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Chemistry Lab Report 4 – Kinetics

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- the thesis submitted has not been previously submitted to this university or any other.
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List of Abbreviations

DI	–	Deionised
IM	–	Insensitive Munitions
OME	–	Ordnance, Munitions & Explosives

List of Equations

Equation 1 – Concentration of a solution

$$n = M \times V$$

n = Number of moles (mol)
M = Concentration of solution (M)
V = Volume (L)

Equation 2 – Molar mass of a substance

$$n = m / MM$$

MM = Molar mass of a substance (g/mol)
n = Number of moles (mol)
m = Mass of a substance (g)

Equation 3 – Rate of reaction

$$\text{Rate of reaction} = \Delta H_2 / \Delta t$$

Rate of reaction (mL/s)
 ΔH_2 = Volume of H₂ gas (mL)
 Δt = Time taken (s)

1. Introduction

1.1. Aim of experiment

Determine the rate of reaction as well as the effects of concentration, surface area and temperature on the rate of reaction.

1.2. Hypothesis

Each of the following parameters will affect the rate of reaction when Mg is dissolved in HCl producing hydrogen (H_2) gas: temperature, concentration and surface area. All the following parameters should increase the rate of reaction when the value is increased.

1.3. Experiment variables

Independent variable:

Surface area, temperature, concentration of HCl (experiment section dependant)

Dependant variable:

Volume of H_2 gas in the gas cylinder.

Control variables:

- Gas cylinder
- Concentration of HCl (except test serial 1)
- Temperature (except test serial 2)
- Surface area of Mg (except test serial 3)
- Mass of Mg sample
- Volume of HCl

2. Results

2.1. Results

Mg		2.0M HCl	
Mass (g)	Moles (mol)	Volume (mL)	Moles (mol)
0.0765	0.0031	5	0.010
0.0765	0.0031	10	0.020
0.0765	0.0031	15	0.030
0.0765	0.0031	20	0.040

Each of the samples made up 20mL of solution:

0.5M HCl

$$n = M \times V$$

$$n = 0.5 \text{ (M)} \times 20 \times (10^{-3}) \text{ (L)}$$

$$n = 0.010 \text{ (mol)}$$

Equation 1

1.0M HCl

$$n = M \times V$$

$$n = 1.0 \text{ (M)} \times 20 \times (10^{-3}) \text{ (L)}$$

$$n = 0.020 \text{ (mol)}$$

Equation 1

1.5M HCl

$$n = M \times V$$

$$n = 1.5 \text{ (M)} \times 20 \times (10^{-3}) \text{ (L)}$$

$$n = 0.030 \text{ (mol)}$$

Equation 1

2.0M HCl

$$n = M \times V$$

$$n = 2.0 \text{ (M)} \times 20 \times (10^{-3}) \text{ (L)}$$

$$n = 0.040 \text{ (mol)}$$

Equation 1

Mg

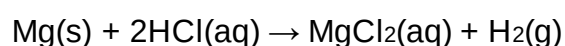
$$n = m / MM$$

$$n = 0.0765 \text{ (g)} / 24.3 \text{ (g/mol)}$$

$$n = 0.0031 \text{ (mol)}$$

Equation 2

Balanced chemical equation for Mg and HCl



2.1.1. Effect of concentration of HCl on H₂ production rate

1.1		1.2		1.3		1.4	
0.5 M HCl		1.0 M HCl		1.5 M HCl		2.0 M HCl	
time (s)	V H ₂ (mL)	time (s)	V H ₂ (mL)	time (s)	V H ₂ (mL)	time (s)	V H ₂ (mL)
0	0	0	0	0	0	0	0
20	3	10	10	10	25	10	42
40	6	20	20	20	45	20	57
60	9	30	28	30	57	30	65
80	12	40	35	40	63	40	70
100	15	50	41	50	67	50	74
120	17.5	60	43	60	70	60	76
140	20	70	53	70	73	70	76
160	22	80	60	80	74	80	76
180	25	90	63	90	75	-	-
200	27	100	66	100	75	-	-
220	29.5	110	69	110	75	-	-
240	31.5	120	70	-	-	-	-
260	34	130	71	-	-	-	-
280	36	140	72	-	-	-	-
300	38	150	72.5	-	-	-	-
320	40	160	73	-	-	-	-
340	42	170	74	-	-	-	-
360	43.5	180	74	-	-	-	-
380	45	190	75	-	-	-	-
400	47	200	75	-	-	-	-
420	48.5	210	75	-	-	-	-
440	50	220	75	-	-	-	-
460	51	227.7	75	-	-	-	-
480	52.5	-	-	-	-	-	-
500	54	-	-	-	-	-	-
520	55	-	-	-	-	-	-
540	56	-	-	-	-	-	-
560	57	-	-	-	-	-	-
580	58	-	-	-	-	-	-
600	59	-	-	-	-	-	-
620	60	-	-	-	-	-	-
640	60.5	-	-	-	-	-	-
660	61.5	-	-	-	-	-	-
680	62	-	-	-	-	-	-
700	63	-	-	-	-	-	-
720	63.5	-	-	-	-	-	-
740	64	-	-	-	-	-	-

760	64.5	-	-	-	-	-	-
780	65	-	-	-	-	-	-
800	66	-	-	-	-	-	-
Average rate of reaction for each molar concentration (mL/s)							
0.15		0.72		1.2		1.3	
Instantaneous rate of reaction for each molar concentration (mL/s)							
0.15		1.0		2.5		4.2	

Table 1 - Test serial 1 - Effects of HCl concentration on H₂ rate of production

0.5M HCl

Rate of reaction = 66 (mL) / 60(s)

Equation 3

Rate of reaction = 0.083 (mL/s)

Instantaneous RoR = 9 (mL) / 60 (s)

Instantaneous RoR = 0.15 (mL/s)

1.0M HCl

Rate of reaction = 43 (mL) / 60 (s)

Equation 3

Rate of reaction = 0.72 (mL/s)

Instantaneous RoR = 10 (mL) / 10(s)

Instantaneous RoR = 1.0 (mL/s)

1.5M HCl

Rate of reaction = 75 (mL) / 60 (s)

Equation 3

Rate of reaction = 1.16 (mL/s) = 1.2 (mL/s)

Instantaneous RoR = 25 (mL) / 10 (s)

Instantaneous RoR = 2.5 (mL/s)

2.0M HCl

Rate of reaction = 76 (mL) / 60(s)

Equation 3

Rate of reaction = 1.27 (mL/s) = 1.3 (mL/s)

Instantaneous RoR = 42 (mL) / 10 (s)

Instantaneous RoR = 4.2 (mL/s)

T₁ = 60 (s)

2.1.2. Effect of temperature on H₂ production rate

Starting temp (oC) = 23.8		Starting temp (oC) = 41.2		Starting temp (oC) = 53.8	
Time (s)	V H2 (mL)	Time (s)	V H2 (mL)	Time (s)	V H2 (mL)
0	0	0	0	0	0
10	10	10	18	10	17
20	20	20	31	20	29
30	28	30	41	30	38
40	35	40	50	40	44
50	41	50	57	50	47
60	43	60	61	60	50
70	53	70	63	70	51
80	60	80	64.5	80	53
90	63	90	65	90	54
100	66	100	66	100	55
110	69	110	67	110	56
120	70	120	68	120	57
130	71	130	68.5	130	57.5
140	72	140	70	140	58
150	72.5	150	70	150	59
160	73	160	71	160	61
170	74	170	71.5	170	62
180	74	180	71.5	180	63.5
190	75	190	71.5	190	65
200	75	200	71.5	200	66
210	75	210	71.5	210	67
220	75	220	71.5	220	68.5
230	75	230	71.5	230	69.5
240	75	240	71.5	240	70.5
250	75	250	71.5	250	71.5
260	75	260	71.5	260	72.5
270	75	270	71.5	270	73.5
280	75	280	71.5	280	74
290	75	290	71.5	290	74.5
300	75	300	71.5	300	75
Average rate of reaction for each molar concentration (mL/s)					
0.25		0.42		0.40	
Instantaneous rate of reaction for each molar concentration (mL/s)					
1.7		1.8		1	

Table 2 - Test serial 2 - Effects of temperature on H₂ rate of production

53.8°C

Rate of reaction = 50 (mL) / 60(s)

Equation 3

Rate of reaction = 0.83 (mL/s)

Instantaneous RoR = 17 (mL) / 10 (s)

Instantaneous RoR = 1.7 (mL/s)

41.2°C

Rate of reaction = 61 (mL) / 60 (s)

Equation 3

Rate of reaction = 1.0 mL/s

Instantaneous RoR = 18 (mL) / 10 (s)

Instantaneous RoR = 1.8 (mL/s)

23.8°C

Rate of reaction = 43 (mL) / 60 (s)

Equation 3

Rate of reaction = 0.72 (mL/s)

Instantaneous RoR = 10 (mL) / 10 (s)

Instantaneous RoR = 1.0 (mL/s)

 $T_1 = 60(s)$ **2.1.3. Effect of surface area on H₂ production rate**

T = 24.6°C	
3.1	3.2
Time (s)	V H₂ (mL)
0	0
10	???
20	8
30	15
40	22
50	27
60	31
70	35
80	39
90	43
100	46
110	49
120	52.5
130	54.5
140	57
150	58.5
160	60
170	61.5
180	62.5
190	64

200	64.5
210	65
220	65.5
230	66
240	66
250	66.5
260	66.5

Table 3 - Test serial 3 - Effects of surface area on H₂ rate of production

Mg mass = 0.073 (g)

Rate of reaction = 31 (mL) / 60(s)

Equation 3

Rate of reaction = 0.52 (mL/s)

Instantaneous RoR = 8.0 * (mL) / 10 (s)

Instantaneous RoR = 0.80 (mL/s)

*Gas syringe not fully reset before test conducted, starting point shifted.

Mg shaving moles = m x MM

Equation 2

n = 0.073 (g) / 24.3 (g/mol)

n = 0.0030 (mol)

T₁ = 60(s)

3. Discussion

3.1. Significance of results

3.1.1. Serial 1 - Effect of concentration of HCl on H₂ production rate

During test serial 1, the trend observed was in parallel with the hypothesis, see table 1. As the concentration of the HCl increased, the rate of H₂ production and therefore rate of reaction increased. This is due to the increase in availability of the reactant within the same volume increasing the frequency that the molecules of HCl are in contact with the Mg.

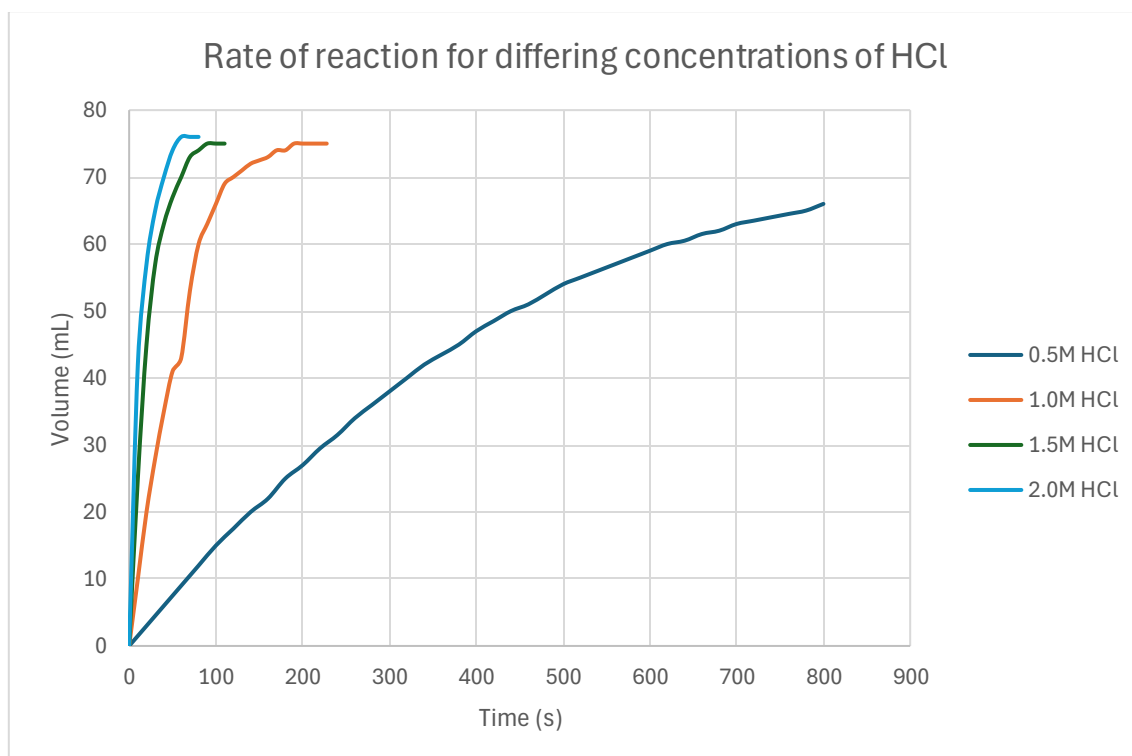


Figure 1 - Effects of concentration of HCl on rate of reaction

Figure 1 below shows the rate of reaction for each of the concentrations through the volume of H₂ produced against the time taken. The gradient of the slope represents the rate of the reaction. The volume of H₂ is reduced due to a hairline crack in the apparatus which caused a slight leak and therefore a loss of H₂, this was replaced after this result.

3.1.2. Serial 2 - Effect of temperature on H₂ production rate

During test serial 2, the trend observed was mostly also in parallel with the hypothesis. An error in the experiment where the Mg strip remained stuck to the glass wall of the test tube was apparent in serial 2.3. This caused the 53.8°C result to have a much shallower curve than expected as well as a reduced initial gradient displaying a lower instantaneous rate of reaction.

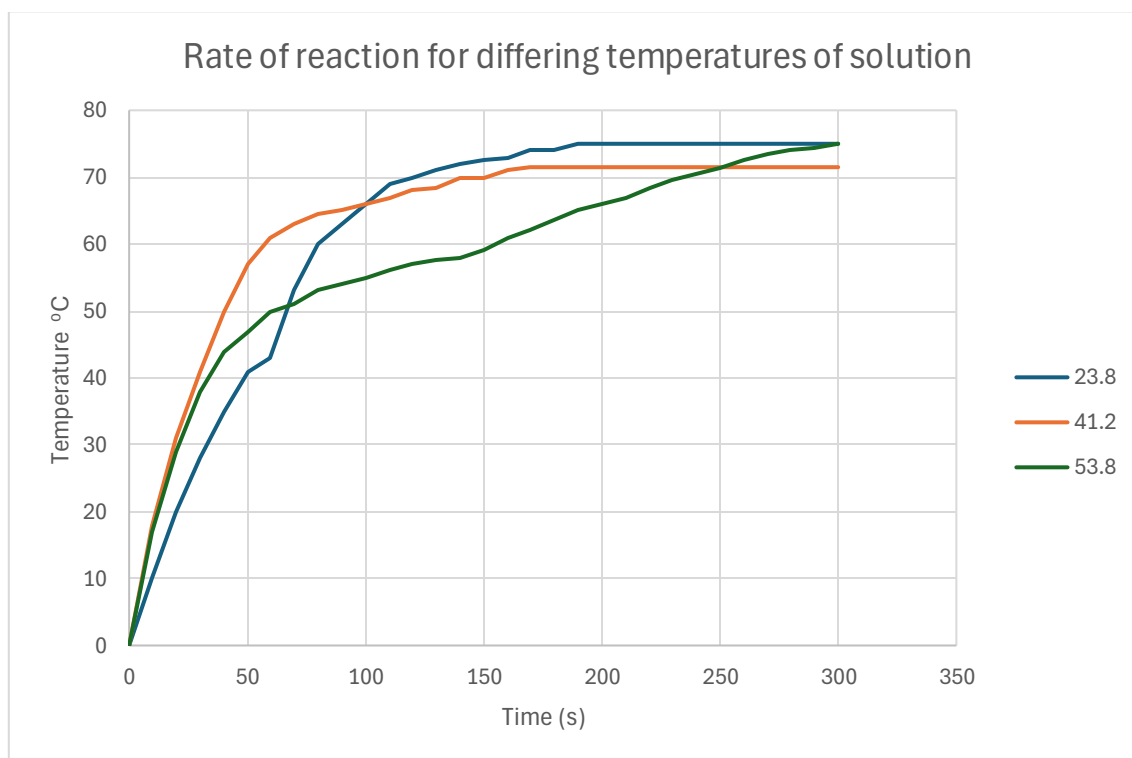


Figure 2 - Effects of temperature of HCl on rate of reaction

Figure 2 shows that the time taken for the higher temperature sample to completely react was shorter than the room temperature sample.

3.1.3. Serial 3 - Effect of surface area on H₂ production rate

During test serial 3, the trend observed was in parallel with the hypothesis. The increase in surface area significantly increased the rate of reaction. This is due to the increase in contact between the Mg and the HCl. This in turn increases the likelihood of collisions within the substance and therefore an increase to the number of molecules reacting at the same time, increasing the rate of reaction.

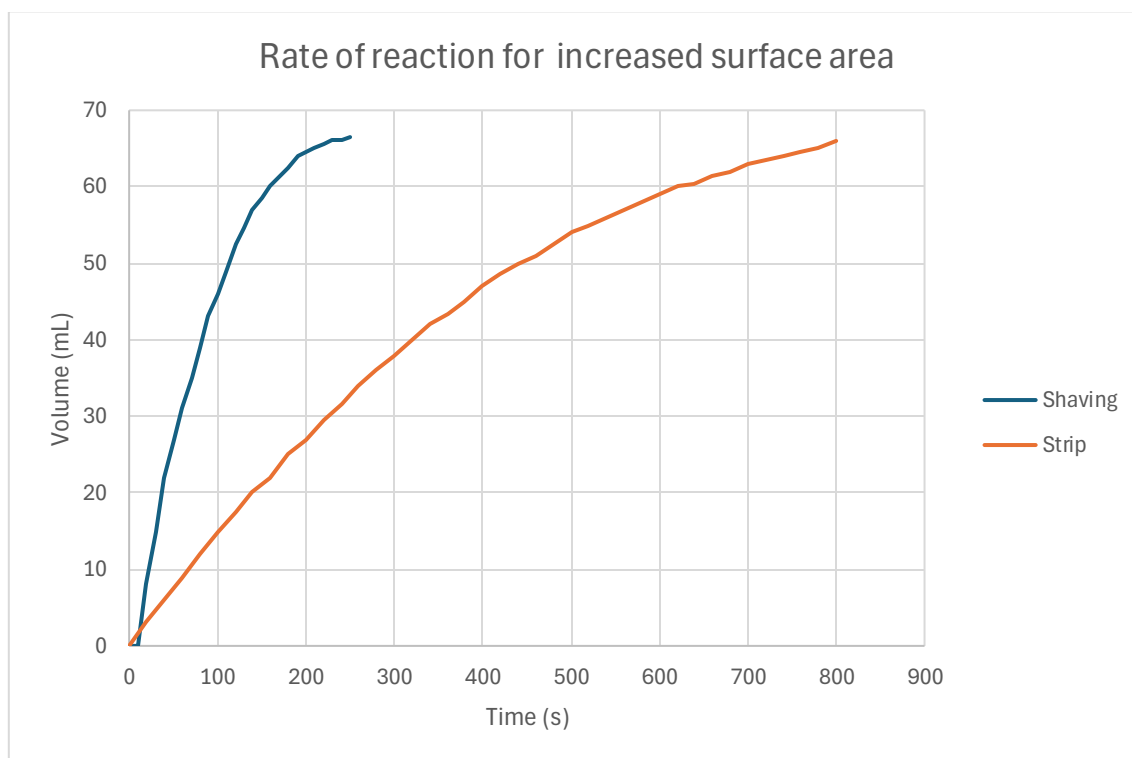


Figure 3 - Effects of surface area of HCl on rate of reaction

3.2. Relevance to OME

3.2.1. Kinetics of explosives

One of the main applications for the rate of reaction within OME is through the design of propellants. Whilst designing propellants, you must consider the mass, surface area and environmental temperature for the munition. An increase in the rate of reaction for propellant will increase the rate of burn, typically producing more gas, more pressure in the barrel and therefore a typical increase in muzzle velocity.

An example of propellant grain design is in a journal entry exploring the design of cylindrical propellant grains and the calculations behind it [1].

Understanding the pressure induced by the propellant burn in a cartridge is important as barrels will be rated to a specific engineering pressure. This pressure includes a factor of safety however it is important to ensure that the propellant design stays within the confines of the specifications.

4. Conclusions

Overall, the hypothesis was proven correct with exception of the error in testing on serial 2. Within this serial, the strip adhered to the side of the test tube causing a reduction in surface area and material to react. This in turn affected the results in favour of 2.2.

For future experimentation, an investigation on the impact of pressure could be explored as an increase in pressure should increase the rate of reaction due to an increase in availability of reactants.

5. References

- [1] C. A. Oshoku, O. O. Babayomi and O. T. Olawole, Analytical Prediction for Grain Burn Time and Burning Area Kinematics in a Solid Rocket Combustion Chamber, vol. 1, Intechopen, 2019.

6. Appendices

6.1. Annex A – Methodology

Lab tools and supplies:

- Long test tube with arm
- Gas syringe*
- Rubber bung and delivery tube to fit the test tube
- Two large beakers for the water bath and reaction mixture
- Pipette and pipette filler
- Two clamp stands
- Test tube holder
- Thermometer
- Ring stand, Bunsen burner, clay triangle
- Stopwatch

Chemicals:

- Magnesium ribbon cut into 4 cm length and weighed
- Magnesium shavings (same mass as ribbon)
- Hydrochloric acid (2.0 M and 1.0 M)
- Deionised (DI) water

6.1.1. Procedure to measure effect of concentration

1. Prepare FOUR 20.0 mL solutions of HCl with the following concentrations: 2.0 M (stock), 1.5 M, 1.0 M and 0.5 M. Use the pipette to measure appropriate volumes of the 2.0 M HCl solution and DI water.
2. Pour the HCl solution with the lowest concentration into the test tube with arm.
3. When ready, add a 4 cm strip of magnesium ribbon to the test tube, quickly put the bung back, and start the stopwatch.
4. For 1 M HCl use the Mg ribbon from the premeasured vial. This set of data will be needed for Part 3.
5. Record the volume of hydrogen gas given off at suitable intervals (e.g. 10 seconds). Continue timing until no more gas is given off.
6. After the reaction is completed, discard the reaction mixture in the waste beaker.
7. Measure the temperature of 1.0 M HCl. It will be needed for Part 2.
8. Repeat the same experiment for three other concentrations of HCl.

9. Plot the graph (V_{H_2} vs t) showing the change in volume of H_2 gas over time for each concentration of HCl.
10. For each concentration of HCl determine the:
11. Average rate of reaction (between $t = 0$ s and $t = t_1$; use the same t_1 for all concentrations)
12. Instantaneous rate of reaction at $t = 0$.

6.1.2. Procedure to measure effect of temperature

13. Effect of temperature on the speed of H_2 gas evolution
14. Set up a water bath. Pour water into the large beaker and heat it over the Bunsen burner till the temperature of water increases by approximately 10 degC when compared to the initial temperature of 1 M HCl measured in the previous part.
15. Pipette 20 mL of 1.0 M stock solution into three test tubes.
16. Place the first test tube with 1.0 M HCl in the water bath and wait until the temperature of the acid reaches the temperature of the water in the water bath.
17. Quickly transfer the warm HCl into the tube with the arm, put 4 cm piece of magnesium ribbon, put the bung back, and start the stopwatch.
18. Continue timing until no more gas is given off.
19. After the reaction is completed, discard the reaction mixture in the waste beaker.
20. Repeat the same experiment for two more temperatures (ideally 10 degC apart).
21. On the separate graph paper provided, plot the graph (V_{H_2} vs t) showing the change in volume of H_2 gas over time for each temperature.
22. For each concentration of HCl determine the:
23. 1 Average rate of reaction (between $t = 0$ s and $t = t_1$; use the same t_1 for all temperatures)
24. Instantaneous rate of reaction at $t = 0$.

6.1.3. Procedure to measure effect of surface area

25. Use the pipette to transfer 20 mL of 1 M HCl at room temperature into the test tube with arm.
26. Quickly add the Mg turnings into the test tube, put the bung back, and start the stopwatch.
27. Continue timing until no more gas is given off.
28. After the reaction is completed, discard the reaction mixture in the waste beaker.
- 29.
30. Plot the graph (V_{H_2} vs t) showing the change in volume of H_2 gas over time for each temperature. Determine the:
 31. 1. Average rate of reaction (between $t = 0$ s and $t = t_1$; **use the same t_1 for both Mg samples**).
 32. Instantaneous rate of reaction at $t = 0$.

6.2. Annex B – Results of experiments

Sheet unavailable.