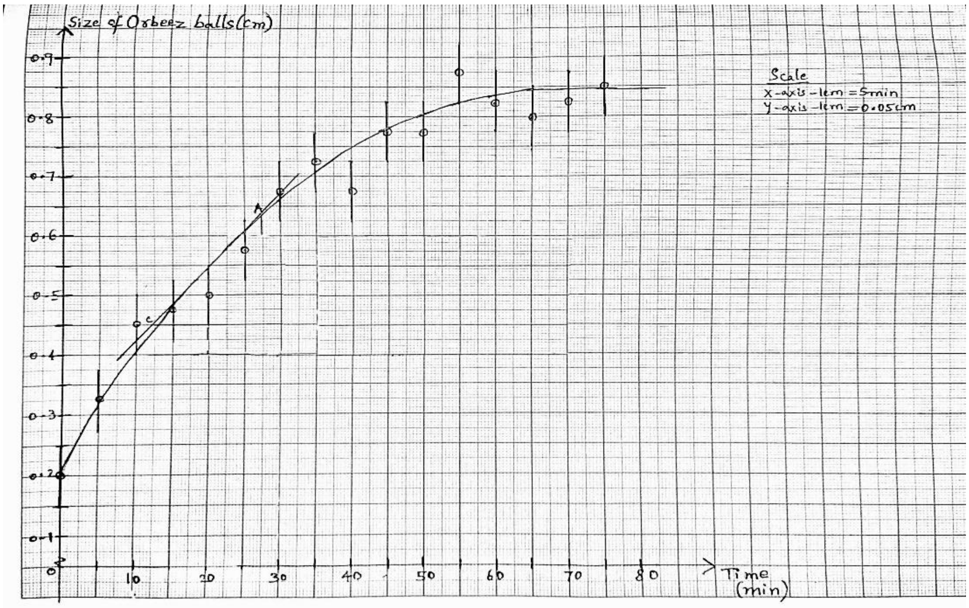

Fig 3: Plot of average size of Orbeez balls versus time elapse for water at room temperature.

Case 2: For hot water.

Table 2: Shows the data of size variation of Orbeez balls with time placed in hot water (~70^0C).

Time (min)	Trail 1: Size of Orbeez balls (cm)	Trail 2: Size of Orbeez balls (cm)	Average size of Orbeez balls (cm)
0	0.2	0.2	0.200
5	0.45	0.4	0.425
10	0.5	0.45	0.475
15	0.4	0.6	0.500
20	0.5	0.5	0.500
25	0.6	0.5	0.550
30	0.7	0.6	0.650
35	0.8	0.75	0.775
40	0.8	0.75	0.775
45	0.8	0.85	0.825
50	0.8	0.8	0.800
55	0.85	0.75	0.800
60	0.85	0.8	0.825
65	0.85	0.85	0.850
70	0.85	0.9	0.875

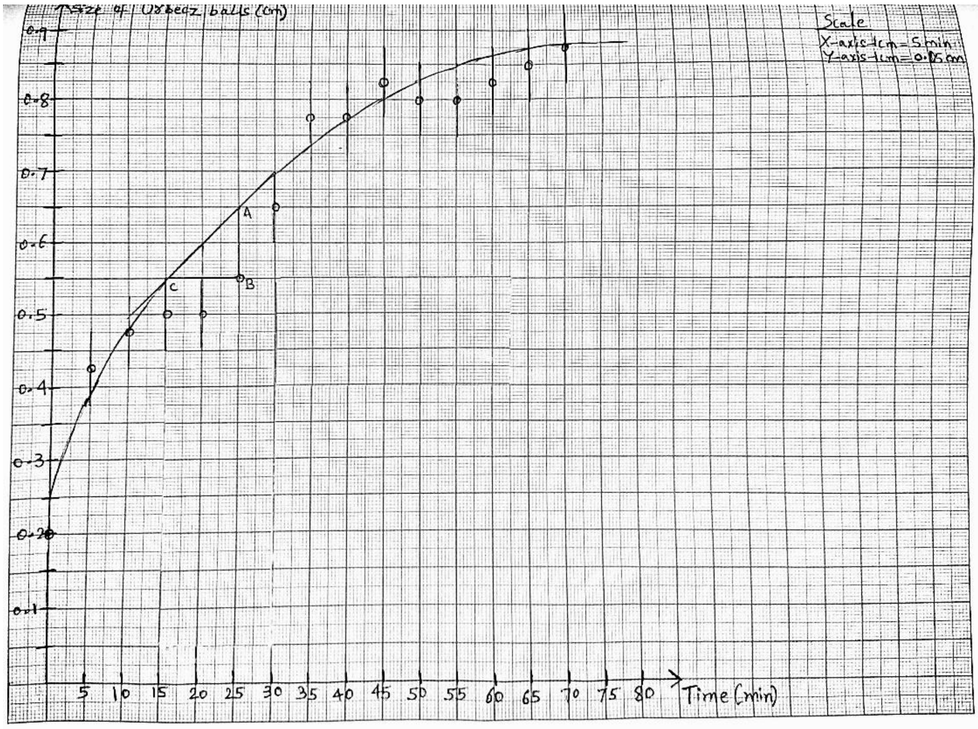

Fig 4: Plot of average size of Orbeez balls versus time elapse for hot water.

Case 3: For cold water

Table 3: Shows the data of size variation of Orbeez balls with time placed in cold water (~5^{0}C).

Time (min)	Trail 1: Size of Orbeez balls (cm)	Trail 1: Size of Orbeez balls (cm)	Average size of Orbeez balls (cm)
0	0.2	0.2	0.2
5	0.25	0.25	0.250
10	0.30	0.25	0.275
15	0.4	0.30	0.350
20	0.4	0.30	0.350
25	0.45	0.45	0.450
30	0.4	0.5	0.450
35	0.6	0.5	0.550
40	0.45	0.45	0.450
45	0.45	0.45	0.450
50	0.6	0.5	0.550
55	0.7	0.55	0.625
60	0.65	0.45	0.550
65	0.65	0.5	0.575
70	0.7	0.5	0.600
75	0.75	0.6	0.675
80	0.7	0.65	0.675

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85	0.8	0.6	0.700
90	0.8	0.65	0.725
95	0.8	0.75	0.775
100	0.75	0.7	0.725

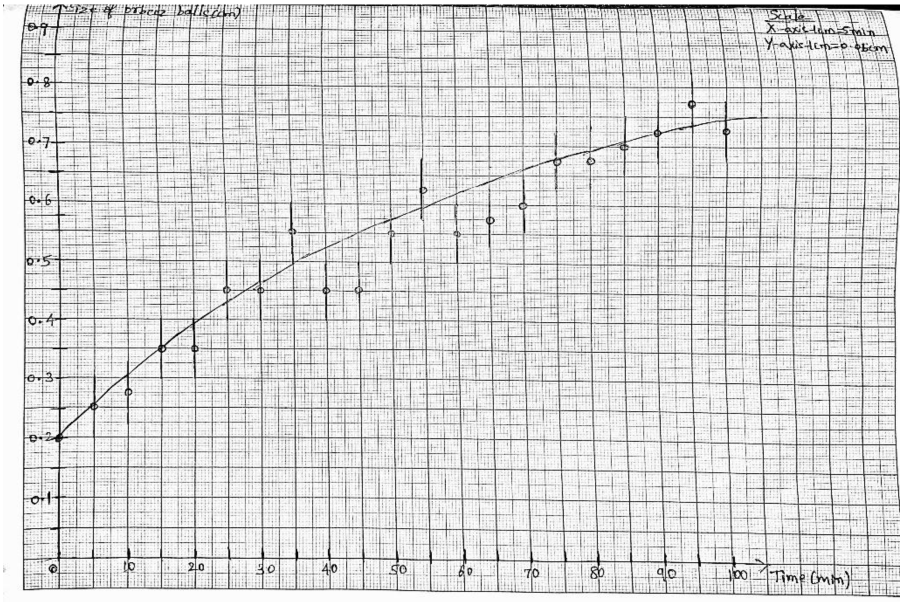

Fig 5: Plot of average size of Orbeez balls versus time elapse for cold water.

While plotting these curves we assume an error of -0.05 to +0.05cm, as the Orbeez balls are not all exactly at the same size initially. We have also assumed that the size varies smoothly with time, hence we try to fit a smooth curve for the data obtained experimentally. To observe the distinction between the three curves, let us plot them in a single graph.

The scale used in all the graphs are X-axis-1cm=5min and Y-axis-1cm=0.05cm.

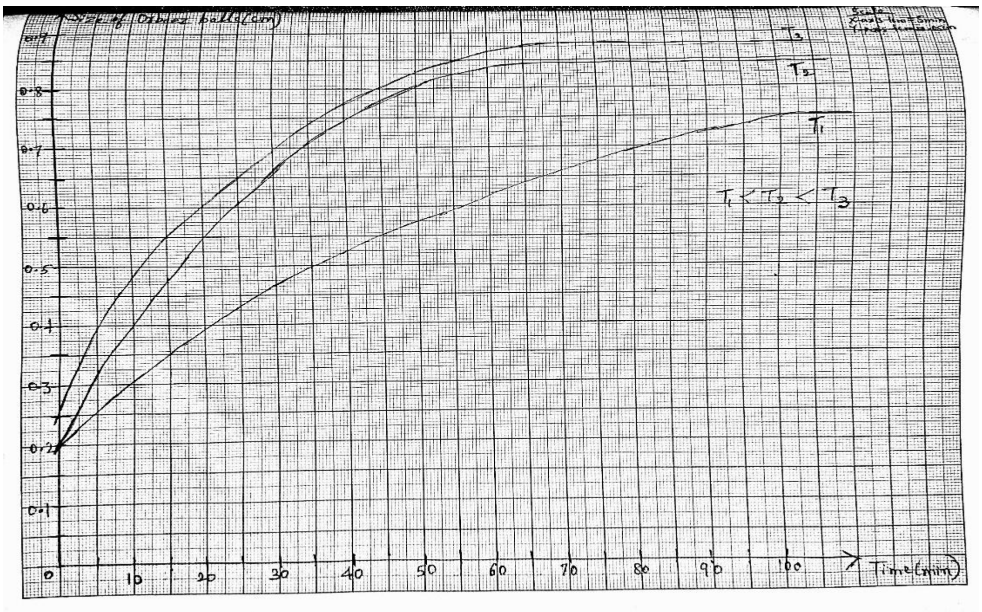

Fig 6: Plot of size of Orbeez balls versus time for T_1, T_2, T_3

Where T_1, T_2, T_3 represent cold water, water at room temperature and hot water respectively.

Here $T_1 < T_2 < T_3$

IV. RESULTS AND DISCUSSION

If we compare the average size of the Orbeez balls for all three cases say at 20 min, we notice that for cold water the average of Orbeez ball is 0.395cm, while for water at room temperature it is 0.550cm and for hot water it is 0.600cm. This indicates at higher temperatures the growth rate has increased. The curve shifts upwards with higher temperature, provided the temperature is within the limits of the superabsorbent polymer, as its composition may change beyond this temperature, losing its water absorbent property.

The variation of size of Orbeez balls with time looks like a Brillouin function [3]. This function is usually denoted by B and is defined as

$$B_J(x) = \frac{2J+1}{2J} cot\,h\left(\frac{2J+1}{2}x\right) - \frac{1}{2J} cot\,h\left(\frac{1}{2}x\right) \quad (1)$$

The graph of Brillouin function for different values of J is as shown in the figure 7

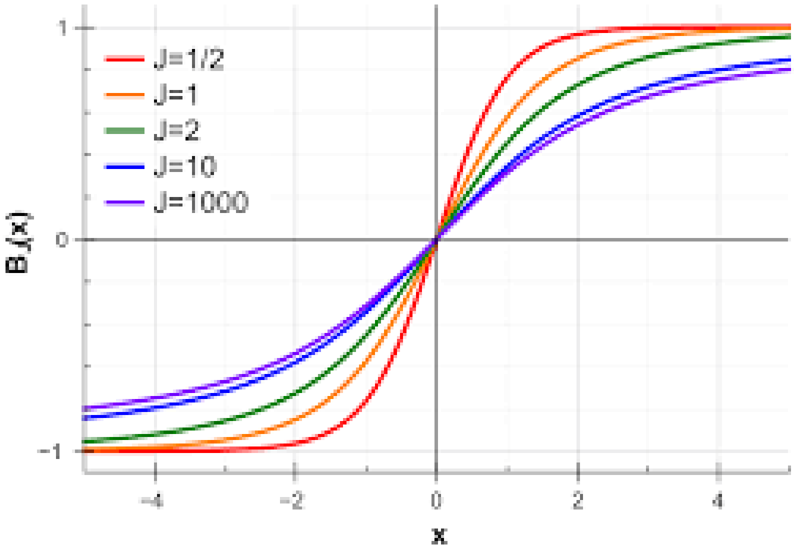

Fig 7: Graph of Brillouin function for J=1/2,1,2,10 and 100. [4]

If we neglect the negative values for 'B' and 'x' and define the function only for positive values, we have the scenario depicted by the variation of size of Orbeez balls with time. Lesser the value of J the more away is the curve from the horizontal axis. Hence, we understand that 'J' must be a function of temperature. Moreover, 'J' must be inversely related to temperature as lower values of 'J' correspond to higher temperature. For the moment we may simply write,

$$J = f(T) \quad (2)$$

Clearly, the role of 'B' is played by size of Orbeez balls 'S' and the role of 'x' is played by time elapse 't'.

Hence the function representing the variation of size of Orbeez balls with time for different temperatures is

$$S_{f(T)}(t) = \frac{2f(T)+1}{2f(T)} cot\,h\left(\frac{2f(T)+1}{2}t\right) - \frac{1}{2f(T)} cot\,h\left(\frac{1}{2}t\right) + S \quad (3)$$

Provided, $S_{f(T)}(t) \geq 0$ and $t \geq 0$. where S is size of Orbeez balls at time zero.

V. CONCLUSION

In this paper, we have performed experiments and determined how polymers like sodium polyacrylate (Orbeez balls) which absorb water and grow in size varies with time for three different temperatures of water, namely; hot water, water at room temperature and cold water. We have plotted graphs in all three cases and studied the behavior of the curves. We observe that within the temperature limits of sodium polyacrylate material the size variation with time is approximately represented mathematically by the Brillouin function with an extra constant term representing its initial size.

VI. REFERENCES

[1] www.wikipedia.org
[2] researchgate.net
[3] Solid state physics by AJ Dekker, 455, equation 18-29
[4] www.commons.wikimedia.org