TKP4105/TKP4110
Hydrogen peroxide decomposition by Baker's yeast
Report

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Summary

In this experiment, the enzyme catalysed reaction of hydrogen peroxide decomposition was investigated. The parameter that was altered in order to investigate the enzymatic acticvity was the concentration of yeast. It was found that the initial rate of decomposition increased with increasing concentration of yeast, following the linear approximation for a volume of 30 mL: $r_{\mathrm{H_2O_2}}(g_{yeast}) = 5 \cdot 10^{-4} \cdot g_{yeast} - 4 \cdot 10^{-6}$.

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1 Introduction

This experiment was conducted as a part of TKP4110 *Chemical reaction technique*, at NTNU in the autumn of 2012. The main goal was to investigate the kinetic properties of Baker's yeast in the process of decomposition of hydrogen peroxide to water and oxygen. This was done by measuring the volume of oxygen produced, which is directly related to the speed at which the hydrogen peroxide was decomposed. The variety of enzymes expressed in yeast makes this a suitable microfactory. In the experiment, the yeast consentration was altered in order to investigate its effect on the initial decomposition rate of H_2O_2. From the experimental data, the initial reaction rates of the decomposition were calculated.

2 Theory

2.1 Decomposition process

Yeast is a eukaryote singlecellular microorganism. It has got a rich variety of enzymes, in order to get nutrition as well as to protect itself. Yeast is a lot less complicated than other eukaryotes, but all the more interesting because it has a lot of similar enzymes as its fellow and more complex eukaryotes. For instance the enzyme, catalase, that catalyse the reaction in which hydrogen peroxide is converted to water and oxygen.

$$2H_2O_2 \rightarrow 2H_2O + O_2 \tag{2.1}$$

The reason why the reaction is catalyzed by catalase is that the structure of the enzyme is made to match with the molecular structure of H_2O_2. The active sites induce the breaking of chemical bonds, and promote the making of new ones. Enzymes lower the activation energy of chemical reactions by promoting a different reaction mechanism, and this is the reason for the increase in the initial reaction rates. These enzymes can not be consumed or altered in the reaction, which is the definition of a catalyst. [3]

The initial reaction rate of this reaction will be the objective of this experiment, with respect to the consentration of yeast. There will be other factors to consider, conducting an experiment with living cells, for instance the effect of change in temperature, the concentraion of H_2O_2, pH of the mixture or other enzymes and reactions also occuring in the same batch. These effects are not to be investigated during this experiment.

The yeast is a living organism, so its activity will vary depending on a number of different factors. Therfore it is necessary to check the catalytic activity of the yeast that will be used. This test is explained in Section 3.2.

2.2 Data analysis

Because this experiment was run as if in a batch reactor, we're only interested in the initial reaction rate, because there is no easy way of measuring the H_2O_2-concentration. The data gathered is then converted and plotted, to find the initial reaction rate as a function of the concentraion of yeast. This is possible, due to the fact that the yeast concentration is constant for each series.

There are two different ways to estimate the initial reaction rate. The first is by estimating the tangent to the curve of the first measuring point. Secondly one can estimate the slope from a straight line through the 3-4 first measuring points. The last approach is more widely used, and also what is to be used for the calculations in this experiment.

2.3 Statistical analysis

In order to estimate the standard errors in the slope and the intersection of the initial reaction rate curves as a function of yeast consentration, statistical analysis is used. The method used will be the method of least squares. This is usually done with computers directly from the plots of the measurements. It is based on calculating the distance between the actual data point, and the estimated function. This distance is denoted d_i:

$$d_i = y_i - a \cdot x_i - b \tag{2.2}$$

where y_i is the actual data point, and $a \cdot x_i - b$ is the calculated value from the linear approximation. Furthermore one can calculte the standard error in the y-values, s_y, using the following equation:

$$s_y = \sqrt{\frac{\sum_{i=1}^{n}(d_i^2)}{n-2}} \tag{2.3}$$

where d_i^2 is used to ensure all the values are positive. This is the basic thought behind the method of least squares. The error in the slope of the linear estimate,

s_a, is given by:

$$s_a = s_y \cdot \sqrt{\frac{n}{n \cdot \sum_{i=1}^{n}(x_i^2) - (\sum_{i=1}^{n} x_i)^2}} \tag{2.4}$$

At last the error in the intersection of the linear estimate with the y-axis, s_b, can be calculated from the following equation:

$$s_b = s_y \cdot \sqrt{\frac{\sum_{i=1}^{n}(x_i^2)}{n \cdot \sum_{i=1}^{n}(x_i^2) - (\sum_{i=1}^{n} x_i)^2}} \tag{2.5}$$

3 Method

The experiment was conducted as described in the document *Hydrogen peroxide decomposition by Baker's yeast*[1].

3.1 Apparatus

The reaction was run in a 50 mL round bottom flask. In order to measure the volume of gas developed during the reaction, a frictionless syringe was used, a glass syringe with a frictionless piston. It was connected to the reaction flask via a tube, just as the reaction was initiated.

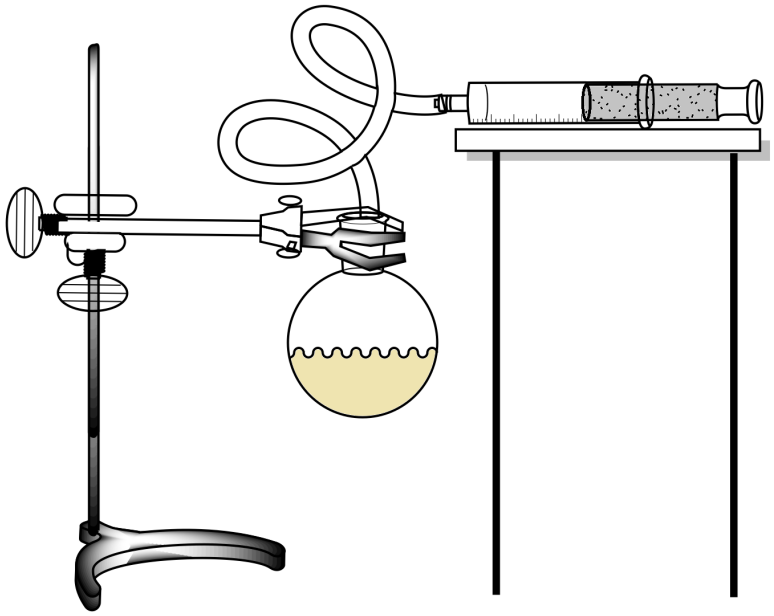

Figure 3.1: Drawing of the experiment setup.

3.2 Preliminary test

A 250 mL sample of yeast suspension was produced in a volumetric flask. 3.0108 grams of dry yeast was used, which amounts to 0.010432 g yeast/mL suspension. The yeast suspension was shaken untill the yeast was homogenously distributed. In order to get an idea about the activity of the yeast, a preliminary test of the

enzyme activity of the yeast was conducted. The time the reaction needed to produce a gas volume of 10 mL, was expected to be ranging from 80 to 120 seconds.

8 mL of yeast suspension was added to the reaction flask, along with 18 mL of water. As 4 mL of 3 wt.% H_2O_2-solution was added, the stopwatch was started and the system sealed. The time it took the syringe to measure a gas volume of 10 mL was observed.

3.3 Experiment 1: Rate dependence on yeast consentration

The experiment was run almost identically to the preliminary test, using a constant volume of 4 mL of 3 wt% H_2O_2 for each of the series. The total volume of the reaction mix was kept at a constant 30 mL. The same yeast suspension made for the preliminary test was used. The concentration of yeast for the different series, was varied as shown in Table 3.1.

Table 3.1: List of how the different yeast concentrations were varied for the reaction mixtures. The volume of H_2O_2 is constant for all the series, however it's been included in the table to emphasise the total volume of the reaction mixture.

Series no.	Yeast suspension, [mL]	3 wt.% Hydrogen peroxide solution, [mL]	Water, [mL]
1	1.0	4.0	25.0
2	2.0	4.0	24.0
3	3.0	4.0	23.0
4	4.0	4.0	22.0
5	5.0	4.0	21.0
6	6.0	4.0	20.0
7	7.0	4.0	19.0

4 Results

The complete set of measurements are found in Appendix E.

4.1 Preliminary test

For the preliminary test it took 28.15 seconds for the reaction to produce 10 mL of O_2-gas. This was a bit too fast, so all the volumes of yeast suspension were halved. This was done in order to get more accurate measurements.

4.2 Rate of decomposition

The initial rate of decomposition of H_2O_2 as a function of the weight of yeast was found using a linear approximation from Figure 4.1. The data for the plot is shown in Appendix D. The initial decomposition rate for a 30 mL solution was found to be:

$$r_{H_2O_2}(g_{yeast}) = 5 \cdot 10^{-4} \cdot g_{yeast} - 4 \cdot 10^{-6} \tag{4.1}$$

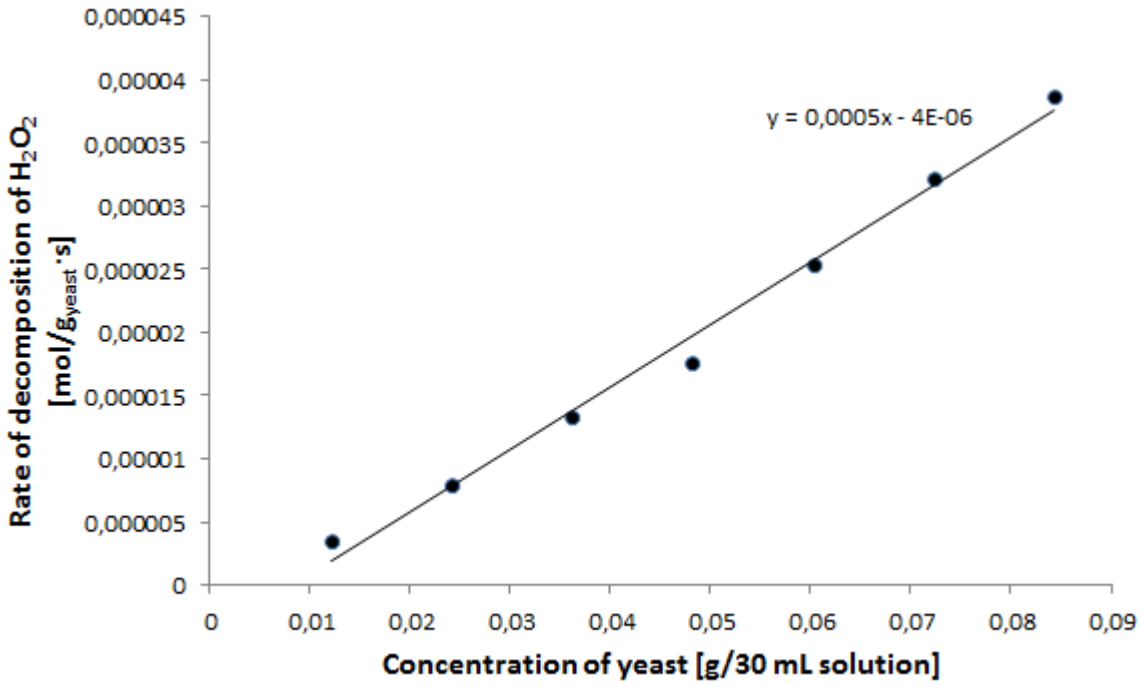

Figure 4.1: All the initial reaction rates plotted as a function of the weight of yeast in the reaction mixture. A linear approximation to the curve has been added.

4.3 Statistical analysis

A statistical analysis was preformed on the measurements using the formulaes under Section 2.3. This gave the following errors for the inital reaction rate, s_y, slope, s_a and intersection with the y-axis, s_b:

$$s_y = 9.9211 \cdot 10^{-6} \qquad [\text{mol } H_2O_2/\text{s}]$$

$$s_a = 1.5568 \cdot 10^{-4} \qquad \left[\frac{\text{mol } H_2O_2/\text{s}}{g_{yeast}}\right]$$

$$s_b = 8.3849 \cdot 10^{-6} \qquad [\text{mol } H_2O_2/\text{s}]$$

5 Discussion

The preliminary test indicated that the enzymatic activity of the yeast that was used, was higher than expected. A consequence of this was that the concentration of yeast had to be reduced in order to get proper measurements.

During the measurements of volume of O_2 gas, a slight delay was noticed. The plots of the individual measurement series also suggest a slight delay, because all the trend lines intersect the y-axis at a considerable negative volume. This indicates that the the entire plot is shifted due to the reaction delay. It is possible that the delay was caused by either lack of stirring or diffusion in and out of the cells. It was also noticed that for low concentrations of yeast, the plots of volume against time were approximatly linear, whilst for higher concentrations, these plots vere slightly curved.

From Figure 4.1 it is clear that the initial reaction rate of H_2O_2 decomposition increases with incresing amount of yeast. This is due to the increasing amount of active sites available to decompose hydrogen peroxide. This result was as expected. The trend line has a slightly negative intersection with the y-axis. This is clearly wrong, since this indicates that in abscense of catalase, hydrogen peroxide would be formed. The estimated error in the intersection is larger than the negative intersection value, which indicates that the plot is within what is reasonable.

5.1 Sources of error

There are several possible sources of error in this experiment. First of all there will allways be a human factor to consider, and this will affect the measurements. However if a certain consistancy is present, all the measurements will be affected in the same way, and relative to each other, the error would be quite small.

A few assumptions have been made, for instance that oxygen behaves as an ideal gas and that the syringe is frictionless. Furthermore there could have been leakage

from the system, corrupting the results. Also the connecting of the syringe to the reaction flask affected the volume, and made the syringe jump a tiny amount. During the experiment, as the initial reaction rate increased the size of the syringe was changed. This may have led to a difference in accuracy of the measurements.

6 Conclusion

A higher concentration of yeast gave a higher initial reaction rate. This is due to a higher number of active sites available. The relationship between the concentration of yeast and the initial reaction rate was found to be approximately linear, following the linear approximation for a 30 mL solution: $r_{\mathrm{H_2O_2}}(g_{yeast}) = 5 \cdot 10^{-4} \cdot g_{yeast} - 4 \cdot 10^{-6}$. It was also observed how efficient the yeast was in decomposing of the hydrogen peroxide. This experiment gave a good insight into how great some enzyme activities are, even when using living cells.

Trondheim, October 15, 2012

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References

[1] Felleslab; *Hydrogen peroxide decomposition by Baker's yeast - Kinetic studies of a biocatalyst in action!*, exercise description.

[2] Sigma-Aldrich; *MSDS Hydrogen peroxide 3 wt. %*, http://www.sigmaaldrich.com/MSDS/MSDS/DisplayMSDSPage.do?country=NO&language=no&productNumber=323381&brand=SIAL&PageToGoToURL=http%253A%252F%252Fwww.sigmaaldrich.com%252FMSDS%252FMSDS%252FPleaseWaitMSDSPage.do%253Flanguage%253D%2526country%253D%2526brand%253D%2526productNumber%253D323381%2526PageToGoToURL%253D%252Fsafety-center.html.

[3] *Elements of Chemical Reaction Engineering 4th Edition*; H. Scott Fogler, Pearson Education International, Massachusetts USA, 2010.

A Example calculations

A.1 Calculations on volume of gas

The following assumptions have been made for this calculation:

- Room temperature in reaction flask
- No biproducts of the decomposition
- Oxygen as an ideal gas
- Amount of O_2 absorbed in the water of the mixture is negligible.

The overall reaction is:

$$2H_2O_2 \rightarrow 2H_2O + O_2 \tag{A.1}$$

4 mL of a 3 wt.% solution of hydrogen peroxide is used. This gives a total weight of H_2O_2 in the reaction mix:

$$m_{H_2O_2} = 4 \cdot 10^{-3}\text{kg} \cdot 0.03 = \underline{0.12 \text{ gram}} \tag{A.2}$$

This molecular weight of H_2O_2 is 34.015 g/mol, so this gives the total number of moles of H_2O_2:

$$n_{H_2O_2} = \frac{m_{H_2O_2}}{Mm_{H_2O_2}} = \frac{0.12 \text{ gram}}{34.015 \text{ g/mol}} = \underline{3.528 \cdot 10^{-3} \text{ mol}} \tag{A.3}$$

From the stoichiometry of the reaction, the total number of moles of oxygen gas is obtained:

$$n_{O_2} = \frac{1}{2} \cdot n_{H_2O_2} = \underline{1.764 \cdot 10^{-3} \text{ mol}} \tag{A.4}$$

The mass of O_2 can be obtained by:

$$m_{O_2} = Mm_{O_2} \cdot n_{O_2} = 32 \text{ g/mol} \cdot 1.764 \cdot 10^{-3} \text{ mol} = \underline{0.0564 \text{ grams}} \tag{A.5}$$

The total theoretical volume of O_2 is found by using the density of O_2, $\rho_{O_2} = 1.309 \cdot 10^{-3}$ g/m^3.

$$V_{O_2} = \frac{0.0564}{1.309 \cdot 10^3 \text{ g/m}^3} = 4.309 \cdot 10^{-5}\text{m}^3 = \underline{\underline{43.09 \text{ mL}}} \tag{A.6}$$

A.2 Calculation of initial reaction rate

As only the first measurements are of importance, the first 4-6 data points for the volume of produced oxygen gas were plotted against time. These plots can be found in Appendix D. From the linear function given by the computational program, the slope was read off. This slope indicates how fast the okxygen gas is produced. The volume of oxygen is then converted to moles of oxygen. Finally the number of moles of H_2O_2 decomposed per unit of time can be found from the stoichiometry of the reaction.

To demonstrate the calculations, test number 6 will be used. For this test, 6 mL of yeast suspension was used, 4 mL 3 wt.% H_2O_2 and 20 mL of water. The measurements were done with a 20 mL frictionless syringe and a stopwatch, and are shown in Table A.1.

Table A.1: Measurements from test no. 6. V_{O_2} is the collected volume of O_2-gas.

Measurement no.	V_{O_2} [mL]	Time [s]
1	1	14.16
2	2	17.29
3	3	19.66
4	4	22.6

These data are shown in Figure A.1, as well as the linear approximation made by the computational program.

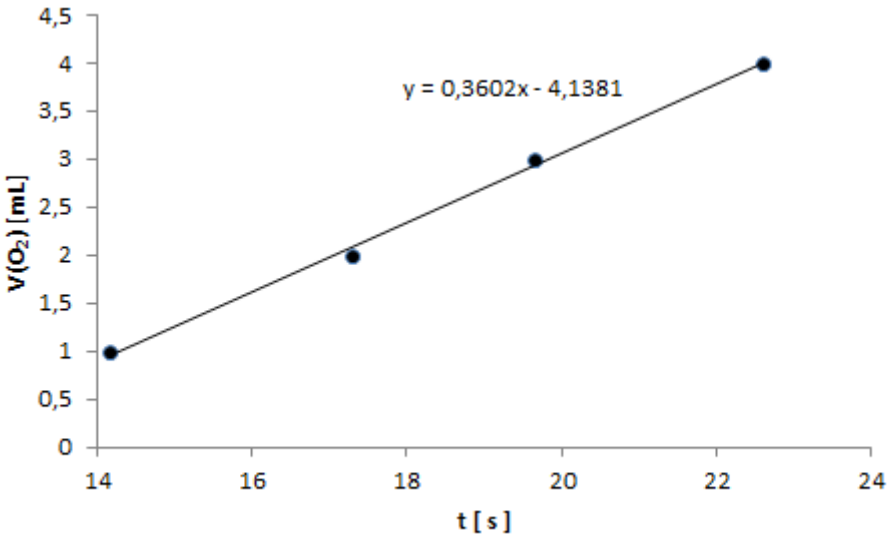

Figure A.1: Values of volume of produced O_2-gas plotted as a function of time.

From Figure A.1, the linear approximation made by the computational program is:

$$y = 0.3602x - 4.1381 \tag{A.7}$$

This gives a slope of 0.3602 mL/s, which in turn gives the initial reaction rate:

$$\frac{dV(\mathrm{O_2})}{dt} = 0.3602 \text{ [mL/s]} \tag{A.8}$$

From the volume of oxygen, one can easily find the number of moles of oxygen produced, using the molar volume of an ideal gas.

$$\frac{dn(\mathrm{O_2})}{dt} = \frac{0.3602 \text{ mL/s}}{22414 \text{ mL/mol O}_2} = 1.61 \cdot 10^{-5} \text{ [mol O}_2\text{/s]} \tag{A.9}$$

From the stoichiometry of the reaction, it is obvious that for each mole of O_2-gas produced, two moles of H_2O_2 have been decomposed. This gives:

$$\frac{dn(\mathrm{H_2O_2})}{dt} = (-2) \cdot 1.61 \cdot 10^{-5} \text{ [mol O}_2\text{/s]} = \underline{\underline{-3,21 \cdot 10^{-5} \text{ [mol H}_2\mathrm{O}_2\text{/s]}}} \tag{A.10}$$

which is the initial reaction rate of the reaction.

B Questions and answers

- Q: Oxygen absorption in water, explain
  - A: If the water volume is kept constant, the amount of oxygen absorbed will also be constant for all the series. This means all the results are 'equally' shifted.
- Q: Measuing of volume intervalls rather than time intervalls
  - A: The resolution of the watch is greater than the resolution on the syringe. This will be the most accurate way of measuring.
- Q: Reaction delay
  - A: Water will absorb the first oxygen gas formed
  - A: The use of yeast as a microfactory in stead of pure enzymes will delay the process, because of the diffusion in and out of the cell. Other enzymes present in the cell may also cause the reaction to delay.
  - A: The mixing of the H_2O_2 and the yeast suspension may be slow because of little or no strirring, until O_2-gas bubbles are formed and contribute to the mixing.
- Q: Error of measured point due to human factor
  - A: This will not affect the relative initial reaction rates because the errors will affect all the points equally.

C Risk assessment and chemical data sheets

Data necessary to fill out the chemical data sheets was found from *Sigma-Aldrich* [2]

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MSDS

	COMPOUND NAME Hydrogen peroxide solution, 3 wt. %		FORMULA H_2O_2	
				HEALTH RISKS Not particulary dangerous, but always contact a physician if in doubt.
PHYSICAL DATA	Molecular weight	Relative density	COMBUSTABILITY Not particulary dangerous, but can release O_2 in sertain reactions.	
	34.01 g/mol	1.000 g/cm^3		
PRECAUSIONS	Wear tightly fitting safety goggles. Handle with gloves.			
HEALTH RISKS Breathing Ingestion Skin Eyes	May be harmful if inhaled. Causes respiratory tract irritation. May be harmful if swallowed. May be harmful if absorbed through skin. Causes skin irritation. Causes eye burns		EXTINGUISHING Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide NOTES	
FIRST AID MEASURES	EYES Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician. SKIN Wash off with soap and plenty of water. Consult a physician.		INGESTION Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician. INHALATION If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.	

SPECIAL NOTES R 5 - Heating may cause an explosion. R 8 - Contact with combustible material may cause fire. R20/22 - Harmful by inhalation and if swallowed. O - Oxidising R35 - Causes severe burns.	
SPILLAGE/ LEFT-OVERS	To be collected and disposed of properly.
STORAGE	Store in a cool, well-ventilated place. Light sensitive.

NTNU	Hazardous activity identification process	Risikovurdering	Nummer	Dato	
		HMS-avd.	HMSRV2601		
		Godkjent av	Side	Erstatter	
HMS					

Unit: *Kjemisk prosessteknologi* **Date:** 14.09.2012

Line manager: *Øyvind Gregersen*

Participants in the identification process (including their function):

Short description of the main activity/main process:

ID no.	Activity/process	Responsible person	Laws, regulations etc.	Existing documentation	Existing safety measures	Comment
1	Yeast fermentation	NDJ		Hydrogen peroxide decomposition by Baker's yeast	Safety goggles and lab coat	
2						
3						
4						
5						
6						
7						

NTNU	Risk assessment	Utarbeidet av	Nummer	Dato
		HMS-avd.	HMSRV2603	04.02.2011
		Godkjent av	Side	Erstatter
HMS /KS				

Unit: *Kjemisk prosessteknologi* **Date:** 14.09.2012

Line manager: *Øyvind Gregersen*

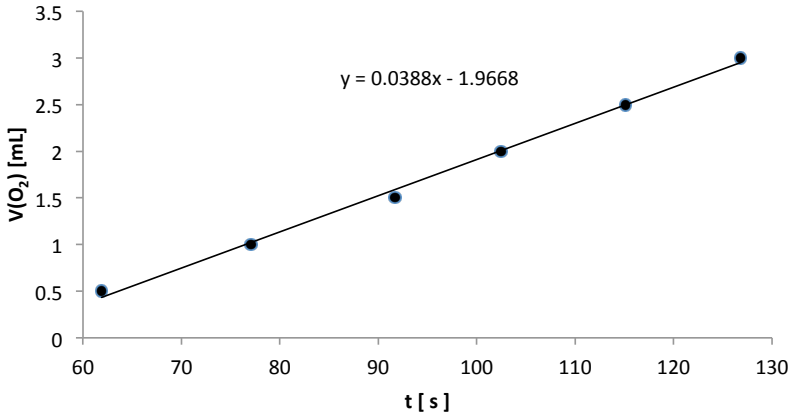
Participants in the identification process (including their function): *0*

Signatures:

ID no.	Activity from the identification process form	Potential undesirable incident/strain	Likelihood:	Consequence:				Risk value	Comments/status Suggested measures
			Likelihood (1-5)	Human (A-E)	Environment (A-E)	Economy/ material (A-E)	Reputation (A-E)	Human	
1	Handling hydrogen peroxide	Spillage	2	B	A	A	A	2B	
2	Break the syringe	Cuts	2	B	A	A	A	2B	
3	Reaction happening too fast	Exploding apparatus	1	B	A	A	A	1B	
4									
5									
6									
7									

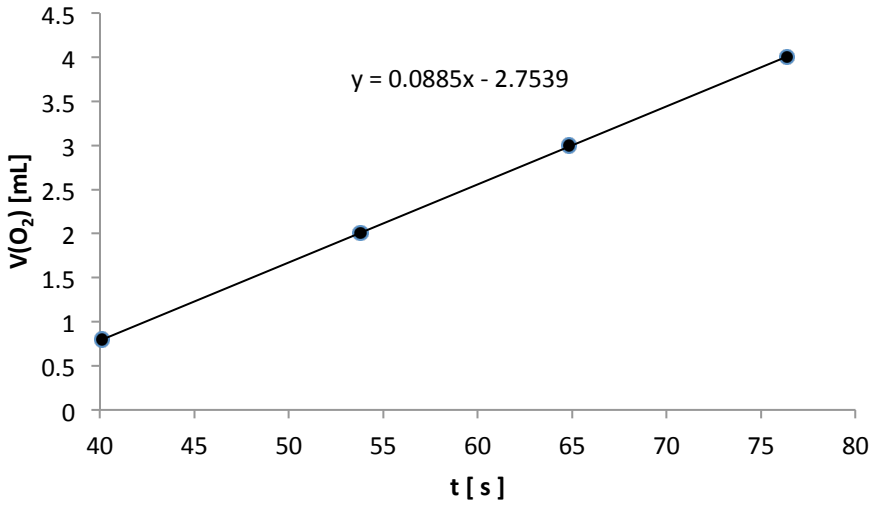
D Graphs for estamation of initial reaction rates

Test nr.	Measure nr.	V H2O [mL]	V O2 [mL]	t [s]
1(1mL yeast)	1	25	0.5	61.89
10mL syringe	2	25	1	77.04
	3	25	1.5	91.7
	4	25	2	102.45
	5	25	2.5	115.11
	6	25	3	126.83



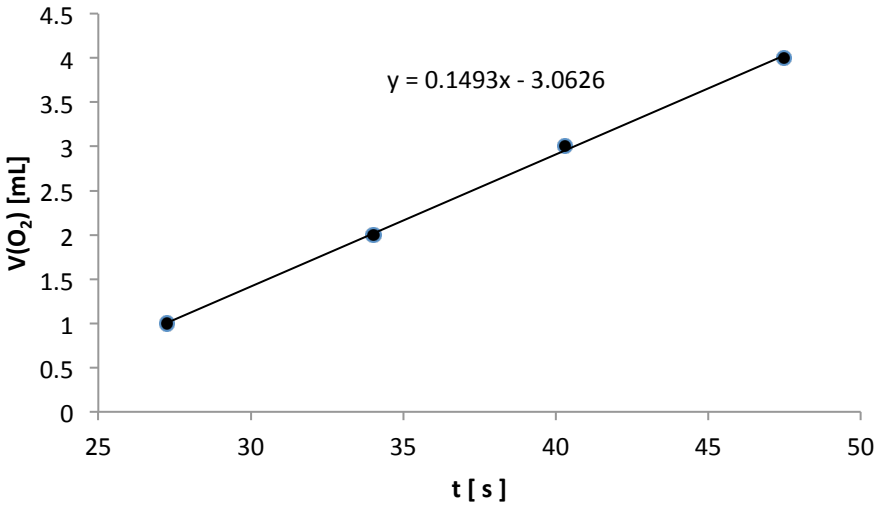
dV(O2)/dt	0.0388	mL/s
dn(O2)/dt	1.73106E-06	mol/s
dn(H2O2)/dt	-3.46212E-06	mol/s

Test nr.	Measure nr.	V H2O [mL]	V O2 [mL]	t [s]
2 (2mL yeast)	1	24	0.8	40.13
10 mL syringe	2	24	2	53.79
	3	24	3	64.85
	4	24	4	76.35



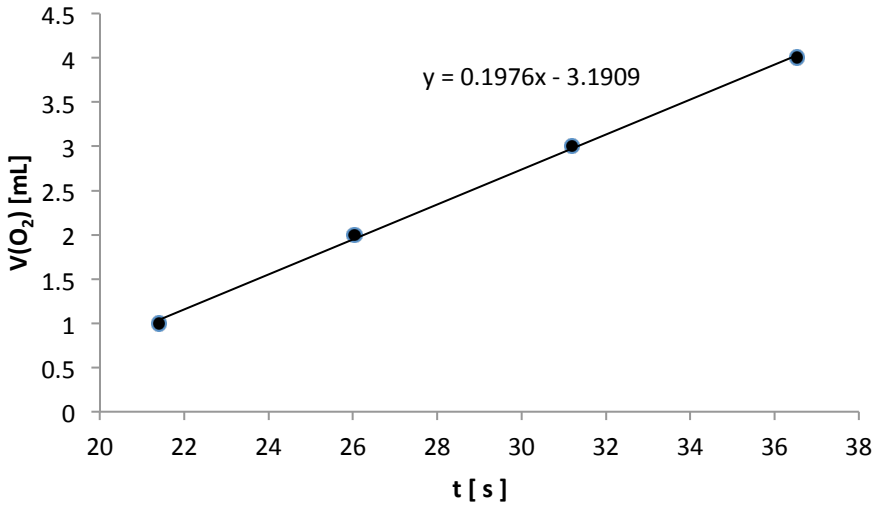
dV(O2)/dt	0.0885	mL/s
dn(O2)/dt	3.94843E-06	mol/s
dn(H2O2)/dt	-7.89685E-06	mol/s

Test nr.	Measure nr.	V H2O [mL]	V O2 [mL]	t [s]
3 (3mL yeast)	1	23	1	27.26
10 mL syringe	2	23	2	34.01
	3	23	3	40.29
	4	23	4	47.48



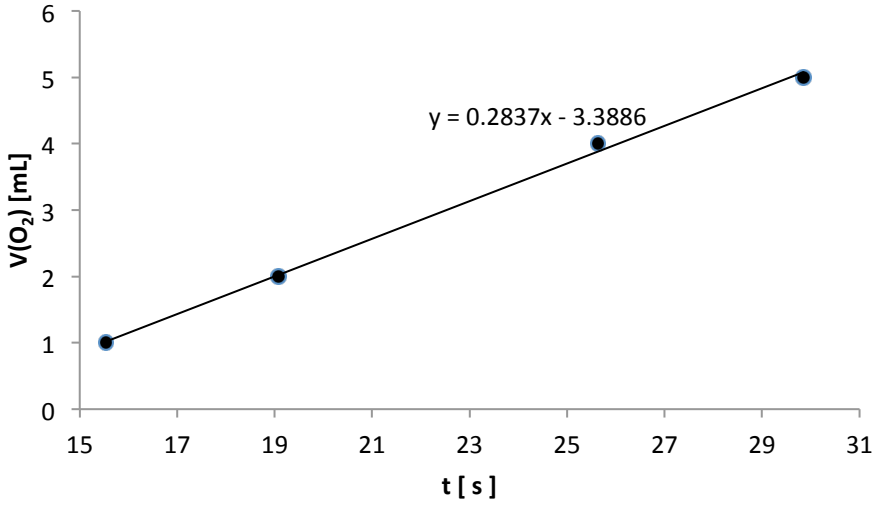
dV(O2)/dt	0.1493	mL/s
dn(O2)/dt	6.66102E-06	mol/s
dn(H2O2)/dt	-1.3322E-05	mol/s

Test nr.	Measure nr.	V H2O [mL]	V O2 [mL]	t [s]
4 (4mL yeast)	1	22	1	21.41
10 mL syringe	2	22	2	26.04
	3	22	3	31.2
	4	22	4	36.54



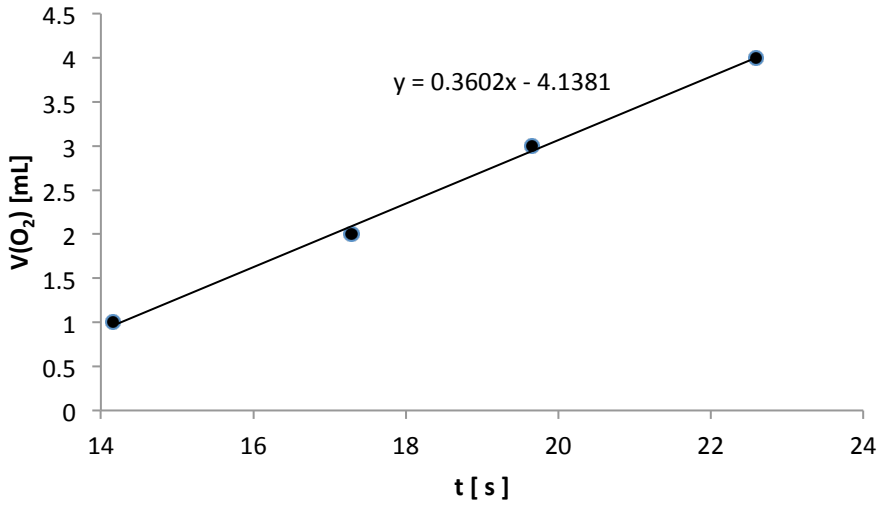
dV(O2)/dt	0.1976	mL/s
dn(O2)/dt	8.81592E-06	mol/s
dn(H2O2)/dt	-1.76318E-05	mol/s

Test nr.	Measure nr.	V H2O [mL]	V O2 [mL]	t [s]	
5 (5mL yeast)	1		21	1	15.54
20mL syringe	2		21	2	19.07
	3		21	3	
	4		21	4	25.63
	5		21	5	29.85



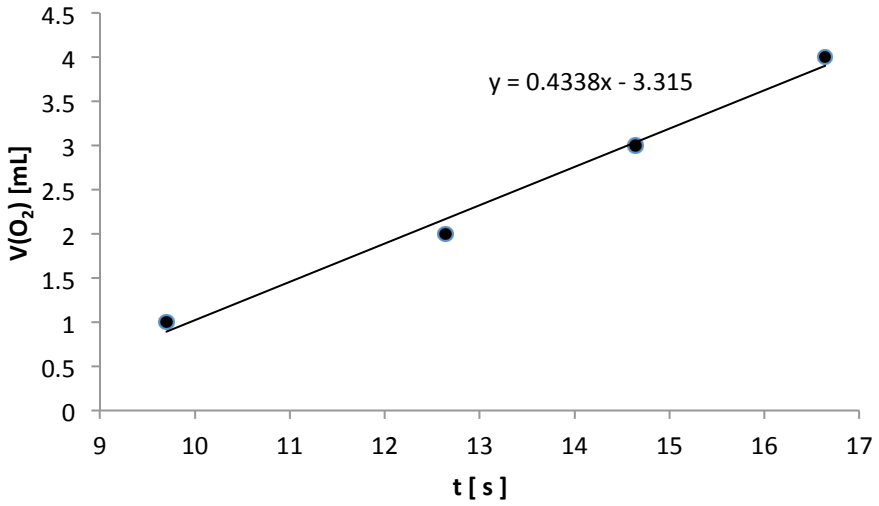
dV(O2)/dt	0.2837	mL/s
dn(O2)/dt	1.26573E-05	mol/s
dn(H2O2)/dt	-2.53145E-05	mol/s

Test nr.	Measure nr.	V H2O [mL]	V O2 [mL]	t [s]
6 (6mL yeast)	1	20	1	14.16
20mL syringe	2	20	2	17.29
	3	20	3	19.66
	4	20	4	22.6



dV(O2)/dt	0.3602	mL/s
dn(O2)/dt	1.60703E-05	mol/s
dn(H2O2)/dt	-3.21406E-05	mol/s

Test nr.	Measure nr.	V H2O [mL]	V O2 [mL]	t [s]
7 (7mL yeast)	1	19	1	9.7
20mL syringe	2	19	2	12.64
	3	19	3	14.64
	4	19	4	16.64



dV(O2)/dt	0.4338	mL/s
dn(O2)/dt	1.9354E-05	mol/s
dn(H2O2)/dt	-3.8708E-05	mol/s

E Notes from the laboratory

Measurements from Experiment 1: Dependence of the rate of the yeast consentration

nr. 1

1mL gjær

Measurement no.	$V_{O_2\,(g)}$ [mL]	Time [s]
1	1	1:17:04
2	2	1:42:45
3	3	2:06:83
4	4	2:31:45
5	5	2:57:45
6	6	3:23:92
7	7	3:52:67
8	8	4:20:67
	9	
	10	

95	40 1,89
1,5:	1:31:70
2,5:	1:55:11
3,5:	2:19:86
4,5:	2:46:04
5,5:	3:11:64
6,5:	3:38:08
7,5:	4:07:04

nr. 2

0,2 mL start

Measurement no.	$V_{O_2\,(g)}$ [mL]	Time [s]
1	1	(0,8) 40:13
2	2	0:53:79
3	3	1:04:85
4	4	1:16:35
5	5	1:27:60
6	6	1:41:51
7	7	1:54:73
8	8	2:07:73
	9	2:22:48
	10	2:38:45

V_{O_2}	time
0,5	
1,5	
2,5	
3,5	
4,5	
5,5	
6,5	
7,5	
8,5	
9,5	

Measurements from Experiment 1: Dependence of the rate of the yeast consentration

nr.3

3mL gjær

Measurement no.	V_{O_2} (g) [mL]	Time [s]
1	1	27:26
2	2	34:01
3	3	40:29
4	4	47:48
5	5	54:98
6	6	1:02:79
7	7	1:11:10
8	8	1:18:76
	9	1:27:69
	10	1:37:32

V_{O_2}	t
0,5	
1,5	
2,5	
3,5	
4,5	
5,5	
6,5	
7,5	

nr.4

4mL gjær

Measurement no.	V_{O_2} (g) [mL]	Time [s]
1	1	21:41
2	2	26:04
3	3	31:20
4	4	36:54
5	5	42:76
6	6	48:01
7	7	54:29
8	8	1:00:73
9	9	1:06:95
10		1:13:98

Fren til nr.4: 10mL sprøyte

Measurements from Experiment 1: Dependence of the rate of the yeast consentration

20mL sprøyte:

nr.5

5mL gjær

Measurement no.	V_{O_2} (g) [mL]	Time [s]
1	1	15:54
2	2	19:07
3	3	
4	4	25:63
5	5	0:29 85
6	6	3398
7	7	
8	8	41:63
9	9	
10	10	050:85
11	11	

V_{O_2}	tid
12	59:76
13	1:04:60
14	
15	1:14:60
16	
17	

nr.6

6mL gjær

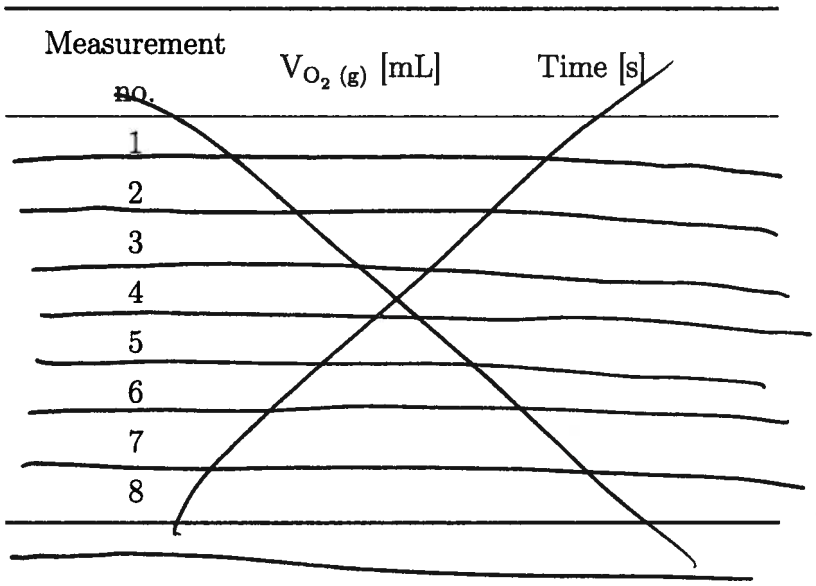
for lite H_2O_2?

Measurement no.	V_{O_2} (g) [mL]	Time [s]
1	1	13:67
2	2	17:26
3	3	20:01
4	4	22:36
5	5	25:83
6	6	29:20
7	7	32:61
8	8	36:95
9	9	39:26
10	10	43:92
11	11	48:01
12	12	51:80
13	13	55:76
14	14	1.00:23
15	15	104:76

Measurements from Experiment 1: Dependence of the rate of the yeast consentration

nr.7

6mL igjen



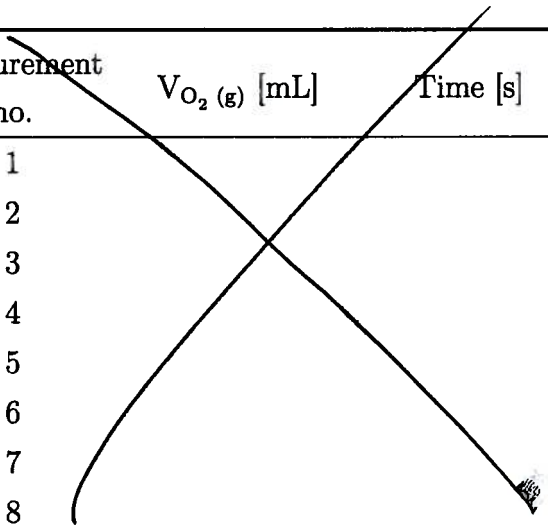
Measurement no.	V_{O_2} (g) [mL]	Time [s]
1	1	14:16
2	2	17:29
3	3	19:66
4	4	22:60
5	5	25:79
6	6	29:10
7	7	32:63
8	8	36:16
9	9	39:54
10	10	43:54
11	11	47:69
12	12	51:44
13	13	55:41
14	14	59:89
15	15	1:04:41

Measurements from Experiment 1: Dependence of the rate of the yeast consentration

nr. 8

7mL

Measurement no.	$V_{O_2\,(g)}$ [mL]	Time [s]
1		
2		
3		
4		
5		
6		
7		
8		



Measurement no.	$V_{O_2\,(g)}$ [mL]	Time [s]
1	1	09:70
2	2	12:64
3	3	14:64
4	4	16:64
5	5	—
6	6	21:54
7	7	24:23
8	8	27:29
9	9	30:07
10	10	32:79
11	11	35:48
12	12	38:70
13	13	42:11
14	14	45:20
15	15	48:42