International Baccalaureate
Extended Essay
Chemistry

Investigating the neutralizing effectiveness and cost-effectiveness of commercial antacids through CO_2 production and back titration.

Research question:

How does the neutralizing effectiveness in the following commercial antacids, (Titralac, Link, Natron, Zantac) differ and is neutralizing effectiveness positively correlated to the cost of medicine?

Word Count: 3995

CONTENTS

INTRODUCTION

Acid reflux is very prominent in our daily lives and is the result of the buildup of excessive amounts of stomach acid, mostly hydrochloric acid, HCl, which is used to digest the food we consume. However, at times this acid can flow back up to the oesophagus, causing the burning sensation we refer to as acid reflux.

Persistent acid reflux could be linked to gastroesophageal reflux disease, also known as GERD. GERD can be an issue if not taken care of and could even result in Oesophageal adenocarcinoma - the cancer of the oesophagus[1]. However, acid reflux can be easily relieved through antacids, which are easily accessible.

Antacids are a class of medication which aid in neutralizing the acid content in our stomachs, especially during acid reflux. The excess HCl can be neutralized by a mild base by common over-the-counter antacids, for example, Titralac, Link, Natron, all containing carbonates as their active ingredient.

I was very intrigued by the difference in effectiveness in these antacids. The medications come at different prices, and sometimes the range in price is astonishing. From a consumer's perspective, I would want to know which commercial antacid is most effective for its price so that I can be financially smarter. Due to this, I proceeded with the following research question;

How does the neutralizing effectiveness in the following commercial antacids, (Titralac, Link, Natron, Zantac) differ and is neutralizing effectiveness positively correlated to the cost of medicine?

[1] Perrine, S., 2018. When Heartburn Is Linked to Cancer. AARP, [online] Available at: <https://www.aarp.org/health/conditions-treatments/info-2018/heartburn-acid-reflux-cancer-risk.html> [Accessed 13 June 2020].

I investigated this through extensive research along with a two-part experiment. I looked at the antacids from two perspectives, the first being how much product, specifically CO_2, is produced. I did this by collecting the gas produced from the neutralization reaction between the HCl and the antacid and recording how many seconds it takes to produce 10, 20, 30, 40, 50cm^3 of CO_2. From this data, I could calculate the different rates of reactions to determine the neutralization speed. Secondly, I performed a back titration to determine the quantity of the hydrochloric acid is neutralized by one tablet of each commercial antacid. All this data thus helped evaluate which medication was most worth its price and why.

Overall, the topic is important and worth investigating as it is based on a common issue which is experienced by all. Furthermore, it is closely linked to many units covered in the IB Chemistry syllabus, specifically acids and bases along with a link to medicine, which is of significance to my future academic plans.

BACKGROUND KNOWLEDGE

THE ROLE OF HYDROCHLORIC ACID IN THE HUMAN DIGESTIVE SYSTEM

Hydrochloric acid is essential for the digestive process, which begins with an anticipation of a meal leading to the vagus nerve indicating a series of steps. Firstly, there is a release of acetylcholine, a neurotransmitter responsible for amplifying or inhibiting information carried between nerve cells, which leads to a binding between the acetylcholine and gastrin cells located in the stomach. The binding results in the secretion of gastrin[2], a hormone stimulating the stomach to produce gastric acid, also known as hydrochloric acid.

[2] Thiel, A., 2016. *Role Of Hydrochloric Acid In Aiding Digestion*. [online] Integrativepro.com. Available at: <https://www.integrativepro.com/Resources/Integrative-Blog/2016/The-Role-of-Hydrochloric-Acid-in-Aiding-Digestion> [Accessed 9 June 2020].

The hydrochloric acid functions as protein and polysaccharide degrader. It does this by providing hydrogen ions, H^+ (aq), which activates pepsinogen, a strong and abundant protein digestive enzyme. The pepsinogen acts as the indication of pepsin, the enzyme used to break down protein into peptides[3].

Subsequently, the increase of peptides leads to better absorption by the small intestine later in the digestive process. Without the HCl secretion, there would be larger fragments of protein that can enter the small intestines[2], reducing efficiency of the digestive system.

THE PROCESS OF ACID REFLUX & THE ROLE OF ANTACIDS

Acid reflux is the phenomenon which occurs when the HCl from the stomach flows up into the oesophagus, causing a 'heartburn' sensation, which is not in fact, linked to the heart[4]. More specifically, the bottom of the oesophagus has a circular band of muscle, known as the lower oesophageal sphincter, which when relaxed, allows food and liquids to flow into the stomach. The sphincter then closes, and the hydrochloric acid starts its process by breaking down the food consumed. If this relaxing movement happens abnormally or weakens, the acid flows back into the oesophagus[5]. The burning feeling occurs as the oesophagus does not

[3] Aabakken, L., 2019. *Pepsin – Store Medisinske Leksikon*. [online] Store medisinske leksikon. Available at: <https://sml.snl.no/pepsinogen> [Accessed 9 June 2020]

[4] MacGill, M. and University of Illnois, 2017. Acid Reflux: Causes, Treatment, And Symptoms. [online] Medicalnewstoday.com. Available at: <https://www.medicalnewstoday.com/articles/146619> [Accessed 12 June 2020].

[5] Beaconhealthsystem.org. 2020. *Gastroesophageal Reflux Disease (GERD) | Beacon Health System*. [online] Available at: <https://www.beaconhealthsystem.org/library/diseases-and-conditions/gastroesophageal-reflux-disease-gerd/> [Accessed 12 June 2020].

have a lining to protect itself from the strong acid, resulting in the oesophagus becoming inflamed, as illustrated in Figure 1.

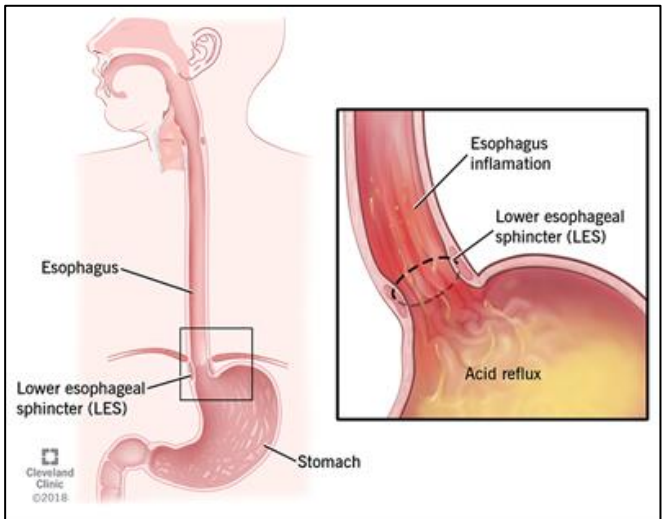

Figure 1: Diagram of the process of an abnormal or weak lower esophageal sphincter allowing hydrochloric acid to enter the esophagus.[6]

The process of acid reflux can be reduced through the utilization of antacids[7]. Antacids are a group of medications, mainly available without prescription, which include carbonates as the active ingredients investigated in this report. Antacids work by neutralizing the hydrochloric acid which has flown up to the esophagus, and by inhibiting pepsin, the digestive enzyme in the stomach. There are different types of salts used in antacids, however I focused on calcium carbonate ($CaCO_3$) and sodium bicarbonate ($NaHCO_3$). This was due to the majority of commercial antacids available in Norwegian pharmacies containing $CaCO_3$ and $NaHCO_3$.

[6] Cleveland Clinic, 2019. *GERD (Chronic Acid Reflux)*. [online] Cleveland Clinic. Available at: <https://my.clevelandclinic.org/health/diseases/17019-gerd-or-acid-reflux-or-heartburn-overview> [Accessed 29 September 2020].

[7] Salisbury, B. and Terrell, J., 2020. *Antacids*. [ebook] Treasure Island: StatPearls. Available at: <https://www.ncbi.nlm.nih.gov/books/NBK526049/> [Accessed 12 June 2020].

It is also vital to mention that many commercial antacids included multiple active ingredients, along with contents to improve taste, etc. making it difficult to investigate and increasing uncertainties.

$CaCO_3$ and $NaHCO_3$ are a species which produce CO_2, thus producing a method which allows for CO_2 measurement allows for more data available for comparison.

ANTACIDS AND THEIR FUNCTION

Calcium Carbonate ($CaCO_3$)

Calcium carbonate is exhibited as an odourless, white powder or colourless crystals[8]. There are both ionic bonds, between the calcium and carbonate ions, and covalent bonds, presented through the bonds between the carbon and oxygen in the carbonate ion, illustrated through Figure 2.

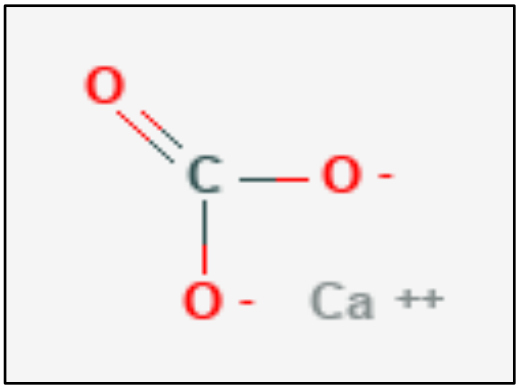

Figure 2: Molecular structure of calcium carbonate

When hydrochloric acid reacts with any carbonate, the products formed are salt, water, and carbon dioxide[9]. In this context, the calcium carbonate and hydrochloric acid will

[8] National Center for Biotechnology Information, 2020. Calcium Carbonate. [online] Pubchem. Available at: <https://pubchem.ncbi.nlm.nih.gov/compound/Calcium-carbonate> [Accessed 13 June 2020].

[9] Brown, C. and Ford, M., 2014. *Higher Level Chemistry*. 2nd ed. Harlow, United Kingdom: Pearson Education Limited.

react together to give calcium chloride, water, and carbon dioxide. The reaction equation is as follows;

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2CO_3(aq)$$

$$H_2CO_3(aq) \rightarrow CO_2(g) + H_2O(l)$$

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$$

Sodium Bicarbonate ($NaHCO_3$)

Sodium bicarbonate is available as odourless, white powder or lumps. It is slightly alkaline, basic with water solubility, and has alkalinizing and electrolyte replacement[10]. Electrolyte replacement is vital for the human body as it manages the acidity of the blood and muscle function[11].

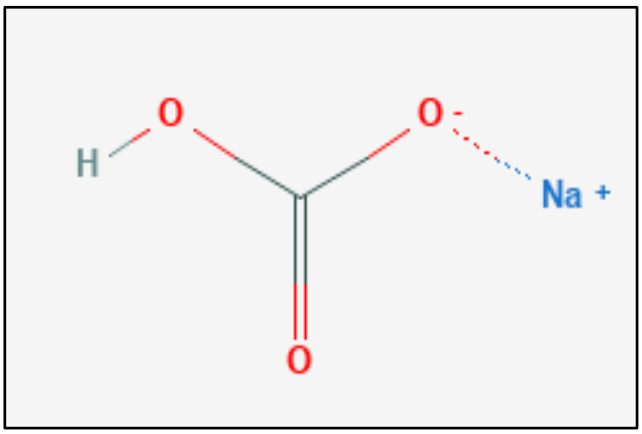

Figure 3: Molecular structure of sodium bicarbonate

The compound is stable in dry air, which is why it is optimal for medication and does not have any risk. It works as an antacid by neutralizing and lessening the impact of excess HCl, but has no effect on how much HCl is produced by the stomach. The process of

[10] National Center for Biotechnology Information, 2020. Sodium Bicarbonate. [online] Pubchem. Available at: <https://pubchem.ncbi.nlm.nih.gov/compound/Sodium-bicarbonate> [Accessed 13 June 2020].

[11] National Library of Medicine, 2020. Electrolytes. [online] Medlineplus. Available at: <https://medlineplus.gov/ency/article/002350.htm> [Accessed 13 June 2020].

neutralizing or buffering the HCl, results in the stomach pH increasing, thus becoming less acidic, and implements relief for the hyperacidity indication[10]. The reaction is shown below;

$$\mathbf{NaHCO_3 + HCl\ (aq) \rightarrow NaCl(aq) + H_2CO_3\ (aq)}$$

$$\mathbf{H_2CO_3\ (aq) \rightarrow H_2O\ (l) + CO_2\ (g)}$$

$$\mathbf{NaHCO_3\ (aq) + HCl\ (aq) \rightarrow NaCl\ (aq) + H_2O\ (l) + CO_2\ (g)}$$

The strong acid will react with the weak base, first producing carbonic acid, H_2CO_3, however due to its unstable state it will further produce water and carbon dioxide. CO_2, will be witnessed through the gas collection method in Experiment 1. The liquid remaining would be sodium chloride (NaCl, a form of salt. All acid-base reactions have water as their byproduct as well, the pH of this solution will be determined by the amount of either reactant in excess[12].

Ranitidine ($C_{13}H_{22}N_4O_3S$)

I decided to investigate the effectiveness of Ranitidine, commercially known as Zantac, due to its controversialness. I am doing this due to its complex synthesis method along with its ability to block histamine, ultimately reducing the overall acid levels in the stomach. The medication was used as a comparing method for the remaining commercial antacids and their neutralizing effectiveness. It has been linked to apparent acute liver

[10] National Center for Biotechnology Information, 2020. Sodium Bicarbonate. [online] Pubchem. Available at: <https://pubchem.ncbi.nlm.nih.gov/compound/Sodium-bicarbonate> [Accessed 13 June 2020].

[11] National Library of Medicine, 2020. Electrolytes. [online] Medlineplus. Available at: <https://medlineplus.gov/ency/article/002350.htm> [Accessed 13 June 2020].

[12] Brown, K., 2017. What Happens When Hcl Is Added To Nahco3.

injury[13], and has stopped selling without prescription. The molecular solution for Ranitidine is exemplified through Figure 4.

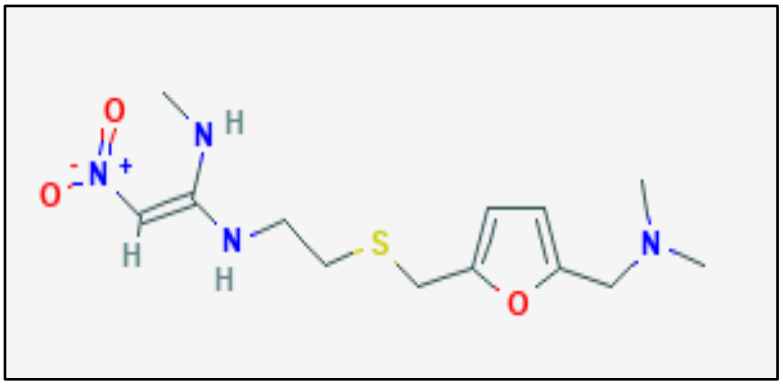

Figure 4: Molecular structure for Ranitidine

As previously mentioned, I have decided to investigate Ranitidine, otherwise known as Zantac, as it is also classified as an antacid but advised not to consume due to its controversiality. The compound is water soluble[14] which makes it applicable to be investigated and compared to sodium bicarbonate and calcium carbonate as other active ingredients in commercial antacids.

[13] National Center for Biotechnology Information, 2020. *Ranitidine*. [online] Pubchem.ncbi.nlm.nih.gov. Available at: <https://pubchem.ncbi.nlm.nih.gov/compound/Ranitidine> [Accessed 14 June 2020].

[14] Schulz, G. and Hawkins, S., 1990. *Ullmann's Encyclopedia Of Industrial Chemistry*. Weinheim: VCH.

INVESTIGATION

VARIABLES

Table 1: Independent variable for the CO_2 Collection and Back Titration

Independent Variables		
Variable	*Name - Active Ingredient*	
Commercial Antacid	Titralac	Calcium carbonate
	Link	Calcium carbonate
	Natron	Sodium bicarbonate
	Zantac	Ranitidine
	Pure $CaCO_3$ - Control	Calcium carbonate

Table 2: Dependent variables for the CO_2 Collection and Back Titration

Dependent Variable		
Variable	*SI Unit*	*How will it be measured*
Rate of CO_2 production	cm^3 / second	Using the stopwatch to time how many seconds it takes for $10cm^3$, $20cm^3$, $30cm^3$, $40cm^3$, $50cm^3$ of CO_2 to be produced from the reaction. Calculate rate according to volume (of CO_2 produced) / time (seconds).
End-point of titration (volume of NaOH required to reach equivalence point)	cm^3	Stopping the titration once the unknown solution turns pink, this indicates the end point.

Table 3: Control variables for the CO_2 Collection and Back Titration

Control Variables		
Controlled Variables	*How will it be controlled?*	*Why is it important?*
HCl concentration	Each trial will have 1.00 mol/dm^3 of hydrochloric acid by making the standard solution myself.	Concentration affects the rate of reaction. A difference in concentration would mean more/fewer HCl particles which affects collision rate.
HCl volume	All tests will have 10cm^3 of HCl and this will be done through a volumetric pipette.	A change in volume of HCl would affect the number of particles, thus rate of reaction.
NaOH concentration	Each trial will have 1.00 mol/dm^3 of sodium hydroxide by creating the standard solution myself through Titrisol.	Concentration affects the rate of reaction. A difference in concentration would mean more/fewer NaOH particles which affects collision rate.
Temperature of system	All tests will be conducted in the room, which would mean the same room temperature.	Temperature is linked to kinetic energy and frequency of collisions, which affects rate of reaction.
The surface area of antacid	All antacids will be in fine powdered form.	Surface area of the reactant links to how exposed particles are to other reactants. This is linked to collision rate thus rate of reaction too.
Mass of antacid	All tests will use exactly one tablet of antacid.	Mass of reactant affects mass of products. The basis of this investigation is to compare neutralization effectiveness per tablet; thus it is vital one tablet is used.
Pressure of system	All tests will be conducted using the same equipment, specifically the same shape and volume of beakers, cylinders, etc.	The width of the flask would affect pressure of the particles in it, directly affecting collision rate thus the rate of reaction.

APPARATUS

Table 4: Apparatus for the preparation of CO_2 Collection and Back Titration

Required to prepare solutions for Experiment 1 and 2	Required for Experiment 1 (CO_2 Collection) for 1 trial	Required for Experiment 2 (for 1 trial)
• 2 x 1dm^3 volumetric flask • 2dm^3 volumetric flask • NaOH - Titrisol (1000ml : 1.00mol/dm^3) • Concentrated HCl - 34% • Pipette • Laboratory funnel • Distilled water • Gloves • Safety Goggles	• 1 Conical flask • 1 tablet of the commercial antacid • 10cm^3 of 1M hydrochloric acid • Mechanical pipette • Electronic balance • Mortar and pestle • Weighing boat glass laboratory funnel • Rubber stoppers • Rubber connecting tube • 50cm^3 gas syringe • Stand • Clasp • Stopwatch	• 1 conical flask • 1 tablet of the commercial antacid • 10cm^3 of 1M hydrochloric acid • Mechanical pipette • Bunsen burner • Stand • Match sticks • Stand • Clasp • Buret • Funnel • Phenolphthalein indicator • Magnetic stirrer • Magnets

METHODOLOGY

Preparing the 1.00mol/dm^3 HCl solution

I used concentrated HCl with 34%, however I was unfamiliar with the percentage unit thus had to convert to 1.00mol/dm^3 unit. I did this by the following calculations;

34% HCl's density = 1.17kg/dm^3 [15]
Molar mass (Mm) of HCl = 36.46g/mol [16]
34% HCl's density x 1.17kg/dm^3 = 0.3978kg/dm^3.
0.3978kg/dm^3 / 36.46g/mol = 10.91mol/dm^3
∴Concentrated HCl (34%) ≈ 11.00mol/dm^3
n/c = v
1.00mol / 11.00mol/dm^3 = 0.091dm^3
∴ 0.091dm^3 of 34% HCl added to 0.909dm^3 of water
∴ 1.00mol/dm^3 HCl

Figure 5: Calculation for converting 34% HCl to mol/dm^3

According to these calculations, I first added 0.909dm^3 of water in a 1.00dm^3 volumetric flask. I then used a laboratory pipette to draw out 0.091dm^3. of the concentrated HCl and carefully poured this into the volumetric flask using a laboratory funnel. This created the 1.00mol/dm^3 HCl solution.

Preparing the 2.00mol/dm^3 HCl solution

I used Figure 5 to convert the 34% HCl to mol/dm^3 and could further determine how to dilute to the 2.00mol/dm^3 solution by the following steps.

$$n/c = v$$
$$2.00mol / 11.00mol/dm^3 = 0.182dm^3$$
$$\therefore 0.182dm^3 \text{ of 34\% HCl added to } 1.818dm^3 \text{ of water}$$
$$\therefore 2.00mol/dm^3 \text{ HCl}$$

I prepared this solution in a 2.00dm^3 volumetric flask. pouring the water, and then the strong acid, along with wearing protective gear as I was working with corrosive substances.

Preparing the 1.00mol/dm^3 NaOH solution

To prepare the titrant, I diluted the Titrisol concentrate with 1. 00dm^3 of distilled water. This was a more efficient way of obtaining the 1.00mol/dm^3 NaOH solution.

Experiment 1 - CO_2 Collection

1. Set up the experiment by attaching the syringe to the stand via the clasp, and attach the rubber connecting tube to the front of the syringe. View Figure 5.1 for visualization of gas collection method setup.

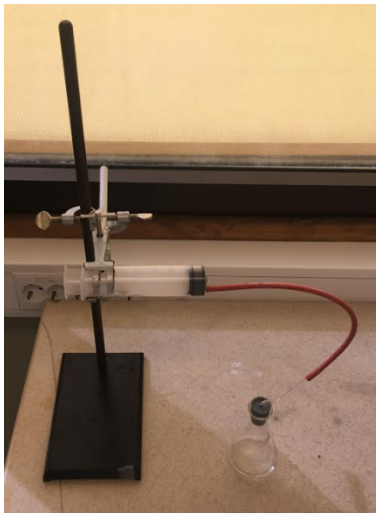

Figure 5.1: Setup of Experiment 1 - Gas collection method.

2. Use a mechanical pipette to measure 10cm^3 of the HCl and add to the conical flask

3. Crush the tablet of antacid in the mortar with pestle so that it´s in powder form. This will control surface area of the independent variable.

4. Use the electronic balance to measure the mass of 1 tablet of the commercial antacid being tested. Place the weighted antacid in the weighted boat glass laboratory funnel. Note this down for further calculations.

5. In a fast motion, pour the antacid in the funnel into the conical flask, place the rubber stopper with the plastic tube attached to the other end. The conical flask will display the neutralization taking place visible through the fizzing.

6. Using the stopwatch, start timing immediately and note down the times when the syringe is gradually surpassing the 10/20/30/40/50cm^3 mark, as this is the indication of CO_2 production.

7. Stop timing once the syringe has slowed down and there is very little and non-visible change of CO_2 produced.

8. Calculate rate according to volume of CO_2 produced / time (seconds). Do this process 5 times for each antacid to ensure reliability of the data and to identify any anomalies.

Experiment 2 - Back Titration

1. Set up the titration by attaching the burette to the stand with the clasp. Make sure the burette is high enough so that the magnetic stirrer and conical flask can be placed directly under. View Figure 5.2 for visualization of the titration setup.

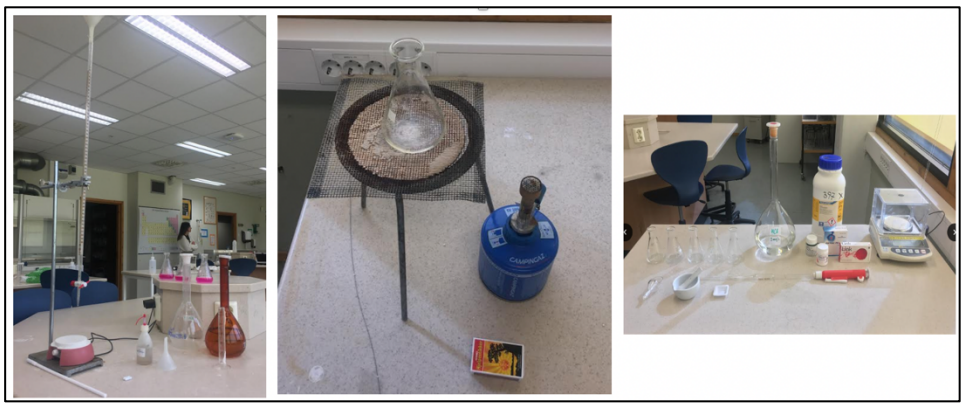

Figure 5.2: Setup of Titration for Experiment 2

2. Use a mechanical pipette to measure 20cm^3 of the HCl and add to the conical flask

3. Crush 1 tablet of antacid in the mortar and pest so that it turns into powder. This will control surface area of the independent variables.

4. Pour the antacid in the funnel into the conical flask and let the reaction take place.

5. To finish the experiment and remove all CO_2 produced, The conical flask will be placed on top of the stand, which has the burning Bunsen burner under it. This will remove the CO_2, produced from the reaction and leave the excess HCl.

6. Allow for the conical flask to boil for 2 minutes before removing it from the stand and adding 4 drops of the Phenolphthalein indicator .
7. Add the magnets into the conical flask and place over the magnetic stirrer to allow the solution to be stirred continuously.
8. Slowly start to titrate the NaOH, noting down the initial and final volume which is when the solution turns pink, marking the end of titration) to determine volume of NaOH required.

RISK ASSESSMENT

As concentrated HCl is a strong acid, it is highly corrosive and has the ability to burn the skin instantly upon contact. Moreover, NaOH is a strong base and is also very corrosive To reduce the risks of these unfortunate events, I thus wore gloves, safety goggles, and a lab coat to avoid contact with the strong acid and base. I also poured the acid and base after pouring the water in the volumetric flask to avoid acid spattering.

RESULTS

Although the price of the medications are not related to the individual experiments, it is linked to the research question as it directly correlates to the cost effectiveness. Due to this, the table below shows the price list and number pills for each packaging.

Table 5: Consumer information for commercial antacids being investigated

Medication	Price (in NOK)	Number of tablets in one packaging	Mass per tablet (mg)
Titralac	69	50	350
Link	109	20	500
Natron	279	100	500
Zantac	--- *	30	150

* The price of Zantac has not been disclosed to the public as it is a prescribed medication now and cannot be bought online.

QUANTITATIVE DATA - EXPERIMENT 1: CO_2 COLLECTION

Table 6: Table showing the time (seconds) taken for all antacids to produce the given volume of CO_2 (cm^3)

Commercial Antacid	Trial	CO2 produced (cm3) in seconds				
		10cm3	20cm3	30cm3	40cm3	50cm3
Pure CaCO3	Uncertainty	±0.71	±1.07	±0.73		
	1	1.78	3.08	5.84	-	-
	2	2.66	4.99	7.04	-	-
	3	1.60	3.18	7.30	-	-
	4	1.25	2.86	6.27	-	-
	5	1.71	4.28	7.13	-	-
Titralac	Uncertainty	±1.54	1.80	±2.78	±3.47	-
	1	6.20	10.87	22.30	35.83	-
	2	6.21	11.27	18.62	31.43	-
	3	5.28	11.61	19.50	30.53	-
	4	4.63	14.34	24.18	38.37	-
	5	4.15	10.75	22.43	32.05	-
Link	Uncertainty	±2.02	±2.30	±5.53	±1.58	-
	1	9.36	15.08	22.22	31.37	-
	2	6.56	10.51	23.74	-	-
	3	5.32	10.48	15.55	29.05	-
	4	9.01	14.95	26.61	-	-
	5	6.55	11.19	17.14	32.20	-
Natron	Uncertainty	±0.56	±0.53	±0.89	±1.14	±1.39
	1	4.63	8.68	13.59	17.28	22.33
	2	5.36	8.94	13.90	18.23	24.90
	3	4.66	7.88	12.12	15.95	22.85
	4	5.75	8.78	12.84	16.55	24.95
	5	4.80	8.80	13.69	18.04	25.10
Zantac	Uncertainty	±1.00	±2.08	±2.32	±3.90	±1.52
	1	9.43	15.68	19.37	26.27	-
	2	7.75	11.52	14.93	18.47	26.82
	3	9.65	12.18	16.14	19.65	29.85
	4	9.62	13.53	17.17	20.98	29.80
	5	7.66	13.54	19.57	25.60	-

QUANTITATIVE DATA - EXPERIMENT 2: BACK TITRATION

Table 7: NaOH used to neutralize 20cm^3 of excess HCl, which was neutralized by all commercial antacids prior to the Back Titration.

Commercial Antacid	Trial	Volume of NaOH used for end-point in Titration (cm3)		
		Burette reading of NaOH		Volume of NaOH (cm3)
		Initial (cm3)	Final (cm3)	±0.5
Pure CaCO3	1	0.00	18.10	18.10
	2	0.00	17.70	17.70
	3	0.00	17.10	17.10
	4	17.10	34.50	17.40
	5	20.00	37.60	17.60
Titralac	1	0.00	21.00	21.00
	2	21.00	41.10	20.00
	3	5.30	27.80	22.50
	4	27.80	48.20	20.40
	5	0.00	21.40	21.40
Link	1	0.00	15.50	15.50
	2	15.50	31.10	15.60
	3	0.00	15.80	15.80
	4	0.00	15.40	15.40
	5	0.00	15.60	15.60
Natron	1	0.00	21.10	21.10
	2	0.00	20.90	20.90
	3	0.00	21.80	21.80
	4	0.00	21.70	21.70
	5	21.70	43.70	21.90
Zantac	1	0.00	26.90	26.90
	2	0.00	26.50	26.50
	3	0.00	26.40	26.40
	4	0.00	26.80	26.80
	5	0.00	26.20	26.20

DATA ANALYSIS AND DISCUSSION

EXPERIMENT 1 - GAS COLLECTION

I calculated the standard deviation for statistical comparison through technology available through a TI – 84 calculator. The reason I focused on standard deviation was too see how close my results are to the actual value, to determine whether my results were precise and accurate. An example of finding the standard deviation is shown under.

The formula of finding the standard deviation is shown below.

$$\sigma = \sqrt{\frac{\Sigma\ (X - \overline{X})^2}{n - 1}}$$

Using this formula, I did the following calculations for all trials, however, here is an example of the calculations for the first trial of the pure $CaCO_3$ gas collection:

$$\sigma = \sqrt{\frac{(1.78 - 1.80)^2 + (2.66 - 1.80)^2 + (1.60 - 1.80)^2 + (1.25 - 1.80)^2 + (1.71 - 1.80)^2}{5}}$$

$$\sigma = \sqrt{0.21812}$$

$$\sigma = 0.47 \text{ (3s.f.)}$$

To organize the information more effectively, I placed the standard deviation, along with the mean values, in a separate table illustrated in Table 8 below.

Table 8: The Mean (μ) and Standard Deviation (σ) of CO2 produced (cm3) in seconds by all commercial antacids through the neutralization experiment.

0.467

Commercial Antacid	Mean (μ) and Standard Deviation (σ) of CO2 produced (cm3) in seconds by all commercial antacids					
		10cm3	20cm3	30cm3	40cm3	50cm3
Pure CaCO3	μ	1.80	3.68	6.72	-	-
	σ	0.52	0.92	0.63	-	-
Titralac	μ	5.29	11.77	21.41	33.64	-
	σ	0.92	1.48	2.29	3.33	-
Link	μ	7.36	12.44	21.05	30.87	-
	σ	1.75	2.37	4.61	1.63	-
Natron	μ	5.04	8.62	13.23	17.21	24.03
	σ	0.49	0.42	0.74	0.97	1.33
Zantac	μ	8.82	13.29	17.44	22.19	28.82
	σ	1.02	1.60	2.02	3.54	1.74

I used the mean from Table 8 to create Table 9 to get an indication of what the different rates of reaction are at different stages of the reaction. A stage in this context is defined as the time it takes to reach 10/20/30/40/50cm^3.

Table 9: The rate of reaction (volume of CO_2 (cm^3) produced per second) in each stage of CO_2 production for each commercial antacid.

Medication	Rate of reaction (cm3 /second)				
	10cm3	20cm3	30cm3	40cm3	50cm3
Pure CaCO3 (control)	5.56	5.43	4.46	-	-
Titralac	1.89	1.70	1.40	1.19	-
Link	1.36	1.61	1.43	1.30	-
Natron	1.98	2.32	2.27	2.32	2.08
Zantac	1.13	1.50	1.72	1.80	1.73

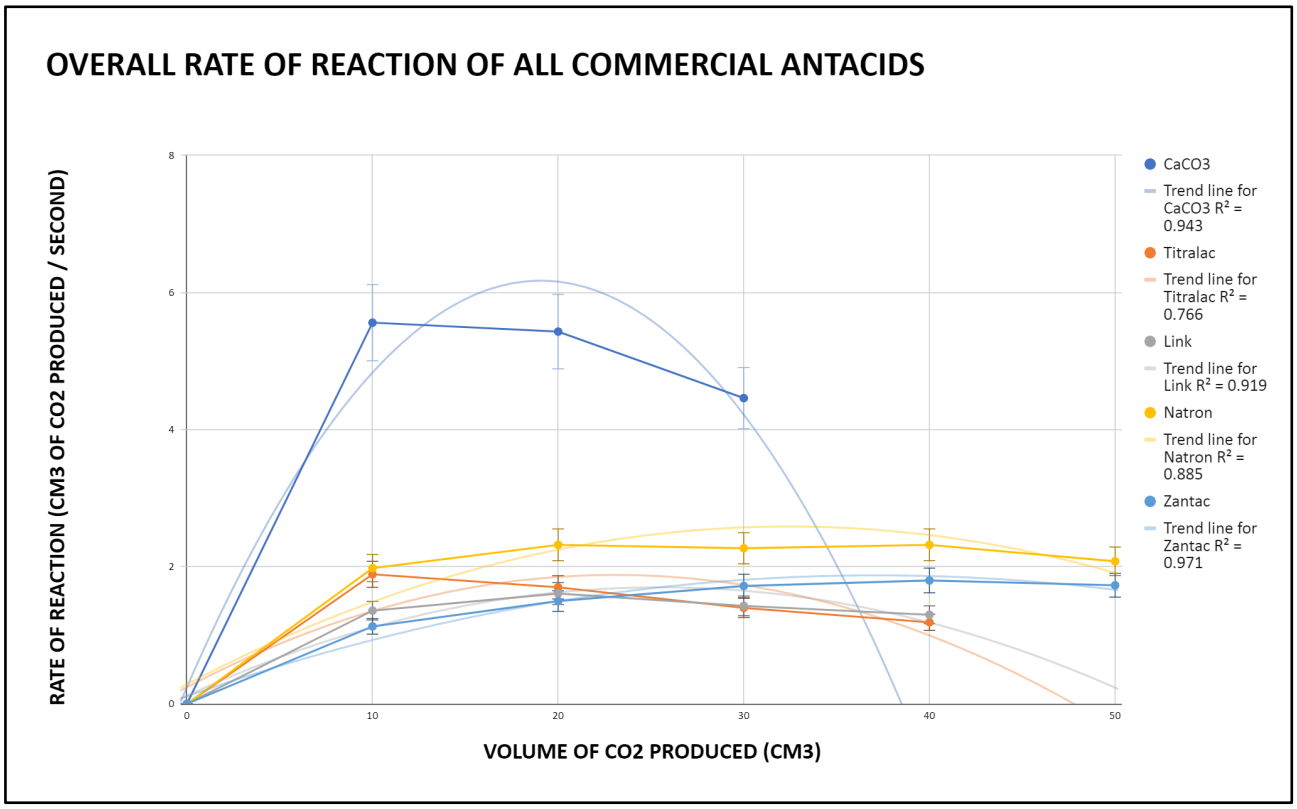

Figure 6: Visualization of Table 10 to show difference in rate of reaction (cm^3 of CO_2 produced per second) for each antacid (including pure $CaCO_3$)

It is first noticeable that the pure $CaCO_3$, the reference point for all commercial antacids, stopped displaying indication of CO_2 produced in the gas syringe, this can be seen through Table 11 where there is no numerical data for $40cm^3$ and $50cm^3$. However, $CaCO_3$ is also the antacid with the highest rate of CO_2 production, according to Table 6 and 9, with the steepest graph which decreases fast as well. This shows that the reaction between pure $CaCO_3$ and HCl would have the fastest start but will decrease in pace very quickly.

Moreover, it was evident that the pure $CaCO_3$ was an outlier in comparison to the other increments as seen through Figure 6, where the $CaCO_3$ trendline Is much steeper than the other trend lines. Due to this, I could not clearly see the visualization of the other medications in Figure 6. To overcome this, I removed the $CaCO_3$ variable to analyze the remaining increments as shown through Figure 7.

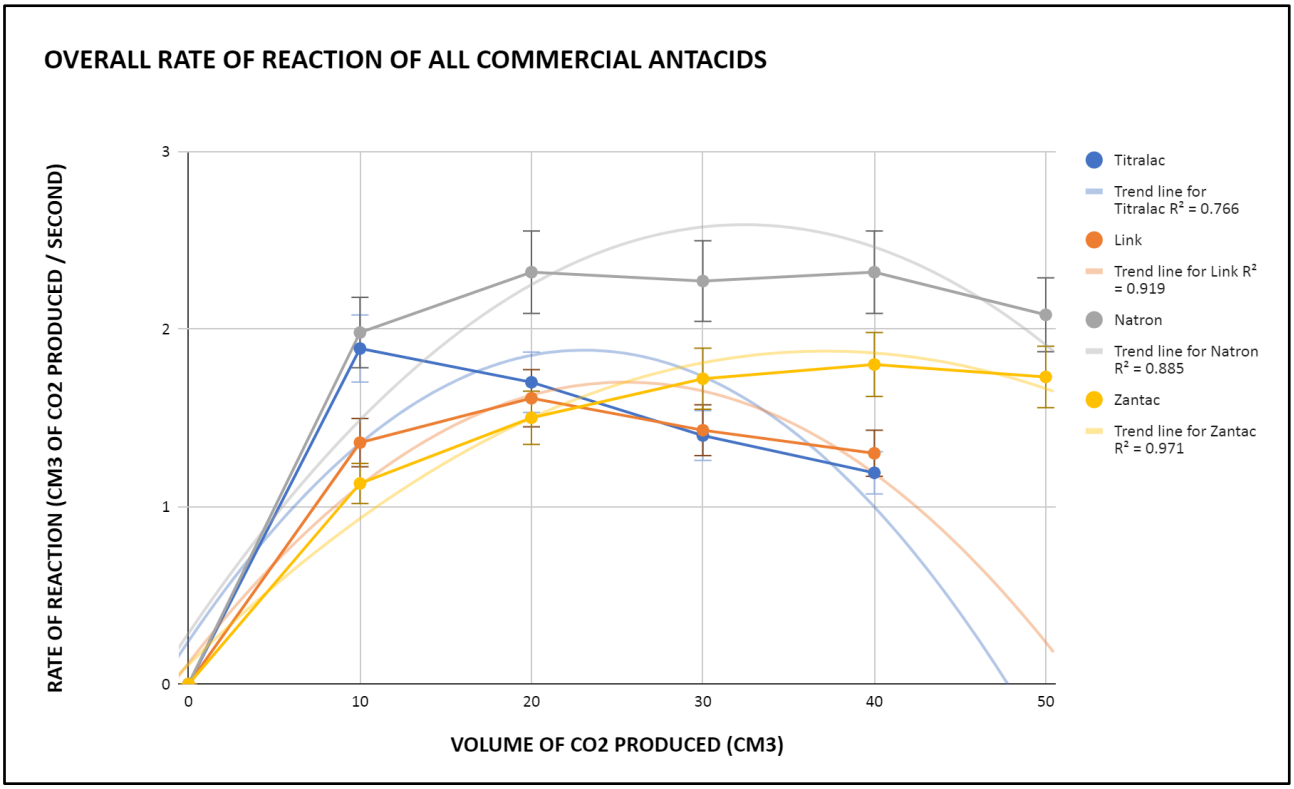

Figure 7: Rate of reaction (cm^3 of CO_2 produced per second) for each commercial antacid (excluding pure $CaCO_3$)

The utilization of the polynomial trend line was important for Experiment 1, as it would indicate at which point the antacid was at its fastest rate to produce CO_2. Furthermore, the polynomial trendline assists in providing an indication on how much CO_2 would be produced from the single tablet of antacid. This information links to the neutralizing effectiveness of the antacid, specifically how much and how quick (in terms of seconds) HCl is neutralized by the

antacid. Thus, theoretically, the more CO_2 production means that there are more antacids functioning, associates to how effective the commercial antacid really is.

It is vital to mention that the R^2 value for the trendlines, except the Titralac (R^2 = 0.766), in both Figure 6 and 7 are above 0.885, which shows a strong correlation between the actual values and the trendline. The Titralac shows moderate correlation with the trend line, which suggests that the rate of reaction will be slightly different to what the trendline estimates.

Linking this to the re al life situation, the immediate, but short effect of the pure $CaCO_3$ could be hazardous to the consumer as it reacts so quickly. This could be a reason why the commercial antacids have slower but longer overall rates of reactions.

EXPERIMENT 2 - BACK TITRATION

To make further calculations more efficient, I found the moles of NaOH used to find the equivalence point in the titrations. As all trials used 1.00mol/dm^3 NaOH, I used the formula n = CV. The calculated data is recorded through Table 10.

Table 10: Calculated values for the moles (mol) of NaOH (titrant) required to reach equivalence point in the back titration against commercial antacids.

Commercial Antacid	Trial	Reaching equivalence point in Back Titration			
		Volume (cm3) of NaOH		Moles (mol) of NaOH	
Pure CaCO3	1	±0.50	18.10	±0.0005	0.0181
	2		17.70		0.0177
	3		17.10		0.0171
	4		17.40		0.0174
	5		17.60		0.0176
	Mean (μ)		**17.58**		**0.0175**
Titralac	1	±1.25	21.00	±0.0013	0.0210
	2		20.00		0.0200
	3		22.50		0.0225
	4		20.40		0.0204
	5		21.40		0.0214
	Mean (μ)		**21.06**		**0.0214**
Link	1	±0.40	15.50	±0.0004	0.0155
	2		15.60		0.0156
	3		15.80		0.0158
	4		15.40		0.0154
	5		15.60		0.0156
	Mean (μ)		**15.58**		**0.0156**
Natron	1	±0.50	**21.10**	±0.0005	0.0211
	2		20.90		0.0209
	3		21.80		0.0218
	4		21.70		0.0217
	5		21.90		0.0219
	Mean (μ)		**21.48**		**0.0215**
Zantac	1	±0.50	26.90	±0.0004	0.0269
	2		26.50		0.0265
	3		26.40		0.0264
	4		26.80		0.0268
	5		26.20		0.0262
	Mean (μ)		**26.56**		**0.0266**

To make comparison more efficient, I decided to utilize the mean values of volume and moles of NaOH used to neutralize the commercial antacids, this will be referred through Table 11.

Table 11: Average volume (cm^3) of NaOH, the titrant, used to neutralize the excess HCl from Experiment 1.

Commercial Antacid	Mean volume (cm^3) used to neutralize excess HCl (from Table 7)	Mean mole (mol) used to neutralize excess HCl (from Table 7)
Pure $CaCO_3$	17.58	0.0175
Titralac	21.06	0.0214
Link	15.58	0.0156
Natron	21.48	0.0215
Zantac	26.56	0.0266

The information above in Table 11 shows a range of volumes of NaOH, a strong base, which was required to neutralize the HCl. It can be examined that the Link, pure CacO3, Titralac (in descending order) have the smallest volume of NaOH which was required to neutralize the excess HCl. This suggests that there was little excess HCl to neutralize, as most of it has already been neutralized by these commercial antacids beforehand.

On the other hand, Natron, but especially Zantac, required the greatest volumes of NaOH to neutralize the HCl which was not already neutralized by Zantac and Natron.

To calculate the volume of HCl that each antacid neutralized, I first calculated the volume of HCl neutralized by the NaOH through the back titration, and then subtracted this from the initial HCl volume which was 20cm^3. This is numerated through Figure 8.

$NaOH\ (aq) + HCl\ (aq) \rightarrow NaCl\ (aq) + H_2O\ (l) + CO_2\ (g)$

Average volume of NaOH used to neutralize excess HCl which was neutralized by pure $CaCO_3$ beforehand = 21.06cm^3

Concentration (NaOH) =1.00mol/dm^3

Moles (NaOH) = 0.02106mol

NaOH : HCl (molar ratio)

1 : 1 (molar ratio)

∴ Moles (HCl) = 0.02106mol

C (HCl) = 2.00mol/dm^3

V(HCl) = n / c

V (HCl) = 0.02106mol / 2.00mol/dm^3 = 0.01053dm^3 = 10.53cm^3

∴ HCl neutralized by pure $CaCO_3$ = 20.00cm^3 - 10.53cm^3 = 9.47cm^3

Figure 8: Calculations to numerically see the volume (cm^3) of HCl neutralized by Titralac.

I utilized this method to calculate the volume of HCl neutralized by the table and used this method for all antacids. The results are in the table below.

Table 12: Neutralization effectiveness of each commercial antacid on 20cm^3 of HCl.

Commercial Antacid	Volume (cm^3) of HCl neutralized by commercial antacid	% of HCl neutralized by commercial antacid
Pure $CaCO_3$	11.21	56.06
Titralac	9.47	47.35
Link	12.21	61.05
Natron	9.26	46.30
Zantac	6.72	33.60

Table 12 exhibits a different perspective on the overall neutralizing effectiveness. Knowing how much of the HCl, which has flown up into the oesophagus is a method for comparing which medication is most effective and worth its price.

In relation to Table 11, it can be seen that all $CaCO_3$ antacids required the least volume of NaOH to neutralize the excess HCl, however this claim is further supported by Table 12. Table 12 reveals that $CaCO_3$ containing antacids neutralize the highest percentage of the HCl. In the context of this investigation, this means the $CaCO_3$ containing antacids would neutralize the highest ratio of the HCl in the acid reflux.

However, there are other factors involved in pills containing $CaCO_3$, such as other chemicals, which dilutes the $CaCO_3$. This makes the $CaCO_3$ less dangerous but more advantageous to human health. A more concentrated dose of $CaCO_3$ would result in higher levels of calcium in the blood, this leads to muscle weakness, increase urination, and

tiredness[15]. Link and Titralac, the commercial antacids containing $CaCO_3$, however, have the shortest reactions in comparison to Zantac and Natron.

Nonetheless, Zantac, containing ranitidine, and Natron, containing sodium bicarbonate as its active ingredient, neutralize the smallest ratio of HCl, meaning they are very ineffective in regards to the other medications. A reason why Zantac is more incompetent as an antacid would be that the main aim of Zantac is to reduce the acid in the stomach, rather than neutralizing it. Even though it had a quick reaction with the HCl, producing more than $50cm^3$ of CO_2, it is deemed hazardous to humans thus should be avoided as an alternative for acid reflux medication.

The research question for this investigation was;

´How does the neutralizing effectiveness in the following commercial antacids, (Titralac, Link, Natron, Zantac) differ and is neutralizing effectiveness positively correlated to the cost of medicine? `

If we compare neutralizing effectiveness through Table 12, in terms of volume of HCl neutralized by the antacid, the effectiveness in ascending order is as follows; Zantac, Natron, Titralac, Link. However, Figure 7 shows the overall rate of reaction, over time Zantac and Natron are the more consistent antacids, having steeper rate of reactions and overall long-term output of CO_2 as well.

Thus, cost effectiveness depends on the purpose the consumer wants their antacid to withhold. Even though Natron and Zantac have faster rate of reactions, they do not have the neutralizing abilities that Titralac and Link have. If the cost is a deciding factor for which

[15] Michigan Health System, 2020. *Calcium Carbonate | Michigan Medicine*. [online] Michigan Medicine. Available at: <https://www.uofmhealth.org/health-library/d00425a1> [Accessed 12 October 2020].

antacid one buys, then Titralac is the most cost-effective option according to the investigation conducted. Titralac costs 69 kroner with 50 x 350mg tablets, as mentioned in Table 5, and its identities indicate consistent and effectual rate of reaction along with significant volumes of stomach acid neutralized.

EVALUATION

CONCLUSION

The results of this investigation show that there is a difference in effectiveness in regards to how long the neutralizing effect is and how much is neutralized. Altogether, the pure $CaCO_3$ had the fastest rate of reaction, along with it being the antacid which neutralized most HCl, 56.06%. The conclusion which can be made from this finding is that $CaCO_3$ is very fast and effective, however the pace of the reaction could be detrimental if humans were to consume this. Pure $CaCO_3$ irritates the skin upon contact[16], however in diluted form, can be beneficial.

Withal, all $CaCO_3$, containing antacids, Link and Titralac, have a more diluted concentration of $CaCO_3$, meaning they are not hazardous to humans and have no disadvantageous repercussions. These medications neutralize the largest proportion of the HCl, however did not have the fastest reaction. This is beneficial as the effect is not immediate, thus not risking an abrupt imbalance in the consumer's stomach chemically. Financially, $CaCO_3$, containing antacids are the cheapest alternatives for commercial antacids,

[16] Oregon Department of Human Services, 1998. *HEALTH EFFECTS INFORMATION - CALCIUM CARBONATE*. [ebook] Oregon, United States. Available at: <https://www.oregon.gov/oha/PH/HealthyEnvironments/DrinkingWater/Monitoring/Documents/health/caco3.pdf> [Accessed 15 June 2020].

meaning consumers will be able to purchase an effective medication for acid refluxes which is not expensive in comparison to alternatives, this includes Zantac and Natron.

Zantac and Natron neutralized the least proportion of the HCl, but produced more than 50cm^3 CO_2, evidently showing a fast but ineffective reaction. This shows incapability as an acid reflux medication, due to Zantac's main aim being to reduce excess acid. As a consumer these commercial antacids would be more expensive and less effective in regards to $CaCO_3$ antacids, thus should not be the first choice for purchasing.

To answer the research question, the most consumer friendly antacid, in regards to both cost and neutralizing effectiveness, is Link.

EVALUATION AND IMPROVEMENTS

Overall, the experiments were significantly connected to the real-life issue, which is very recurrent and global itself. Having two experiments which looked at different perspectives gives the reader and antacid consumers more insight on the effectiveness of the medications. To ensure personal engagement and precision in the experiment, I created all solutions myself, through prior calculations, which would be useful for future lab work. I used Titrisol, a tool for producing solutions efficiently. Conducting 5 trials for each independent variable ensured there was a range of results, providing more reliable data, along with the R^2 value being significantly correlated increasing the reliability in the trends shown in the data from the experiments.

Statistically speaking, the methodology to measure CO_2 production had the largest standard deviation, indicating that the results are very spread and not accurate. Additional factor resulting in the inaccuracies is human error. The time between pouring in the $CaCO_3$ and putting the cap with the syringe on varied throughout all trials. This is something I attempted to improve on gradually, however it was impossible to do this part of the

experiment without human error. To improve this, the increase number of trials and utilization of a lab assistant would reduce thus human error and potentially decrease standard deviation.

If I were to conduct a similar investigation into antacids, the usage of Zantac would be avoided. Throughout the investigation, I felt that there was no comprehensive understanding of this medication which increased complications and reduced my confidence of the prior research along with the data findings.

However, the mistakes and obstacles faced during this process were very beneficial and will definitely assist in future practical work. Moreover, my interest in chemistry and lab work increased, as I familiarized myself with the lab more and enjoyed the overall process.

BIBLIOGRAPHY

Aabakken, L., 2019. *Pepsin – Store Medisinske Leksikon*. [online] Store medisinske leksikon. Available at: <https://sml.snl.no/pepsinogen> [Accessed 9 June 2020]

Beaconhealthsystem.org. 2020. *Gastroesophageal Reflux Disease (GERD) | Beacon Health System*. [online] Available at: <https://www.beaconhealthsystem.org/library/diseases-and-conditions/gastroesophageal-reflux-disease-gerd/> [Accessed 12 June 2020].

Brown, C. and Ford, M., 2014. *Higher Level Chemistry*. 2nd ed. Harlow, United Kingdom: Pearson Education Limited.

Brown, K., 2017. What Happens When Hcl Is Added To NaHCO3.

International Baccalaureate Organization, 2014. Chemistry Data Booklet. 2nd ed. [ebook] p.6. Available at: <https://www.ibchem.com/root_pdf/data_booklet_2016.pdf> [Accessed 13 June 2020].

MacGill, M. and University of Illnois, 2017. Acid Reflux: Causes, Treatment, And Symptoms. [online] Medicalnewstoday.com. Available at: <https://www.medicalnewstoday.com/articles/146619> [Accessed 12 June 2020].

Michigan Health System, 2020. *Calcium Carbonate | Michigan Medicine*. [online] Michigan Medicine. Available at: <https://www.uofmhealth.org/health-library/d00425a1> [Accessed 12 October 2020].

National Center for Biotechnology Information, 2020. Calcium Carbonate. [online] Pubchem. Available at: <https://pubchem.ncbi.nlm.nih.gov/compound/Calcium-carbonate> [Accessed 13 June 2020].

National Center for Biotechnology Information, 2020. Sodium Bicarbonate. [online] Pubchem. Available at: <https://pubchem.ncbi.nlm.nih.gov/compound/Sodium-bicarbonate> [Accessed 13 June 2020].

National Center for Biotechnology Information, 2020. *Ranitidine*. [online] Pubchem.ncbi.nlm.nih.gov. Available at: <https://pubchem.ncbi.nlm.nih.gov/compound/Ranitidine> [Accessed 14 June 2020].

National Library of Medicine, 2020. Electrolytes. [online] Medlineplus. Available at: <https://medlineplus.gov/ency/article/002350.htm> [Accessed 13 June 2020].

Oregon Department of Human Services, 1998. *HEALTH EFFECTS INFORMATION - CALCIUM CARBONATE*. [ebook] Oregon, United States. Available at: <https://www.oregon.gov/oha/PH/HealthyEnvironments/DrinkingWater/Monitoring/Documents/health/caco3.pdf> [Accessed 15 June 2020].

Perrine, S., 2018. When Heartburn Is Linked to Cancer. AARP, [online] Available at: <https://www.aarp.org/health/conditions-treatments/info-2018/heartburn-acid-reflux-cancer-risk.html> [Accessed 13 June 2020].

Salisbury, B. and Terrell, J., 2020. *Antacids*. [ebook] Treasure Island: StatPearls. Available at: <https://www.ncbi.nlm.nih.gov/books/NBK526049/> [Accessed 12 June 2020].

Thiel, A., 2016. *Role Of Hydrochloric Acid In Aiding Digestion*. [online] Integrativepro.com. Available at: <https://www.integrativepro.com/Resources/Integrative-Blog/2016/The-Role-of-Hydrochloric-Acid-in-Aiding-Digestion> [Accessed 9 June 2020].

2016. Concentration Density Finder. Darmstadt, Germany: Merck & Co.