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Temperature Influence on Chemical Reaction Rates and Gas Formation

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ABSTRACT

Reaction rate is fundamentally defined as the change in the concentration of reactants or products per unit time, and is known to be influenced by several determinants, including surface area, temperature, catalysts, and reactant molarity or concentration. The present study specifically investigates the validity of the widely accepted principle that temperature plays a significant role in modulating reaction rates. Experimental variations were introduced, both in terms of temperature levels and the types of chemical mixtures employed. The findings confirm that temperature indeed accelerates gas generation across all tested reaction systems. However, in mixtures exhibiting higher viscosity, gas formation proceeds more slowly due to reduced molecular mobility. Consequently, in the softener–baking soda system, the onset and progression of gas evolution show noticeable differences compared to less viscous mixtures.

Keywords: Reaction rate, Temperature effect, Gas formation, Viscocity, Chemical mixtures.

1. INTRODUCTION

Reaction rate is commonly defined as the change in the concentration of reactants or products over a given time interval. Beyond concentration-based measurements, reaction rates may also be quantified through variations in pressure, color, volume, electrical charge, optical rotation, or refractive index using appropriate physical analytical techniques.[1] Several key factors influence reaction rates, including surface area, temperature, catalysts, and the molarity or concentration of the reactants.[2]

Temperature has a pronounced effect on the rate of a chemical reaction. When the temperature is raised, the average kinetic energy of the reacting particles increases, causing them to move faster. As a result, collisions occur more frequently and with higher energy, so a greater fraction of these collisions become effective. Consequently, the overall reaction rate increases.[3]

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Recent studies have shown that combining baking soda with acetic acid consistently generates carbon dioxide (CO_2), thereby confirming the occurrence of an acid–base reaction characterized by visible effervescence and measurable gas production.[4] This well-known reaction is also widely used in educational and demonstration-based activities, particularly in volcano-simulation experiments, where the mixture of baking soda, acetic acid, dishwashing liquid, and food coloring produces CO_2-driven foaming eruptions that resemble flowing volcanic lava. Inspired by these findings, the present study investigates whether gas formation is exclusive to acid–base interactions or whether it may also arise when baking soda (a base) is mixed with neutral substances such as water or with other alkaline materials such as fabric softener. Distinct from previous work, our primary focus lies in examining the role of temperature. By varying both the chemical mixtures and reaction temperatures, we assess whether the well-established principle that increasing temperature accelerates reaction rates remains consistent across systems with different chemical characteristics (base–base, base–neutral, and acid–base). Through this investigation, we aim to develop a more comprehensive understanding of how temperature influences gas-formation kinetics in diverse chemical environments.

2. EXPERIMENTAL

2.1. Chemicals, Equipment and Instrumentation

The instruments employed in this study included a beaker, analytical balance, thermometer, measuring spoon, spirit lamp with tripod, and a stopwatch. In situations where these laboratory instruments are not readily available, alternative household items may be used without compromising the execution of the procedure for instance, a bowl may substitute for a beaker, a stove may replace the spirit lamp and tripod, and a smartphone may function as a stopwatch. These readily accessible substitutes allow the experiment to be conducted effectively outside a conventional laboratory setting.

The chemical materials utilized in this research consisted of glacial acetic acid (CH_3COOH, 100%, Merck), sodium bicarbonate ($NaHCO_3$, 100%, Merck), distilled water (H_2O, 100%, Merck), and quaternary ammonium compounds (QACs, 10%) contained within the commercially available fabric softener.

2.2. Research Procedure

A glass beaker was prepared, and one measuring spoon of sodium bicarbonate was placed into it. A total of 1 L of water was then prepared for heating; prior to heating, the initial temperature of the water was measured and recorded. Afterward, one measuring spoon of the water was transferred into the beaker containing baking soda, and the resulting gas evolution was observed. Two minutes after mixing, the final temperature of the water–baking soda system was measured and documented. This procedure was repeated by incrementally increasing the temperature of the water up to 100 °C, ensuring that the initial temperature was recorded before each trial. For additional temperature variations, the water was also cooled using a refrigerator.

Once the water–baking soda trials were completed, the same procedure was repeated using different solvent systems, namely acetic acid and quaternary ammonium compound (QAC) solutions sourced from fabric softener. In each case, gas formation was monitored, and both the initial and final temperatures of the respective mixtures were recorded.

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3. RESULTS AND DISCUSSION

3.1. Gas Formation Mechanism

In this experiment, the temperature was varied up to 100 °C, enabling clear distinctions to be observed across different heating levels. Acetic acid (CH_3COOH), a commonly encountered carboxylic acid, exists as a liquid with a melting point of 16.7 °C and a boiling point of 118 °C. Baking powder, meanwhile, is classified as an acid salt derived from the neutralization of a carbonate-based acid with sodium hydroxide, and it functions as a mild alkali when incorporated into formulations. At temperatures above 149°C (300 °F), baking powder undergoes thermal decomposition to yield sodium carbonate, water, and carbon dioxide.[5] Acetic acid readily reacts with sodium bicarbonate to form sodium acetate, water, and carbon dioxide according to the following reaction:

$$\mathbf{NaHCO_3(s) + CH_3COOH(aq) \rightarrow CH_3COONa(aq) + CO_2(g) + H_2O(l).}$$

The interaction between vinegar and baking soda is therefore well known to produce vigorous effervescence resulting from CO_2 evolution. This reaction is endothermic, meaning that heat is absorbed from the surroundings, leading to a measurable decrease in environmental temperature and a cooling sensation on the reaction vessel.[6] The findings of this experiment confirm the occurrence of a chemical reaction characterized by gas formation and the generation of new products. When sodium bicarbonate is mixed with acetic acid, noticeable bubbles or foam appear, representing the CO_2 released during the reaction. The magnitude of bubble formation is influenced by the quantities of baking soda and vinegar used: greater amounts of both reagents produce larger volumes of foam, and smaller amounts produce correspondingly reduced foaming.[7, 8] Gas itself consists of rapidly moving particles; although gases share the same fundamental molecular composition as solids and liquids, their constituent molecules move far more freely, resulting in distinct macroscopic behavior.[9, 10]

3.1. Temperature Effects on Gas Formation

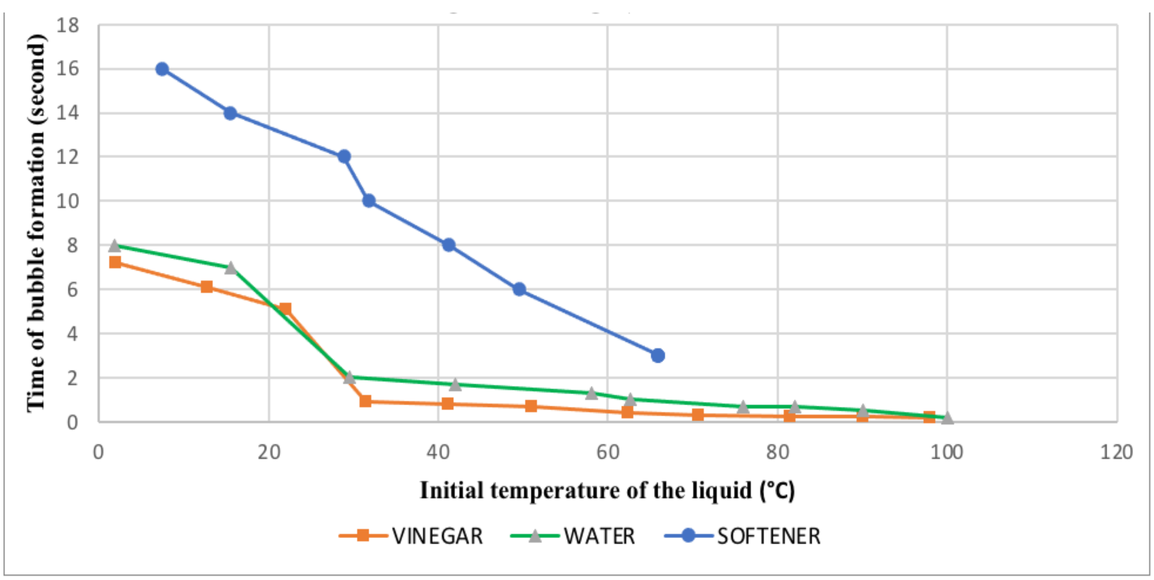

Figure 1. Relationship Between Temperature and Gas Formation Time

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For the softener and baking soda mixture, the graph shows a downward trend. This indicates that the higher the temperature of the softener before being mixed with baking soda, the faster the gas is produced. Therefore, the statement that "temperature affects gas formation" remains valid for this reaction. Although both softener and baking soda are alkaline, their combination still produces gas bubbles.

In the case of water and baking soda, the graph also shows a decreasing pattern. However, starting from approximately 29.5°C onward, the gas formation time does not appear to change significantly. The reaction that may occur is:

$$\mathbf{NaHCO_3 + H_2O \rightarrow CO_2 + H_2O + NaOH}$$

For the acetic acid (vinegar) and baking soda mixture, the graph again shows a decreasing trend. From around 31.5°C and above, the gas formation time remains relatively constant without notable differences. The reaction that occurs is:

$$\mathbf{NaHCO_3(s) + CH_3COOH(aq) \rightarrow CH_3COONa(aq) + CO_2(g) + H_2O(l)}$$

Even though the three liquids are at the same temperature, their gas formation times are not identical. For instance, at 40°C, the gas formation time for softener differs considerably compared to that for water or acetic acid.

Table 1. Evaluation of the starting temperature, ending temperature, and gas formation time for each chemical mixture.

Type Of Liquid	Initial Temperature (°C)	Temperature After 2 Minute (°C)	Time Of Bubble Formation (sec)	Description
Vinegar	2.0	17.9	7.2	The liquid is cooled, bubbles form for a very long time, the number of bubbles is only small, and a precipitate forms
	12.8	19.6	6.1	The liquid is cooled and then left in an open room for some time, bubbles form for a very long time, the number of bubbles is only small, and a precipitate forms.
	22.1	24,2	5.1	The liquid is not cooled or heated, bubbles take a long time to form, the number of bubbles is only small, and a precipitate forms
	31.5	28.9	0.9	The liquid starts to be heated over low heat, bubbles form for a long time, the number of bubbles starts to increase, and a precipitate forms
	41.2	34.3	0.8	The liquid begins to be heated, bubbles form faster than before, the number of

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				bubbles begins to increase, and a precipitate forms
	51	38.6	0.7	The liquid is heated, bubbles form faster than before, the number of bubbles is large and large, and a precipitate forms
	62.3	42,5	0.4	The liquid is heated, bubbles form faster than before, with many and large bubbles, and still form a precipitate after 2 minutes
	70.7	45.9	0.3	The liquid is heated, bubbles form more quickly, with more and larger bubbles, and still form a precipitate after 2 minutes
	81.5	46.9	0.24	The liquid is heated, bubbles form more quickly, with more and larger numbers of bubbles, and still form a precipitate after 2 minutes
	90.1	48.1	0.23	The liquid is heated, bubbles form very quickly, with a very large number of bubbles, and still form a precipitate after 2 minutes
	98	51.2	0.19	The liquid is heated, bubbles form very quickly, with a very large number of bubbles, and still form a precipitate after 2 minutes
Water	1.8	22.5	8	The liquid is cooled, bubbles form for a very long time, and only a few, then form a precipitate
	15.5	26.2	5	The liquid is cooled and then left for a while in an open room, the bubbles form for a long time, and only a few, then form a precipitate
	29.5	27.6	2	Neither heated nor cooled, the bubbles form faster than before, only a few, small ones, and immediately form a precipitate
	42	32.5	1.7	It has started to be heated, bubbles form faster than before, just a little, bigger than before, and immediately form a precipitate

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	58.1	34.2	1.3	Still heated, bubbles form faster than before, just a little, bigger than before, and immediately form a precipitate
	62.6	37.8	1	Still heated, bubbles form faster than before, start to look more numerous, bigger than before, and continue to form a precipitate
	75.9	38.7	0.7	Still heated, bubbles form faster than before, start to look more numerous, bigger than before, and continue to form a precipitate
	82	40.2	0.7	When heated, bubbles form just as quickly as before, the number and size of which are not much different from before, and still form a precipitate
	90	45.6	0.5	Heated, the bubbles formed very, many and large, and still formed a precipitate after 2 minutes
	100	46.7	0.2	Heated, the bubbles formed very, many and large, and still formed a precipitate after 2 minutes
Softener	7,4	12.2	16	Cooled in the freezer. Bubbles form for a very long time, their shape is more similar to solid foam, only forms a little, then forms a precipitate
	15,5	19.8	14	Cooled in the freezer then left in the open room first. The bubbles take a long time to form, the shape is similar to solid foam, only forms a little, then forms a precipitate too
	28,9	28.8	12	Neither heated nor cooled. foam forms faster than before, forms denser and more foam than previous data, and forms a precipitate after 2 minutes
	31,8	31.4	10	Starting to be heated over low heat, the foam forms faster than before, the shape of the foam is still the same, and still forms a precipitate
	41,3	34.2	8	Still heated, the foam forms faster than before, the size of the foam is larger

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				and the quantity is greater, and it still forms a precipitate after 2 minutes
	49,5	37.6	6	Heated, the foam forms faster than before, the size of the foam is larger and the quantity is greater, and it still forms a precipitate after 2 minutes
	65,9	49.8	3	The temperature obtained is maximum, the foam forms very much and is large, and 2 minutes later it still forms a precipitate

Based on Table 1, it can be observed that temperature has a significant effect on the rate of gas formation during the reaction. In the mixture of baking soda and water, lower water temperature results in slower gas production, whereas higher temperature leads to faster gas formation . A similar pattern is seen in the mixtures with acetic acid and softener. Scientifically, temperature can influence the strength of atomic bonds, thereby triggering chemical changes.[11] The reaction between vinegar and baking soda produces carbon dioxide gas, which in everyday conditions is known to exhibit higher concentrations in the late afternoon.[12, 13]

In addition to temperature, pressure also contributes to the rate of gas formation.[14] Higher pressure increases both the speed and the amount of gas produced, which explains why stirring the mixture can further accelerate gas formation.[15, 16]

The table also reveals an interesting finding: when softener is mixed with baking soda, gas formation takes slightly longer even when the temperature is raised. This occurs because the viscosity of the softener is higher than that of water or acetic acid. Several studies indicate that high viscosity can inhibit the formation of gas bubbles during a reaction, which becomes a limitation when gas production is required for the reaction to proceed efficiently.[17, 18]

4. CONCLUSION

Temperature has a major influence on the rate of a chemical reaction, especially in the formation of gas. The particles within a substance are always in constant motion, and when the temperature increases, the kinetic energy of these particles also increases. Higher kinetic energy leads to more frequent and more effective collisions, allowing the particles to overcome the activation energy. This condition causes chemical reactions, including gas formation, to proceed more quickly. However, viscosity can sometimes become a limiting factor in gas production. This can be seen in the mixture of softener and baking soda. Even though the softener is at a high temperature, the time required for gas to form remains relatively long because the softener has a higher viscosity.

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