Chemistry Higher Level

Internal Assessment

Investigation of hypochlorite content in solutions made by home-made disinfectant machine

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Contents

1 Introduction

Chlorine bleach is a common cleaning product mainly used to remove colour or dyes from fabric. However, it can also kill bacteria and disinfect household surfaces. In the COVID-19 pandemic, many consumers started regularly disinfecting appliances and surfaces at home using dilute bleach. Some companies began selling small appliances that electrolyse dilute salt-water to make a solution of sodium hypochlorite, which is the main active ingredient in chlorine bleach.
One example is the "CleanJug" manufactured by the electronics company Momax.

Figure 1: The CleanJug Homemade Disinfectant Machine, from Momax website

These machines became rather popular and many families purchased one. They often costed up to 700 HKD, or 90 USD, which shocked me as it just seems like a normal electrolysis cell. I became skeptical of the claims of the product, which is that the electrolysed water is suitable for use in disinfection, and can kill 99% of germs. (Clean-Jug Homemade Disinfectant Machine, n.d.)

1.1 Aim

In this investigation, I will find out about the disinfecting ability of electrolysed dilute salt water made using a commercial device (via determining hypochlorite content), and make recommendations on how to disinfect surfaces using it.

2 Theoretical background and hypothesis

The main active ingredient in both commercial bleach and home-made disinfectant is *sodium hypochlorite*, or NaClO. It destroys micro-organisms by harming degrading phospholipids in cell membranes, deactivating enzymes, and interfering with cell metabolism. (Estrela et al., 2002)
Industrially, sodium hypochlorite solution is produced via the *Hooker Process*, in which chlorine is passed through cold sodium hydroxide solution.

$$2\,\mathrm{NaOH\,(aq)} + \mathrm{Cl_2(g)} \longrightarrow \mathrm{NaClO\,(aq)} + \mathrm{NaCl\,(aq)} + \mathrm{H_2O\,(l)}$$

On a small scale, it can be made by oxidation of chloride during electrolysis of salt water.

$$\begin{aligned}
&\mathrm{Cl^-(aq)} + \mathrm{H_2O\,(l)} \longrightarrow \mathrm{ClO^-(aq)} + 2\,\mathrm{H^+(aq)} + 2\,\mathrm{e^-} && \mathrm{E^\circ} = -1.49\,\mathrm{V} \\
&2\,\mathrm{H_2O\,(l)} + 2\,\mathrm{e^-} \longrightarrow \mathrm{H_2(g)} + 2\,\mathrm{OH^-(aq)} && \mathrm{E^\circ} = 0\,\mathrm{V} \\
\text{Overall:}\quad &\mathrm{Cl^-(aq)} + \mathrm{H_2O\,(l)} \longrightarrow \mathrm{ClO^-(aq)} + \mathrm{H_2(g)} && \mathrm{E^\circ} = -1.49\,\mathrm{V}
\end{aligned}$$

However, the electrolysis can yield side products. Chloride and hypochlorite can also be oxidised into other ions or gases. These products do not have the same disinfection effect. (Harvey, 2020)

$$\begin{aligned}
2\,Cl^-(aq) &\longrightarrow Cl_2(g) + 2\,e^- && E^\circ = -1.40\,V \\
ClO^-(aq) + H_2O\,(l) &\longrightarrow ClO_2{}^-(aq) + 2\,H^+(aq) + 2\,e^- && E^\circ = -1.64\,V \\
ClO_2{}^-(aq) &\longrightarrow ClO_2(g) + e^- && E^\circ = -1.19\,V \\
ClO_2(g) + H_2O\,(l) &\longrightarrow ClO_3{}^-(aq) + 2\,H^+(aq) + e^- && E^\circ = -1.18\,V \\
ClO_3{}^-(aq) + H_2O\,(l) &\longrightarrow ClO_4{}^-(aq) + 2\,H^+(aq) + 2\,e^- && E^\circ = -1.20\,V
\end{aligned}$$

Although more hypochlorite will be produced as time goes on, more of it could be further oxidized. This mean that it is impractical to simply calculate hypochlorite content of electrolysed salt-water using electrochemical principles, and it must be measured by experiment.

$$E = E^o - \frac{RT}{nF} \ln \frac{[\text{oxidised form}]}{[\text{reduced form}]}$$

As more hypochlorite is produced, according to the Nernst equation above, its production becomes less favourable, while its further oxidation into chlorite and other ions becomes more favourable. At some point, the rates of hypochlorite depletion and production are equal.
Therefore, my hypothesis is that there should be an *optimum time* for electrolysis that yields the largest hypochlorite concentration.

3 Methodology

3.1 Determination of disinfecting ability

As hypochlorite is the active ingredient in disinfectant, disinfecting ability is proportional to its concentration.
Hypochlorite content can be quantitatively decided by redox titration. As it is unstable in solution, it must first be used up to make a more stable compound. In this case, it acts as an oxidizing agent to oxidize iodide into iodine.

$$\begin{aligned}
ClO^-(aq) + 2\,H^+(aq) + 2\,e^- &\longrightarrow Cl^-(aq) + H_2O\,(l) \\
2\,I^-(aq) &\longrightarrow I_2(aq) + 2\,e^- \\
\text{Overall:}\ ClO^-(aq) + 2\,I^-(aq) + 2\,H^+(aq) &\longrightarrow I_2(aq) + Cl^-(aq) + H_2O\,(l)
\end{aligned}$$

The elemental iodine dissolves in water due to it combining with leftover iodide to form the more soluble triiodide ion.

$$I^-(aq) + I_2(aq) \rightleftharpoons I_3{}^-(aq)$$

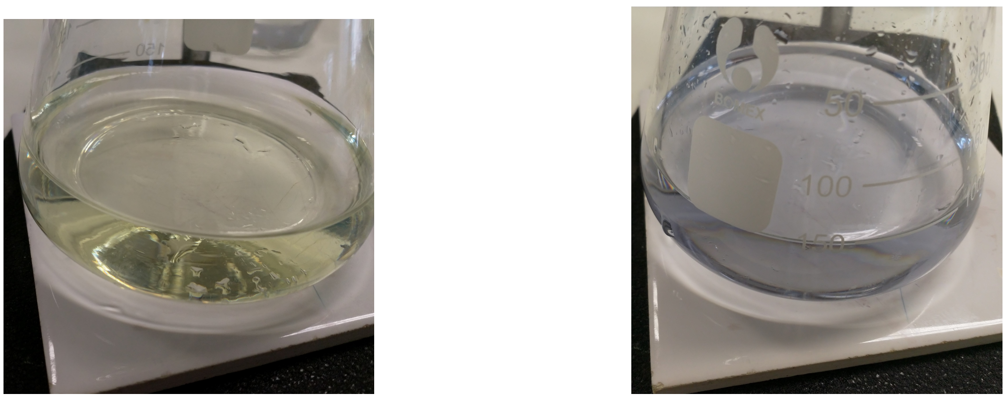
Therefore, a large excess of iodide should be added to the hypochlorite.

3.2 Titration of iodine

The iodine content can then be determined by titration with sodium thiosulphate.

$$I_2(aq) + 2\,S_2O_3{}^{2-}(aq) \longrightarrow 2\,I^-(aq) + S_4O_6{}^{2-}(aq)$$

As iodine solution is yellow, and the final solution is colourless, the end-point is not obvious. Therefore, starch solution should be added, forming a blue-black starch-triiodide complex and making the end-point more obvious. However, the complex does not dissociate easily, especially when it is more concentrated. This leads to potential overestimation of the volume of sodium thiosulphate required, and thus the concentration of iodine. Therefore, to make sure the complex dissociates, the starch must be added *near the end of the titration*, when the solution is pale yellow.



(a) The point at which starch has to be added

(b) After addition of starch solution

Figure 2: Before and after addition of starch

3.3 Parameters of electrolysis

To discover the capabilities of the machine for household use, the manufacturer's instructions should be followed. On the website, it recommends:

- 2g of salt
- Water filled up to the "Max" line of the machine
- Salt-water electrolysed for 10 minutes
- Using provided power adapter attached to mains supply, with voltage of 12V and power of 26W

The manufacturer claims that 10 minutes of electroysis can produce disinfectant suitable for a "deep clean" of bathroom surfaces and clothes. (Clean-Jug Homemade Disinfectant Machine, n.d.)
By measurement, the capacity of the machine was found to be 330mL. This volume of water will be used for every trial.
If all chloride is converted to hypochlorite, the resulting NaClO concentration will be 0.772%.

3.4 Standard for comparison

As a standard for disinfecting ability, I chose the guidelines for home disinfection by the Centre for Disease Control and Prevention (or CDC) in the US. For disinfection of household surfaces, they recommend mixing 5.25% to 8.25% sodium hypochlorite bleach with water, in a ratio of either 5 tablespoons bleach per gallon, or 4 teaspoons bleach per quart. This results in 0.1025% to 0.172% sodium hypochlorite solution. This solution needs to be in contact with the surface for at least 1 minute. (Cleaning And Disinfecting Your Home, 2020)

3.5 Variables

- ***Controlled variables:***

Volume of water The volume is fixed at the capacity of the machine, 330mL, to keep initial concentration in trials constant

Voltage and current adapter used Voltage affects the favourability of different redox reactions, while current affects the rate of formation of ions. As mentioned above, V=12V while $I = P/V = 2.167W$

Concentration of iodide While simply excess for formation of triiodide is enough, the concentration should be kept constant for convenience. While iodide solution would normally need to be standardized, there is no need as long as there is excess

Concentration of thiosulphate This must be kept constant and precise as it is the titrant. The volume of water and mass of solid $Na_2S_2O_3$ must be the same in every trial.

Form of sodium thiosulphate solid used Solid anhydrous $Na_2S_3O_3$ can absorb water to form hydrates. This would require solutions prepared from it to be standardized. Therefore, I will use $Na_2S_2O_3 \cdot 5\,H_2O$. Since the pentahydrate cannot accomodate more water, it will not absorb moisture and can be treated as standard.

Form of salt used Solid, reagent-grade sodium chloride was used for all trials

Titration setup and procedure A white tile should always be present for ease of colour comparison, and the flask has to be swirled to ensure uniform colour.

- ***Independent variable:*** Time of electrolysis

- ***Dependent variable:*** Volume of sodium thiosulphate used in titration

4 Experimental procedure

4.1 Preparation of 0.05M potassium iodide solution

1. 2.08g of potassium iodide was weighed
2. It was dissolved in a 250mL beaker with distilled water
3. The solution was added to a 250mL volumetric flask using a funnel
4. The beaker was washed, with the washings added to the flask
5. The solution was topped up to the flask marking using a Pasteur pipette

4.2 Preparation of 0.005M sodium thiosulphate solution

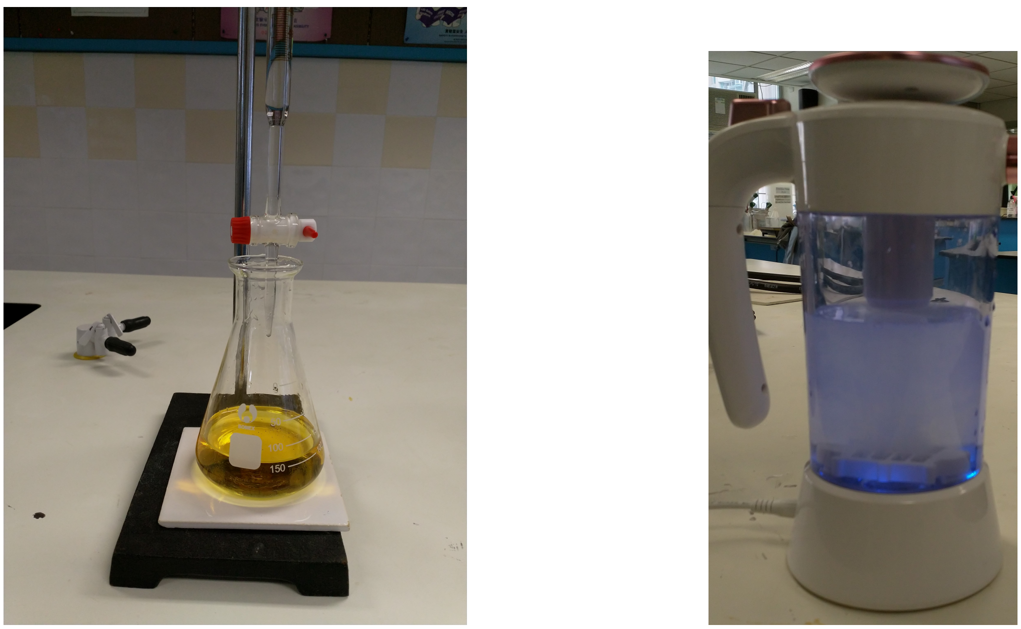
1. 3.10g of sodium thiosulphate pentahydrate was weighed
2. It was dissolved in a 250mL beaker using distilled water
3. The solution was added to a 250mL volumetric flask using a funnel
4. The beaker was washed, with the washings added to the flask
5. The solution was topped up to the flask marking using a Pasteur pipette (This makes 0.05M $Na_2S_2O_3$ solution)
6. 25mL of the solution was transferred to another 250mL volumetric flask using a pipette
7. The solution was topped up to the flask marking using a Pasteur pipette (This dilutes the solution to 0.005M)

4.3 Preparation of starch indicator

1. 100mL of water was brought to a gentle boil in a beaker
2. The heat was shut off, and approx. 1g of starch was added
3. The solution is stirred with a glass rod until all starch was dissolved

4.4 Electrolysis of salt-water and analysis of hypochlorite content

1. The machine was filled with 330mL of water and the desired amount of salt was added
2. The machine was sealed and shaken well to dissolve the salt
3. The power supply was switched on for the desired duration
4. Four 25mL samples were extracted and transferred to a 250mL conical flask
5. 25mL of 0.05M potassium iodide solution was added to each flask
6. Each sample was titrated with 0.005M sodium thiosulphate
7. During the *last stage* of titration, when the solution is pale yellow, 1 or 2 drops of 1% starch solution are added. The end-point is reached when the solution turns from blue-black to clear.



(a) Titration setup with iodine solution

(b) Electrolysis in progress

Figure 3: Experimental setups

4.5 Precautions

The electrolysed water should be added to the iodide solution *as soon as possible* to prevent decomposition or further oxidation of hypochlorite.

Both the iodide and thiosulphate solutions must be prepared *on the same day as the experiment.* They can become cloudy, as iodide can be oxidised into iodine or iodate (Wong, 1980), while thiosulphate can undergo disproportionation to form sulfur. (D'Huart et al., 2018)

4.6 Repeated trials

Each sample of electrolysed water is analysed via 1 trial titration (to determine approximate position of end-point) and 3 proper ones, which the actual results will be derived from. Each electrolysis duration will be tested 3 times. This means at least *12 titrations in total* for each electrolysis duration tested.

5 Results

Only mean titrant volumes of each trial will be shown below. Full titration results are shown in the appendix.

5.1 Electrolysis according to manufacturer's instructions

Parameters: 2g of salt, 10 min of electrolysis

Titrations	Trial	1	2	3
Volume	9.8	9.7	9.5	9

Sample 1

Titrations	Trial	1	2	3
Volume	9.2	8.6	8.9	8.9

Sample 2

Titrations	Trial	1	2	3
Volume	9.3	9.2	9.3	8.8

Sample 3

Trials	1	2	3
Mean $\Delta V(\mathrm{Na_2S_2O_3})(mL)$	9.4	8.8	9.1

$$\text{Average volume of thiosulphate solution} = \frac{9.4 + 8.8 + 9.1}{3} = 9.1 \text{ mL}$$

Average number of moles of thiosulphate $= 0.005 \times 9.1 \times 10^{-3} = 4.55 \times 10^{-5}$ mol
Average number of moles of hypochlorite = Average number of moles of iodine $= 2.28 \times 10^{-5}$ mol

$$\text{Concentration of NaClO} = \frac{2.28 \times 10^{-5}\text{mol}}{0.025\text{L}} = \frac{9.12 \times 10^{-4}\text{mol}}{\text{L}} = \frac{0.0679\text{g NaClO}}{\text{L solution}} = 6.79 \times 10^{-3}\%$$

This concentration is about *15 times less* than the one recommended by the CDC.
Although less concentrated solutions can still kill bacteria given a longer contact time with surfaces, this concentration is still too small. The disinfectant is likely to dry, or the hypochlorite will be used up before successful disinfection.
Therefore, *more salt must be used.* 5g of salt can lead to a more concentrated solution while still being reasonably economical for households. Therefore, further trials to find optimum electrolysis time will be done with *5g of salt.*

5.2 Electrolysis using larger amount of salt

Titration data

Electrolysis duration	ΔV(Sample 1) (mL)	ΔV(Sample 2) (mL)	ΔV(Sample 3) (mL)
3 min	11.6	10.2	12.1
5 min	18.2	17.9	19.4
7 min	24.1	21.5	22.9
9 min	22.5	23.3	23.4
10 min	25.5	24.9	26.7
12 min	25.9	29.3	28.5
15 min	31	27.6	30.5
17 min	33.3	31.8	31.5
20 min	30.8	32.8	32.2

Final concentration of NaClO

The method of calculation is identical as the one used in section 5.1. An additional example is shown below:

Parameters: 5g of salt, 10 min of electrolysis
Average volume of thiosulphate solution = 25.7 mL
Average number of moles of thiosulphate = 1.285×10^{-4} mol
Average number of moles of hypochlorite = Average number of moles of iodine = 6.425×10^{-5} mol
Concentration of NaClO = $\dfrac{6.425 \times 10^{-5}\text{mol}}{0.025\text{L}} = 1.91 \times 10^{-2}\%$
Percentage of CDC-recommended concentration = 18.75%

Electrolysis duration	[NaClO] ($10^{-2}\%$)	Percentage of CDC-recommended concentration
3 min	0.84	8.21
5 min	1.38	13.44
7 min	1.70	16.58
9 min	1.72	16.75
10 min	1.91	18.67
12 min	2.08	20.26
15 min	2.21	21.57
17 min	2.40	23.39
20 min	2.38	23.19

5.3 Error calculation

Titration is a very precise method, and the uncertainties in measurement will be insignificant compared to that from systematic error or variations in experimental technique.
Experimentally possible values of the concentration lie anywhere between the maximum and minimum values obtained (from an individual titration instead of the average result). Concentrations from these results should be taken as the upper bound and lower bound respectively.

Example of error calculation
Parameters: 5g of salt, 10 min of electrolysis

Minimum volume of $Na_2S_3O_3$(aq) = 24.7 mL
Maximum volume of $Na_2S_2O_3$(aq) = 27 mL
Minimum concentration of NaClO = $1.84 \times 10^{-2}\%$
Maximum concentration of NaClO = $2.01 \times 10^{-2}\%$

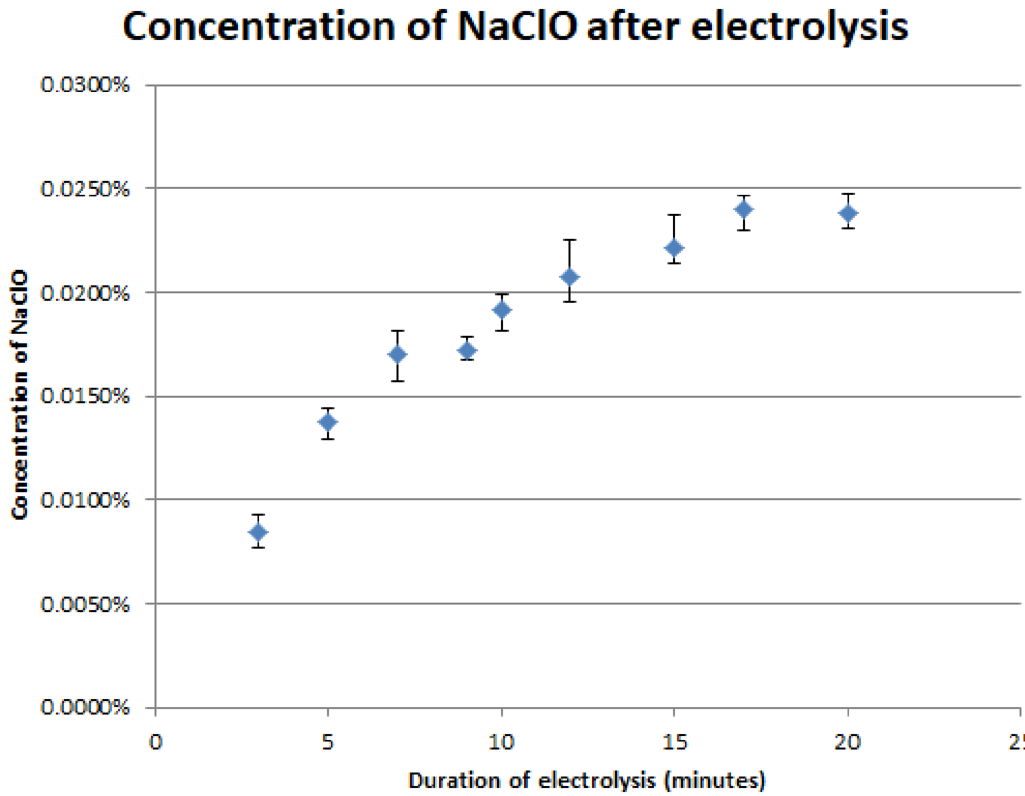
All errors are shown as error bars in the graph below.

5.4 Summary of results

NaClO concentration of disinfectant made according to manufacturer's instructions:
$6.79 \times 10^{-3}\%$, 6.6% of CDC-recommended concentration

NaClO concentration of disinfectant made with 5g of salt:

Time (min)	3	5	7	9	10	12	15	17	20
Concentration ($10^{-2}\%$)	0.84	1.38	1.70	1.72	1.91	2.08	2.21	2.40	2.38
Percentage of CDC-recommended concentration	8.21	13.44	16.58	16.75	18.67	20.26	21.57	23.39	23.19



6 Analysis of results

If the disinfectant is made by fully following the instructions given by the manufacturer, the hypochlorite concentration will be too low for effective disinfection. If 5g of salt is used, it will take around 17 minutes for the hypochlorite concentration to reach its maximum of approximately 0.024%, when its rate of depletion matches its rate of production.

6.1 Sources of systematic error

Conversion to chlorine During the process of sample collection before titration, the hypochlorite can be converted into chlorine gas, which can escape from the water.

$$ClO^-(aq) + Cl^-(aq) + H_2O(l) \rightleftharpoons Cl_2(g) + 2\,OH^-(aq)$$

This is prevented in normal bleach as there is significant alkali present. However, this is not true for home-made disinfectant. Therefore, the result will not accurately reflect hypochlorite content after application to surfaces.
During electrolysis, if the container is not sealed tight enough, the chlorine can easily escape. This means the equilibrium will continue to tend to the right, causing significant loss of ClO^-.

Reduction of other ions Other ions produced during electrolysis such as chlorite, chlorate, and perchlorate can also be reduced by the iodide ions. Therefore, the titration results may over-estimate hypochlorite content.

Inaccurate end-point Even if the starch solution is added when the solution is pale yellow, the dissociation of starch-triiodide complex is still unfavourable. This means the hypochlorite content can still be over-estimated.

6.2 Cost comparison

Another way to look at the results is to see if producing disinfectant by electrolysis is cheaper than just diluting supermarket bleach. If it is, we can also find how much disinfectant has to be made before enough money is saved to equal the value of the machine. All prices below are in Hong Kong Dollar.

Material costs

Cheapest price of salt in supermarket = \$3.31 /100 g
Cheapest price of 2.4% bleach in supermarket = \$28.1 /L
Cost of machine from official website = \$698
As for household cost of water and electricity, the rates are different depending on consumption level. For simplicity, I will assume the household has enough consumption to have to pay the maximum rates.
Cost of water = \$9.05 per m^3 ("HK WSD: Residential water tariffs", n.d.)
Cost of electricity = \$1.605 /kWh ("HK Electric: Residential tariffs", n.d.)

Cost of 1 portion of home-made disinfectant

Cost of water $= 330 \times \frac{9.05}{10^6} = \$2.99 \times 10^{-3}$
Cost of salt $= 5 \times \frac{3.31}{100} = \$0.1655$
Total electrical energy used $= 26W \times 17min \times 60 = 26.5kJ = 7.37 \times 10^{-3}kWh$
Cost of electricity $= 1.605 \times 7.37 \times 10^{-3} = \$0.0118$
Total cost = \$0.18

Cost of diluting bleach to make equivalent disinfectant

To make 0.024% disinfectant from 2.4% bleach, a 1:99 dilution is needed.
Cost of water $= 330 \times 0.99 \times \frac{9.05}{10^6} = \$2.96 \times 10^{-3}$
Cost of bleach $= 330 \times 0.01 \times \frac{28.1}{10^3} = \$0.0927$
Total cost = \$0.0957

Even if the cost of the machine (which is about 600 HKD) is not accounted for, the homemade disinfectant is still at least 80% more expensive. If a household uses it, they will simply lose more and more money during successive uses.
Therefore, I suggest that the only reason one should buy this machine is if the process of diluting bleach poses a serious danger (either from the strong alkali or release of chlorine).

6.3 Practicality for household use

Even the maximum hypochlorite concentration right after electrolysis is below the one recommended by the CDC for 1-minute disinfection. The concentration may even decrease during use as the hypochlorite is converted to chlorine.
Therefore, consumers should let the disinfectant stay on the surface for a longer time before scrubbing, or even apply it multiple times.

Making and using homemade disinfectant is also inconvenient, and takes a significant amount of time as the electrolysis lasts over 10 minutes.

However, there can be one advantage to this method.
Commercial bleach is a sodium hypochlorite solution mixed with sodium hydroxide. (May, 2011) As aforementioned, the basicity keeps the hypochlorite stable so it is not converted into chlorine. This makes even diluted bleach slightly corrosive. The process of dilution can also be risky as the user's skin can be burned by the undiluted bleach.

Therefore, despite the time and cost, making dilute disinfectant at home may be a safer solution for consumers with skin that is sensitive to strong alkali, or for households with children.

6.4 Potential improvements in methodology

Other tests of disinfecting ability Indirectly measuring disinfection ability by hypochlorite content is not that rigorous or accurate. It also does not reflect the situation during the actual process of disinfection. Instead, a direct measurement using colonies of bacteria or other micro-organisms may be a better test.

Use of other forms of salt Laboratory technical-grade sodium chloride was used in the experiment, but household salt contains many impurities such as other minerals, or iodide salts. So, this may not be an accurate reflection of household use

Testing other machines Other disinfectant machines may use different forms of electrolytic cell. The Momax machine used here places its electrodes flat at the bottom. Other machines may have different methods, such as using metal strips/rods as electrodes similar to laboratory setups. These may be more efficient at producing hypochlorite. Therefore, it may be worth also testing them.

7 Conclusion

Home-made disinfectant machines are effective at making *dilute disinfectant*, as they can produce hypochlorite ions via electrolysis.
However, this method of making disinfectant has many flaws:

- The amount of salt recommended by manufacturer is not enough
- The time required to make effective disinfectant is long, at above 10 minutes
- The cost of salt-water electrolysis is more costly than just using diluted bleach, and the machine itself is also expensive

However, not only is the cost of salt and electricity make this method more expensive than just diluting bleach. This might only be a better option if bleach poses a danger to the household.
Of course, this is only a rough, preliminary investigation. Other more in-depth and rigorous experiments may be needed to truly determine whether these machines are worth it.

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A Raw titration data

For all data, overshoot titrations are indicated in red. These are not accounted in calculations, and an additional titration will be done.

2g of salt, 10 min of electrolysis

Titrations	Trial	1	2	3
Volume	9.8	9.7	9.5	9

Sample 1

Titrations	Trial	1	2	3
Volume	9.2	8.6	8.9	8.9

Sample 2

Titrations	Trial	1	2	3
Volume	9.3	9.2	9.3	8.8

Sample 3

5g of salt, 3 min of electrolysis

Titrations	Trial	1	2	3
Volume	12.2	11.9	12.3	12.1

Sample 1

Titrations	Trial	1	2	3
Volume	10.1	10.3	10.1	10.2

Sample 2

Titrations	Trial	1	2	3	4
Volume	11.7	11.6	11.7	11.5	11.6

Sample 3

5g of salt, 5 min of electrolysis

Titrations	Trial	1	2	3
Volume	18.1	17.7	18	18

Sample 1

Titrations	Trial	1	2	3
Volume	18.1	18	18.1	17.6

Sample 2

Titrations	Trial	1	2	3
Volume	19.3	19.7	19.3	19.2

Sample 3

5g of salt, 7 min of electrolysis

Titrations	Trial	1	2	3
Volume	24.5	24.4	24.2	23.8

Sample 1

Titrations	Trial	1	2	3	4
Volume	22.1	21.7	21.3	21.5	21.6

Sample 2

Titrations	Trial	1	2	3
Volume	22.8	23	22.8	22.9

Sample 3

5g of salt, 9 min of electrolysis

Titrations	Trial	1	2	3
Volume	23.1	22.6	22.1	22.8

Sample 1

Titrations	Trial	1	2	3
Volume	23.3	23	23.5	23.4

Sample 2

Titrations	Trial	1	2	3
Volume	23.5	23.6	23.5	23.2

Sample 3

5g of salt, 10 min of electrolysis

Titrations	Trial	1	2	3
Volume	25.9	25.5	25.7	25.3

Sample 1

Titrations	Trial	1	2	3
Volume	24.7	25.1	24.7	24.8

Sample 2

Titrations	Trial	1	2	3
Volume	27	26.6	26.8	26.6

Sample 3

5g of salt, 12 min of electrolysis

Titrations	Trial	1	2	3
Volume	25.8	26	26	25.6

Sample 1

Titrations	Trial	1	2	3
Volume	29.6	29.5	29.2	29.2

Sample 2

Titrations	Trial	1	2	3
Volume	28.9	28.5	28.7	28.4

Sample 3

5g of salt, 15 min of electrolysis

Titrations	Trial	1	2	3
Volume	30.9	31.1	30.8	31

Sample 1

Titrations	Trial	1	2	3
Volume	27.6	27.6	27.5	27.6

Sample 2

Titrations	Trial	1	2	3
Volume	30.7	30.6	30.6	30.3

Sample 3

5g of salt, 17 min of electrolysis

Titrations	Trial	1	2	3	4
Volume	33.3	33.5	33.4	33.4	33.1

Sample 1

Titrations	Trial	1	2	3	4
Volume	31.9	31.8	31.6	31.9	31.7

Sample 2

Titrations	Trial	1	2	3
Volume	31.8	31.7	31.6	31.3

Sample 3

5g of salt, 20 min of electrolysis

Titrations	Trial	1	2	3
Volume	31	30.9	30.6	30.8

Sample 1

Titrations	Trial	1	2	3
Volume	33	32.9	32.7	32.7

Sample 2

Titrations	Trial	1	2	3
Volume	32.4	32.2	32.3	32.1

Sample 3