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Investigating the Viability of Hydrogen Production from Sodium Borohydride Using Acetic Acid and Extracts from Spoilt Lemon, Lime and Orange

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Abstract. With the fast depletion of fossil fuel sources for energy production and coupled with their negative impacts on the environment, the continued search for alternative sources that are renewable, sustainable and environmentally friendly has become imperative. This research examined the performance of sodium borohydride for the production of hydrogen gas using 5 ml each of organic acid (acetic acid), spoilt extracts of citrus fruits (lime, lemon and orange) without the use of neither catalyst nor heat source. A three neck flat bottom flask was used in which sodium borohydride was reacted with extracts from the three spoilt fruits and acetic acid with concentrations of 1, 5, 7, 12 and 17.5 M. Volume of hydrogen gas produced were recorded and the results revealed that using 7 M solution of acetic acid and 1.0 gram sodium borohydride generated the highest volume of 2460 ml of hydrogen gas in 63.72 min while the undiluted extracts of spoilt orange, lemon and lime gave 100 ml in 0.68 min, 90 ml in 1.67 min and 60 ml in 0.5 min respectively. For the diluted fruit extracts, lime, orange and lemon at a dilution factor of 2 each, generated hydrogen gas of 80ml in 0.5 min, 70ml in 1.3 min and 70ml in 0.62 min respectively. All the reactions took place at an ambient temperature of 27°C. Being able to conveniently retrieve hydrogen from its combined state when needed would advance the use of hydrogen as a source of energy.

Keywords: sodium borohydride, acetic acid, hydrogen, spoilt citrus extract.

1. Introduction

Given the importance of energy to human existence it has become imperative to find sustainable alternative sources of energy given the ever growing population of the human race and its increased demand for energy [1]. Human existence on earth is possible due to man's ability to access energy and transform it from one form to another to meet his needs; most of the energy accessed by man has been transformed into either electrical energy, heat energy or mechanical energy. Electrical energy is the energy used in powering technology such as mobile phones, air conditioners, electric cars, light bulbs, computers, electric cookers, washing machines and various other types of machinery that require electricity for operation, heat energy is used for cooking our foods, keeping warm in winter, melting and molding of metals, drying substances, sterilization and numerous other activities which require heat, some chemical reactions require heat energy to be initiated and completed [2]. At present crude oil, coal and natural gas are the predominant sources of energy in our everyday lives from electricity generation, transportation (air, land & sea) and domestic cooking unfortunately none of these sources of energy is sustainable nor renewable thus prompting the need for the search for sustainable and renewable sources of energy. The consequence of the combustion of petroleum, coal and natural gas for energy production; contributes to the release of greenhouse gases in the atmosphere, which are not just detrimental to our environment but also to both human and animal life [3]. An alternative source of energy which proves extremely attractive is hydrogen firstly because it is the most abundant chemical substance on the earth, constituting about 75% of all baryonic mass and secondly when combusted releases steam ($2H2 + O2 \rightarrow 2H2O$) hence is environmentally friendly, sustainable and renewable. Thirdly hydrogen has the highest energy per mass of any fuel [4]. Hydrogen has an energy density of 142 MJ/Kg which is three times greater than that of gasoline fuel [5]. Storage of hydrogen in portable forms such that it is easily accessible when needed has been one of the concerns of researchers in the field of energy which include stationary power, portable power and transportation, hydrogen can be stored in three forms, as a gas, liquid or a solid [6]. As a gas hydrogen is stored in high pressure tanks of 691 atmospheres tank pressure, for comparison the environment in which humans live is about one atmosphere depending on altitude and temperature, as a liquid hydrogen is stored at very low temperatures because the boiling point of hydrogen at atmospheric pressure (1 atm) is; -252.8°C and as a solid hydrogen can be adsorbed on the surfaces of solids or absorbed within the solid [7]. To achieve the most cost-effective and safe hydrogen storage method for on-board and off-board hydrogen production and usage, storage as a solid appears most attractive. Most of the electrical energy generated from hydrogen is generated through hydrogen fuel cells; compared to batteries as long as the is a steady source of hydrogen to the fuel cell it continues to generate electricity without ceasing [8] unlike batteries that stop once the chemical reaction producing the electricity stops. Metal hydrides have been found to be a good source for hydrogen absorption hence could be used for hydrogen storage, in addition to being a good store for hydrogen it should be able to easily release the stored hydrogen when needed safely an added advantage would be the characteristic of the metal hydride to be easily replenished back with hydrogen after desorption of the hydrogen absorbed in it [9]. On an examination between hydrogen and the s-block elements of the periodic table (s-block elements are group 1 and group 2 elements of the periodic table alkali metals in group one of the periodic table being strongly electropositive readily accept hydrogen atoms to form metal hydrides which react vigorously with cold water to liberate hydrogen gas, compared to alkaline earth metals in group two of the periodic table the group one metal hydrides react with cold water to liberate one mole of hydrogen gas while the group two metal hydrides react with cold water to liberate two moles of hydrogen gas which makes group two metal hydrides a better choice for hydrogen absorption/desorption than group one metal hydrides[10]. Even though hydrogen has the highest energy per mass of any fuel its density at ambient temperature is considerable low [11] hence resulting in a low energy per unit volume output. Among the group two metal hydrides magnesium hydride appears to be the most favorable considering that it has 7.66 weight percent of hydrogen [12] which gradually decreases down the group; calcium hydride (CaH2) having 4.75 weight percent hydrogen and strontium hydride (SrH2) having 2.25 weight percent hydrogen. Beryllium hydride being the first metal hydride from group two preceding magnesium hydride would have been a much preferred choice being that it has 18.28 weight percent hydrogen, but being that it is extremely toxic makes it environmentally unfriendly due to its toxicity the use of beryllium requires adequate dust control equipment because if inhaled results in berylliosis a life-threatening ailment. Secondly all the elements of groups one and two in the periodic table form hydrides by direct combination with hydrogen except beryllium making its cyclic ability expensive. Thirdly beryllium is a relatively rare element in the universe [10]. Other metals of interest are the metal borohydrides which have a high weight percentage of hydrogen when compared with various hydrogen storage and production compounds with sodium borohydride having 10.6 wt% hydrogen content, lithium borohydride having 18.3 wt% hydrogen content and potassium borohydride having 7.4 wt% hydrogen content[13] the lightweight of the borohydrides is an added advantage; particular interest is taken in sodium borohydride because of its stability in dry air enabling it to be safely handled some draw-backs being the sluggish kinetics of the reaction and high thermodynamics associated with the reactions[14]. Attempts to improve on the slow kinetics and high temperature a composite mixture of sodium borohydride and zinc fluoride with heat not exceeding 100°C was used during the dehydrogenation process [15]. Other metal hydrides which have been investigated for the production and storage of hydrogen are NaBH4, LiBH4, KBH4, LiH, NaH and NaAlH4 one of the metal hydrides which was of interest was sodium borohydride (NaBH4) due to certain properties the compound exhibited such as being non-toxic, non-flammable and low cost when compared with the other metal hydrides making it economical, the research focused on the hydrolysis of sodium borohydride (NaBH4) using bimetallic Co-Ni based complex catalysts[16]. Being able to conveniently retrieve hydrogen from its combined state when needed has limited the effective use of hydrogen has a fuel. Reacting sodium borohydride with acids and various spoilt fruit extracts and observing their performance for fast kinetics at ambient temperature without the use of any external heat source; taking into consideration acids that are cheap and easily accessible without the use of any catalyst would improve the use of hydrogen has a source of energy

1.1 Objectives of the Study

Various concentrations of acetic acid will be reacted with sodium borohydride. Extracts of spoilt lime, lemon and orange will be diluted by various amounts and reacted with sodium borohydride. Volume of hydrogen produced for each concentration / dilution is recorded. The concentration with the best performance in hydrogen production with time is noted

2.0 Materials and Method

2.1 Materials

Sodium borohydride (98% purity; sigma-aldrich), Silica gel; (IND), Glacial acetic acid (100% purity; EMSURE), Citric acid (99.5% purity; BDH), Distilled water (water distiller; W4000, SN M17035), Spoilt lemon, lime and oranges sourced from local market; Sango-Ota, Ogun State, Nigeria.

2.2 Equipment / Apparatus

Analytical Balance (RadwagWagiElektroniczne AS 310/C/2, SN 351204/12), Fume Cupboard (Frontier Junior EFB-4A1, SN 2012-68013), Hot plate magnetic stirrer (Stuart UC152), Thermometer (GHZeal), Stoppers, Stopwatch, Teflon tube, Retort stand, Spatula, Test tube rack. Separating funnel 500 ml, 3 – Neck flat bottom flask, Beakers, Measuring cylinder, Laboratory funnel, Pipette, Burette, & Petri Dish (J-Sil Borosilicate glass)

2.3 Experimental Set-up

The 3-neck flat bottom flask is fitted with an exit for generated hydrogen gas, a burette through which the spoilt fruit extract and acetic acid is charged into the reactor and a thermometer. The reactor is placed on a magnetic stirrer which is switched-on as soon as either acetic acid or spoilt fruit extract is charged into the reactor.

2.4 Procedures

2.4.1 Reaction of Acetic Acid with Sodium Borohydride

NaBH4 (s) + 3CH3COOH (aq) → NaBH (CH3COO)3 (aq) + 3H2 (g)

This gives stoichiometric amounts of

1 mole of NaBH4 (s) is 37.83 g/mole and 3 moles of CH3COOH (aq) is 180.15 g/mole.

For ease of management the amounts were scaled down as shown in table 1

Table 1: Scaled-down amounts of sodium borohydride and acetic acid reactants used

S/N	Reactants	Molar amounts	Stoichiometric amounts	Scaled-down amounts	Scaled-down amounts
1	NaBH4 (s)	37.83 g/mole	37.83 g/mole	$\frac{37.83\ g/mol}{37}$	1.022 g/mole
2	3CH3COOH (aq)	60.05 g/mole	180.15 g/mole	$\frac{180.15\ g/mol}{37}$	4.869 g/mole

2.4.2 Procedure for the Production of Hydrogen from Sodium Borohydride using Acetic acid

0.04 grams of sodium borohydride was added into the reactor after which 5 ml of 1 M solution of acetic acid was charged into the reactor, volume of hydrogen produced was measured and time interval during which it was produced. Another 0.04 g of sodium borohydride was added into the same reaction mixture in the reactor and volume of hydrogen produced measured with time. 0.04 g of sodium borohydride was continuously added to the reaction mixture in the reactor until 1.022 g/mole the stoichiometric amount was added and total volume of hydrogen produced measured with time. The same procedure was repeated for different concentrations of acetic acid; the concentrations chosen were 17.5 M, 12 M, 7 M, 5 M and 1 M concentrations all with a volume of 5 ml.

2.4.3 Obtaining Extracts from Spoilt Citrus Fruits

Spoilt oranges, lime and lemon were sourced from the local market and their juices extracted and filtered using a sieve to ensure no particle is left in the fruit extracts. The spoilt fruit extracts were diluted with water as shown in table 2, reacted with 0.04 g of sodium borohydride and volume of hydrogen produced during each dilution noted and recorded.

2.4.4 Procedure for the Production of Hydrogen from Sodium Borohydride using Spoilt Citrus Extract

0.04 g of sodium borohydride was charged into the reactor after which it was corked airtight, the burette was filled with 5 ml of undiluted spoilt fruit extract. The undiluted spoilt fruit extract was charged into the reactor after which the magnetic stirrer was switched-on; volume of hydrogen produced was noted and recorded. The same procedure was repeated with diluted spoilt fruit extract, the spoilt fruit extract was diluted as shown in table 2 and volume of hydrogen produced during each dilution recorded.

Table 2: Dilution factor with corresponding volume of water used for spoilt citrus fruit extracts

S/N	Volume of undiluted spoilt fruit extract (ml)	Volume of water added (ml)	Dilution Factor
1	5	0	1
2	5	2.5	1.5
3	5	5	2
4	5	7.5	2.5
5	5	10	3
6	5	12.5	3.5
7	5	15	4
8	5	17.5	4.5
9	5	20	5
10	5	22.5	5.5
11	5	25	6

3.0 Results and Discussion

3.1 Results

Table 3: Variation of hydrogen gas generation from the reaction of 1M of 5 ml acetic acid with sodium borohydride at an ambient temperature of 27℃

Number of runs	Cumulative NaBH4(g) used	Cumulative Volume Hydrogen produced (ml)	Time (min)	Cumulative Time (min)
1	0.04	105	0.07	0.07
2	0.08	205	0.1	0.17
3	0.12	290	0.33	0.5
4	0.16	400	0.62	1.12
5	0.20	480	2.75	3.87
6	0.24	560	3.75	7.62
7	0.28	615	4.33	11.95
8	0.32	645	6.73	18.68
TOTAL	**0.32**	**645**		**18.68**

Table 4: Variation of hydrogen gas generation from the reaction of 5M of 5 ml acetic acid with sodium borohydride at an ambient temperature of 27℃

Number of runs	Cumulative NaBH4(g) used	Cumulative Volume Hydrogen produced (ml)	Time (min)	Cumulative Time (min)
1	0.04	100	0.2	0.2
2	0.08	210	0.083	0.28
3	0.12	290	0.22	0.50
4	0.16	400	0.28	0.78
5	0.20	510	0.33	1.11
6	0.24	600	0.25	1.36
7	0.28	655	0.2	1.56
8	0.32	740	0.083	1.65
9	0.36	830	0.2	1.85
10	0.40	900	0.28	2.13
11	0.44	1000	0.18	2.31
12	0.48	1080	0.15	2.46
13	0.52	1180	0.22	2.68
14	0.56	1255	0.2	2.88
15	0.60	1360	0.25	3.13
16	0.64	1430	0.47	3.60
17	0.68	1540	0.55	4.15
18	0.72	1640	0.55	4.70
19	0.76	1720	0.78	5.48
20	0.80	1800	0.97	6.45
21	0.84	1905	1.17	7.62
22	0.88	2005	1.67	9.29
23	0.92	2105	1.95	11.24
24	0.96	2205	2.4	13.64
25	1.00	2300	2.62	16.26
TOTAL	**1.00**	**2300**		**16.26**

Table 5: Variation of hydrogen gas generation from the reaction of 7M of 5 ml acetic acid with sodium borohydride at an ambient temperature of 27℃

Number of runs	Cumulative NaBH4(g) used	Cumulative Volume Hydrogen produced (ml)	Time (min)	Cumulative Time (min)
1	0.04	100	0.28	0.28
2	0.08	210	0.40	0.68
3	0.12	280	0.35	1.03
4	0.16	390	0.63	1.66
5	0.20	480	0.33	1.99
6	0.24	580	0.53	2.52
7	0.28	655	0.58	3.1
8	0.32	765	0.67	3.77
9	0.36	835	0.63	4.4
10	0.40	925	0.78	5.18
11	0.44	1035	0.83	6.01
12	0.48	1125	0.78	6.79
13	0.52	1215	1.83	8.62

14	0.56	1325	2.15	10.77
15	0.60	1415	1.22	11.99
16	0.64	1525	1.83	13.82
17	0.68	1625	3.1	16.92
18	0.72	1735	4.53	21.45
19	0.76	1835	3.73	25.18
20	0.80	1935	4.5	29.68
21	0.84	2035	4.67	34.35
22	0.88	2145	5.83	40.18
23	0.92	2255	7.7	47.88
24	0.96	2350	7.47	55.35
25	1.00	2460	8.37	63.72
TOTAL	**1.00**	**2460**		**63.72**

Table 6: Variation of hydrogen gas generation from the reaction of 12M of 5 ml acetic acid with sodium borohydride at an ambient temperature of 27℃

Number of runs	Cumulative NaBH4(g) Used	Cumulative Volume Hydrogen produced (ml)	Time (min)	Cumulative Time (min)
1	0.04	110	0.40	0.40
2	0.08	205	0.43	0.83
3	0.12	280	0.42	1.25
4	0.16	380	0.53	1.78
5	0.20	450	0.33	2.11
6	0.24	530	0.40	2.51
7	0.28	605	0.38	2.89
8	0.32	705	0.42	3.31
9	0.36	795	0.33	3.64
10	0.40	895	0.47	4.11
11	0.44	995	0.48	4.59
12	0.48	1095	0.53	5.12
13	0.52	1195	0.70	5.82
14	0.56	1295	1.58	7.40
15	0.60	1395	2.13	9.53
16	0.64	1495	3.00	12.53
17	0.68	1595	3.67	16.20
TOTAL	**0.68**	**1595**		**16.20**

Table 7: Variation of hydrogen gas generation from the reaction of 17.5M of 5ml acetic acid with sodium borohydride at an ambient temperature of 27℃

Number of runs	Cumulative NaBH4(g) used	Cumulative Volume Hydrogen produced (ml)	Time (min)	Cumulative Time (min)
1	0.04	110	1.48	1.48
2	0.08	205	1.67	3.15
3	0.12	295	2.47	5.62
4	0.16	395	3.48	9.10
5	0.20	505	4.50	13.60
6	0.24	595	16.67	30.27
7	0.28	705	12.87	43.14

8	0.32	795	19.27	62.41
9	0.36	895	20.85	83.26
10	0.40	995	27.38	110.64
TOTAL	**0.40**	**995**		**110.64**

Table 8: Results for Reaction between Sodium Borohydride and Extract of Spoilt Lime at an ambient temperature of 27℃

Number of Runs	NaBH4 (grams)	Volume of undiluted extract (ml)	Volume of dilution water (ml)	Time per run (min)	Cumulative Time (min)	Volume of Hydrogen per run (ml)	Cumulative Volume of Hydrogen Produced (ml)
1	0.04	5	0	0.5	0.5	60	60
2	0.04	5	2.5	0.77	1.27	70	130
3	0.04	5	5	0.5	1.77	80	210
4	0.04	5	7.5	0.8	2.57	60	270
5	0.04	5	10	0.83	3.4	60	330
6	0.04	5	12.5	0.83	4.23	70	400
7	0.04	5	15	0.83	5.06	70	470
8	0.04	5	17.5	1.08	6.14	60	530
9	0.04	5	20	0.67	6.81	30	560
10	0.04	5	22.5	0.5	7.31	50	610
11	0.04	5	25	0.77	8.08	50	660
TOTAL					**8.08**		**660**

Table 9: Results for Reaction between Sodium Borohydride and Extract of Spoilt Lemon at an ambient temperature of 27℃

Number of Runs	NaBH4 (s) (grams)	Volume of undiluted extract (ml)	Volume of dilution water (ml)	Time per run (min)	Cumulative Time (min)	Volume of Hydrogen per run (ml)	Cumulative Volume of Hydrogen Produced (ml)
1	0.04	5	0	1.67	1.67	90	90
2	0.04	5	2.5	0.5	2.17	50	140
3	0.04	5	5	0.62	2.79	70	210
4	0.04	5	7.5	0.57	3.36	50	260
5	0.04	5	10	0.58	3.94	60	320
6	0.04	5	12.5	0.52	4.46	50	370
7	0.04	5	15	0.5	4.96	50	420
8	0.04	5	17.5	1.82	6.78	55	475
9	0.04	5	20	1.67	8.45	55	530
10	0.04	5	22.5	1.5	9.95	50	580
11	0.04	5	25	2.3	12.25	50	630
TOTAL					**12.25**		**630**

Table 10: Results for Reaction between Sodium Borohydride and Extract of Spoilt Oranges at an ambient temperature of 27℃

Number of Runs	NaBH4 (s) (grams)	Volume of undiluted extract (ml)	Volume of dilution water (ml)	Time per run (min)	Cumulative Time (min)	Volume per run (ml)	Cumulative Volume of Hydrogen Produced (ml)
1	0.04	5	0	0.68	0.68	100	100

2	0.04	5	2.5	0.75	1.43	60	160
3	0.04	5	5	1.3	2.73	70	230
4	0.04	5	7.5	0.63	3.36	60	290
5	0.04	5	10	1.33	4.69	60	350
6	0.04	5	12.5	0.95	5.64	60	410
7	0.04	5	15	1.12	6.76	60	470
8	0.04	5	17.5	1.33	8.09	60	530
9	0.04	5	20	1.42	9.51	60	590
10	0.04	5	22.5	1.52	11.03	60	650
11	0.04	5	25	1.97	13.00	60	710
TOTAL					**13.00**		**710**

3.2 Discussion of Results

3.2.1 Dilution Factors

The spoilt fruit extracts were diluted with water using various dilution factors as shown in table 2 to investigate its hydrogen gas production when reacted with sodium borohydride, does it increase in as dilution increases or does it decrease; is there a particular dilution that is more productive when compared to the other dilution factors. It was observed from table 8, 9, & 10 that dilution factors of 1 & 2 produced the largest volumes of hydrogen gas when compared with other dilution volumes signifying the dilutions which yield optimum performance for hydrogen gas production from the extracts of spoilt lime, lemon & orange. A dilution factor of 2 represents an equal volume of solute mixed with an equal volume of diluent

3.2.2 Acetic acid solutions (Tables 3 to 7)

Tables: 3, 4, 5, 6 & 7 are results for acetic acid solutions of 1 M, 5 M, 7 M, 12 M & 17.5 M respectively reacted with sodium borohydride with the sole objective of investigating its viability for hydrogen production and if viable which of the solutions has the optimum performance for hydrogen production. 1 M solution of acetic acid shown in table 3 produced 645 ml of hydrogen gas on a cumulative addition of 0.32 g of sodium borohydride, on further addition of sodium borohydride molecules no hydrogen gas was produced. 5 M solution yielded a cumulative volume of 2300 ml of hydrogen gas from a cumulative amount of 1.00 g of sodium borohydride, 7 M solution yielded a cumulative volume of 2460 ml of hydrogen gas from a cumulative amount of 1.00 g of sodium borohydride, 12 M solution yielded a cumulative volume of 1595 ml of hydrogen gas from a cumulative amount of 0.68 g of sodium borohydride while 17.5 M solution produced a cumulative volume of 995 ml of hydrogen gas from a cumulative amount of 0.40 g of sodium borohydride shown in tables 4, 5, 6 & 7 respectively. It was observed from tables 3, 4, 5, 6 & 7 that table 5 containing the data for the 7 M solution of acetic acid produced the largest volume of hydrogen gas 2460 ml, this could be attributed to the dilution as compared to table 7 which has 17.5 M solution acetic acid and table 3 which has 1 M solution of acetic acid. 7 M solution is the solution which has the largest effective concentration of hydrogen ions as compared to the actual concentration in solution [17] [18].

3.2.3 Temperature

This research was aimed at producing hydrogen without the use of any neither catalyst nor external heat source making it cost-effective and readily available for on-board usage. Ambient temperature of 27℃ was the laboratory temperature at the time of carrying-out the investigation.

3.2.4 The effect of acetic acid concentration on the volume of hydrogen generated

Acetic acid was reacted with sodium borohydride in various concentrations of 17.5 M, 12 M, 7 M, 5 M and 1 M shown in Figure 1

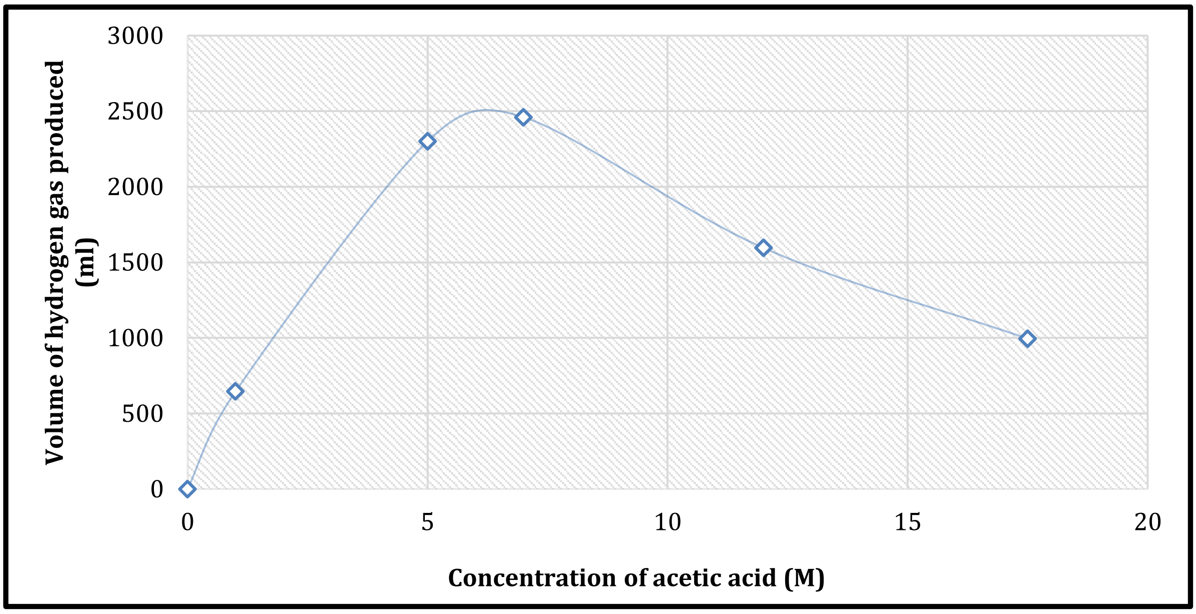

Figure 1: Variation of hydrogen gas produced with the concentration of acetic acid

From figure 1 it was observed that the volume of hydrogen generated increased steadily with the concentration of acetic acid. The graph increased until it got to a maximum at 2500 ml of hydrogen generated at an optimum concentration of 6.3 M and began to decline, hydrogen generation beyond the optimum acetic acid concentration was counterproductive because they all yielded lower volume of hydrogen gas. This may be adduced to the reduced activity of the acid at high concentration; in acidic solutions with high concentrations activity is much lower than the actual concentration because the effective concentration of hydrogen ions is lower than the actual concentration in the solution, as some of the hydrogen ions present in the solution are unable to participate in the reaction [17][18].

3.2.5 The effect of spoilt citrus extracts on hydrogen gas generation from sodium borohydride

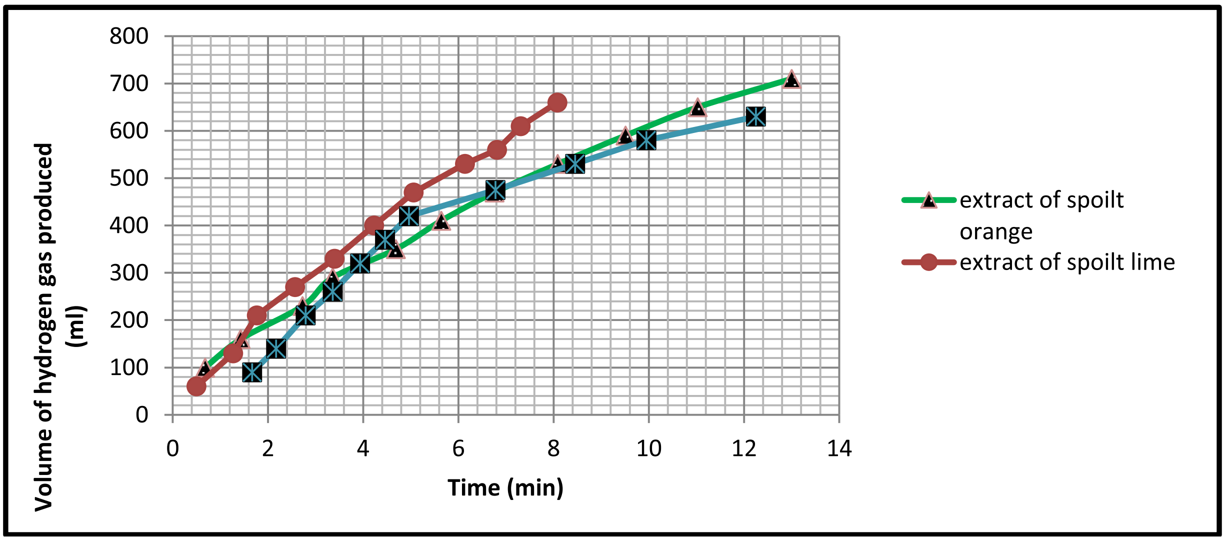

Figure 2: Volume of hydrogen gas produced against time for spoilt lime, lemon & orange extract.

From Figure 2 it was observed that as the spoilt fruit extracts were diluted and reacted with sodium borohydride it continues to generate hydrogen gas. 660 ml in 8.08 min, 630 ml in 12.25 min and 710 ml in 13.00 min for spoilt fruit extracts of lime, lemon and orange respectively. Each point on the graphs represents a new dilution as shown in table 2, it was observed from tables 8, 9 and 10 that dilution factors of 1 and 2 yields better performance for hydrogen gas production compared to the other dilution factors. Cumulatively the spoilt orange extract yields largest volume of hydrogen gas, as the dilution of the spoilt fruit extract increases hydrogen production gradually decreases; this could be attributed to the fact that the active ingredients in the spoilt fruit extracts are gradually being diluted as well as reacting with the sodium borohydride molecules.

3.2.6 Confirmatory Test

To ensure it was hydrogen gas being produced the flame test was carried-out on the gas. Burning flames could be used to identify whether a gas is flammable or oxidizing, hydrogen gas is flammable over a wide range of concentrations in air. For an oxidizing gas such as oxygen, the flame on the splint is allowed to burn for five seconds then extinguished by shaking or blowing out. While the ember is still glowing hot it is introduced into the suspected oxidizing gas, if it where oxygen for example; the glowing ember re-ignites to produce a sustained flame[19]. The gas from the reactor was tubed to a burner; a match stick was lit and placed over the burner after which it was opened releasing the trapped gas. The gas ignited with a pop sound and was sustained for a few seconds before extinguishing; confirming the presence of hydrogen gas.

4. Conclusion

A summary of the findings of this research enables these conclusions to be drawn. Sodium borohydride was successfully reacted with acetic acid and hydrogen gas was produced. A solution of 7 M of acetic acid produced the best performance for hydrogen gas production when reacted with 1.00 gram of sodium borohydride yielding 2460 ml of hydrogen gas in 63.72 min. The undiluted extracts of spoilt orange, lemon and lime gave 100 ml in 0.68 min, 90 ml in 1.67 min and 60 ml in 0.5 min respectively. For the diluted fruit extracts, lime, orange and lemon at a dilution factor of 2 each, generated hydrogen gas of 80 ml in 0.5 min, 70 ml in 1.3 min and 70 ml in 0.62 min respectively. Reactions between sodium borohydride, acetic acid, and spoilt fruit extracts of lime, lemon and orange were safely carried out at an ambient temperature of 27°C. The reaction of these selected organic acids (acetic and citric acids) proceeded without the use of catalyst.

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