AIR EXCHANGE RATE MEASUREMENT MUSEUM AMSTELKRING

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Method

Air exchange rate in the Church is measured in three different situations. The first measurement was performed on a cold day on March 13th 2006. Second and third measurements were performed on a warm day, September 29th 2006. During the first and second measurement all windows of the church remained closed. During the third measurement one window high in the church was opened. The location of this window is shown in Appendix A. This is the specific window which is being opened when additional ventilation of the Church is required.
Measurements were performed using a B&K (Innova) Multi-gas Monitor type 1302 and tracergas (SF_6). The instrument has a lower detection threshold for SF_6 of 0.005 ppm and an upper threshold of 500 ppm. An indication of the air exchange rate is calculated from the decay of the tracergas using:

$$n = \frac{\ln(C_0) - \ln(C_{t1})}{t_1}$$

Where:

n	=	air exchange rate	[h^{-1}]
C_0	=	concentration at time = 0	[ppm]
C_{t1}	=	concentration at time = t_1	[ppm]
t_1	=	total measurement period	[h]

Additional calculations are performed using curve fitting in the Matlab environment.
Concentrations were measured on 5 different locations with an interval of 2 minutes. Locations of the measurement were:

- Church ground floor
- Church 1st gallery
- Church 2nd gallery
- Church ground floor behind altar
- Sael (March) / Church ground floor in front of altar (September)

In March it was possible to lead a tube through a space between the planking of the Church to measure concentrations in the Sael. In September this was not possible due to expansion of the wooden floor parts, so concentrations in front of the altar were measured. Refer to Appendix B for locations of the concentration measurement.
During the first measurement in March the entrance door to the building remained closed and only was opened when visitors enter the building. In September the entrance door was open throughout the day.
During the measurement on the 29th of September temperatures were measured on four different locations:

- Church: at organ
- Behind the altar
- Sael
- Outside: alley behind staff room

Refer to Appendix B for locations of the temperature measurements.

Results

First measurement (March 13th 2006)

The gas was released on the ground floor of the Church at 1:34 p.m. During the measurement in March concentrations were about 1 ppm when mixed. Figure 1 shows the decay of the concentrations for the five measured locations plotted against time.

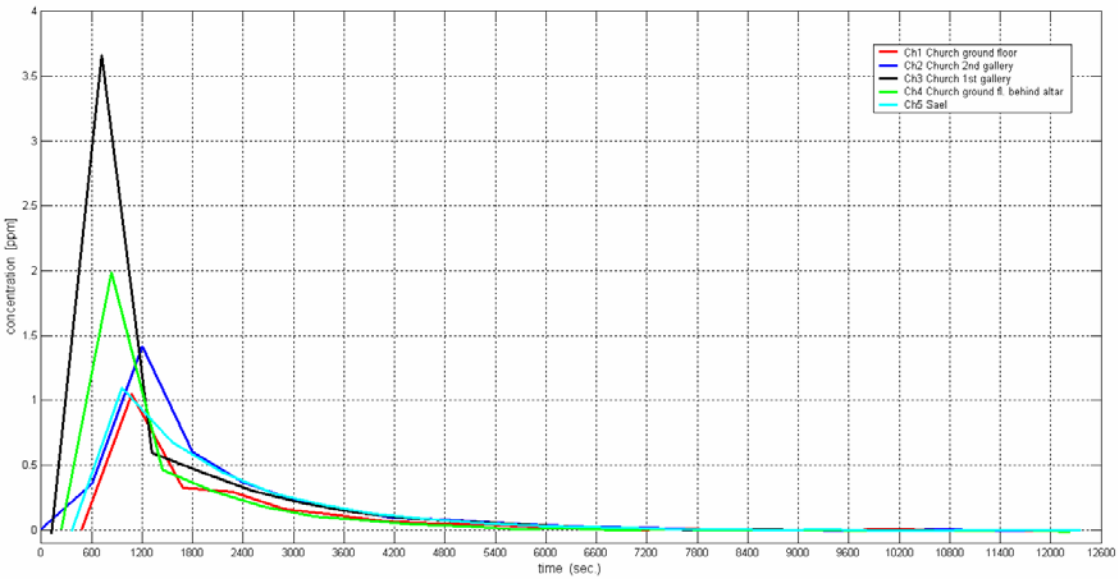


Figure 1 The results of the first tracergas measurement from channel 1 to 5 plotted against time.

Refer to Appendix D for the calculations of the first measurement. In Table 1 results are listed.

Table 1 Calculated air exchange rates by using a Matlab curve fitting routine and as calculated by hand.

Channel	Location	Result using Matlab-file "fitfunstart.m"*	Calculations done by hand
1	Church ground floor	2.1 h^{-1}	1.9 h^{-1} between 1680 - 10080 s
2	Church 2nd gallery	2.7 h^{-1}	2.0 h^{-1} between 1800 - 10800 s
3	Church 1st gallery	2.3 h^{-1}	2.8 h^{-1} between 1920 - 9720 s
4	Behind altar	2.8 h^{-1}	2.2 h^{-1} between 2040 - 11640 s
5	Sael	2.5 h^{-1}	2.5 h^{-1} between 2160 - 9360 s

*Given values are calculated over a period of 10200 seconds

Wind condition during the measurement on the 13th of March was 3,9 m/s = 3 Bft, direction east southeast. Outside temperature was -1.2˚C mean, with a maximum of 3.0˚C. Data obtained from KNMI data station Amsterdam Schiphol. Refer to Appendix C for results of temperature measurements which were done during the measurement.

Second measurement (September 29th 2006)

The gas was released on the ground floor of the Church at 10:24 a.m. Fans were used to mix the released gas with the air. Concentrations were about 2 ppm when mixed. Figure 2 shows the decay of the concentrations for the five measured locations plotted against time.

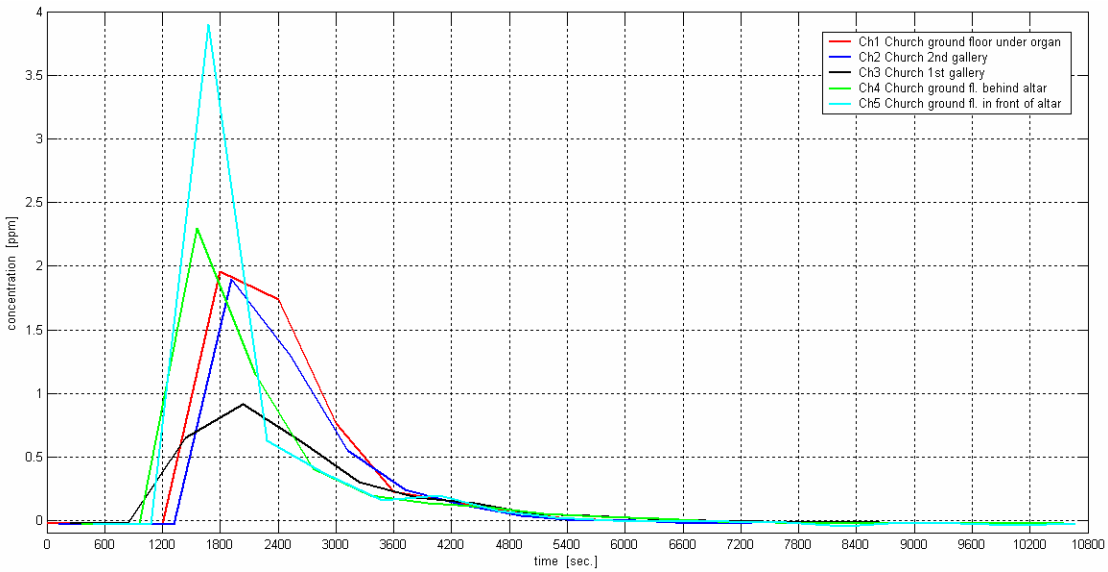


Figure 2 The results of the second tracergas measurement from channel 1 to 5 plotted against time. All window in the Church are closed.

Refer to Appendix E for the calculations of the first measurement. In Table 2 results are listed.

Table 2 Calculated air exchange rates by using a Matlab curve fitting routine and as calculated by hand.

Channel	Location	Result using Matlab-file "fitfunstart.m"*	Calculations done by hand
1	Ground fl. under organ	5.2 h^{-1}	5.8 h^{-1} between 2400 - 5400 s
2	Church 2nd gallery	4.9 h^{-1}	6.2 h^{-1} between 2520 - 6120 s
3	Church 1st gallery	3.4 h^{-1}	3.7 h^{-1} between 2640 - 6240 s
4	Behind altar	2.8 h^{-1}	3.5 h^{-1} between 2760 – 5760 s
5	Church in front of altar	2.6 h^{-1}	4.0 h^{-1} between 2880 - 5280 s

*Given values are calculated over a period of 7800 seconds

Wind condition during the measurement on the 29th of September was 4,7 m/s = 3 Bft, direction south. Outside temperature was 17.9˚C mean, with a maximum of 21.9˚C.

Third measurement (September 29th 2006)

The gas was released on the ground floor of the Church at 1:18 p.m. Fans were used to mix the released gas with the air. Concentrations were about 1.4 ppm when mixed. Figure 3 shows the decay of the concentrations for the five measured locations plotted against time.

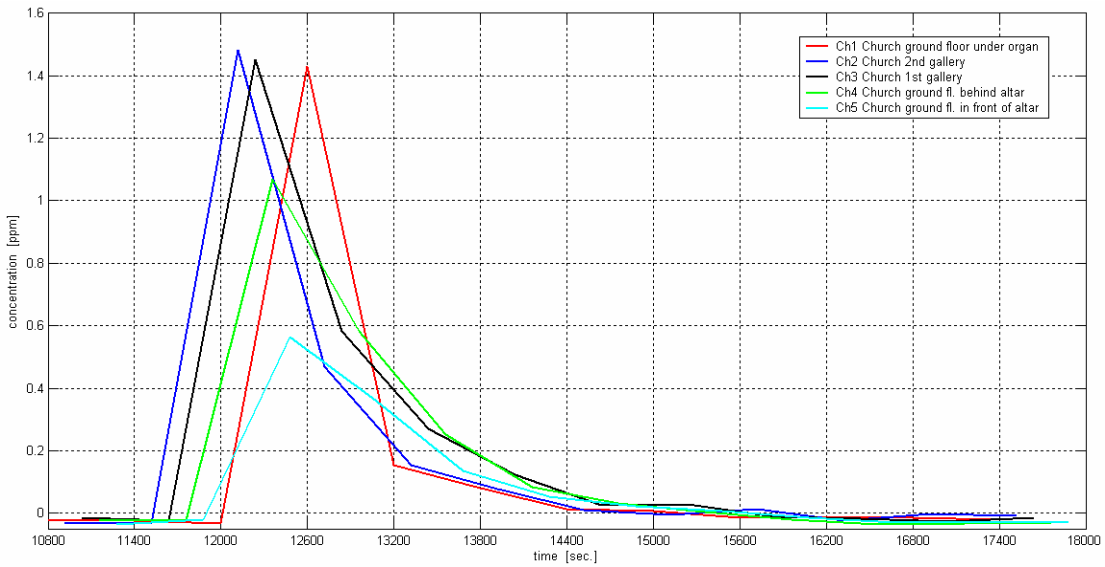


Figure 3 The results of the third tracergas measurement from channel 1 to 5 plotted against time. One window in the Church is opened.

Calculation using curve fitting did not work well with this subset of data. Therefore values are calculated by hand over two periods per channel. Refer to Appendix F for the calculations of the first measurement. In Table 3 results are listed.

Table 3 Results of the air exchange rates as calculated by hand. Per channel two values are calculated.

Channel	Location in Church	Air exchange rate [h^{-1}]	Period [s]
1	Ground fl. under organ	6.1	Between 13200 – 15000
		7.9	Between 12600 – 15000
2	2nd gallery	4.9	Between 12720 – 15720
		7.4	Between 12120 – 14520
3	1st gallery	4.5	Between 12840 – 15240
		4.7	Between 12240 – 15240
4	Behind altar	7.5	Between 12960 – 15360
		6.7	Between 12360 – 15360
5	Church in front of altar	5.9	Between 13080 – 15480
		5.3	Between 12480 – 15480

Conclusion

The following values give an indication of the air exchange rate in the Church. Values are obtained by calculating the mean of the measured values per locations in the Church.

- During the first measurement the mean value of the ACH in the Church is 2.3 h^{-1}
- During the second measurement the mean value of the ACH in the Church is 4.5 h^{-1}
- During the third measurement the mean value of the ACH in the Church is 5.9 h^{-1}

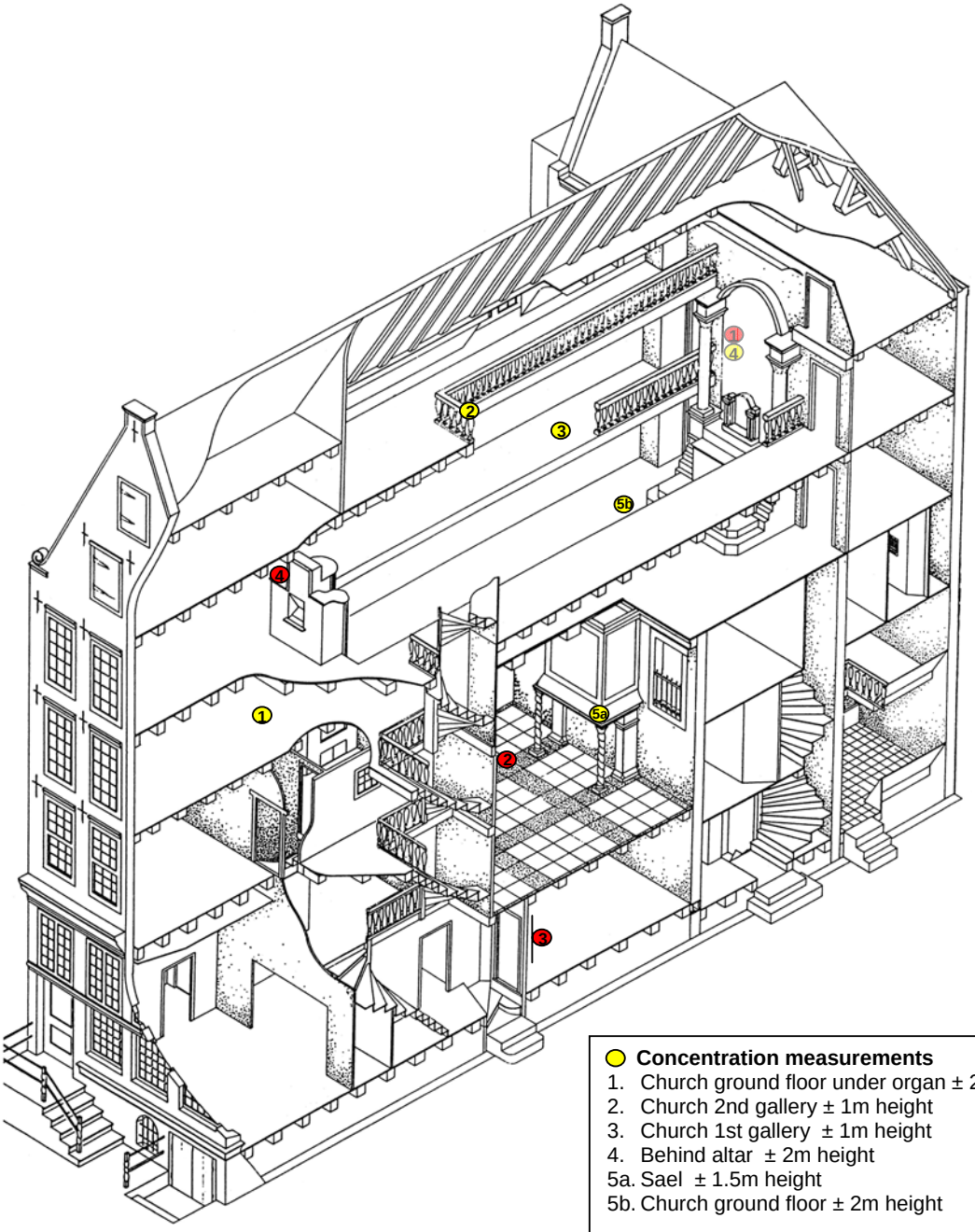
During wintertime the doors at the entrance of the building only open shortly each time visitors enter or leave. During summertime entrance doors stay open throughout the day. The entrance space is in free connection with the Church space. This may be a reason for the significant higher ACH during summer, despite the lower delta T between inside and outside. Especially when during summer a window high in the Church is open, ACH numbers probably increase due to a flow caused by the stack effect and wind pressure. Wind conditions did not differ much during the March and September measurement so these probably do not play a major role causing the difference.

Appendix A

Location of open window during measurement 3

Appendix B

Locations of concentration and temperature measurements



Concentration measurements

1. Church ground floor under organ ± 2m height
2. Church 2nd gallery ± 1m height
3. Church 1st gallery ± 1m height
4. Behind altar ± 2m height

5a. Sael ± 1.5m height

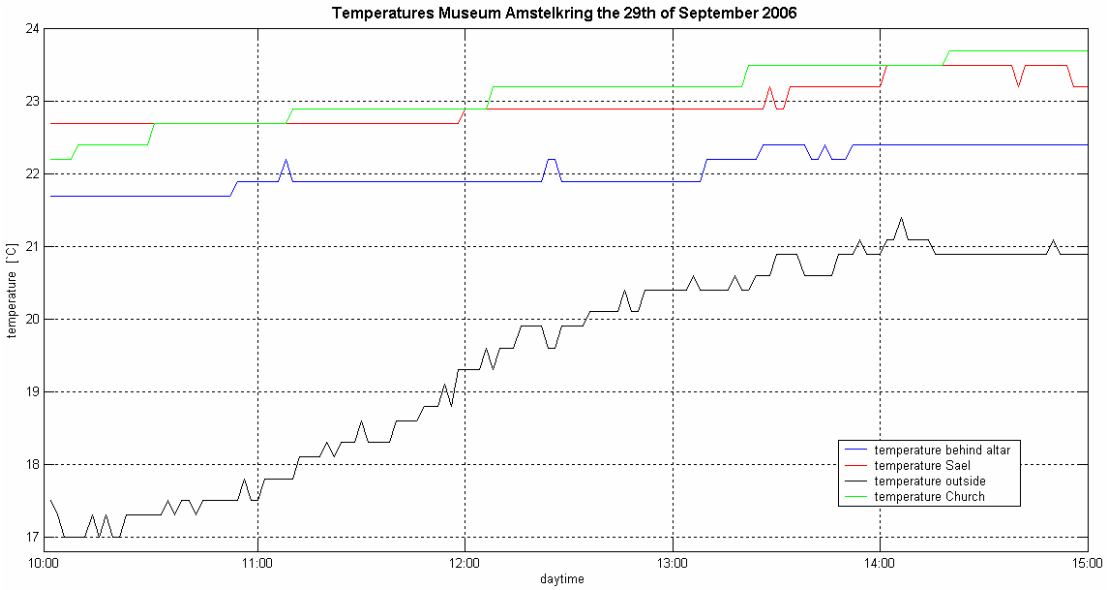
5b. Church ground floor ± 2m height

Temperature measurements

1. Behind altar
2. Sael
3. Outside in alley
4. Church at organ

Appendix C

Results of temperature measurements



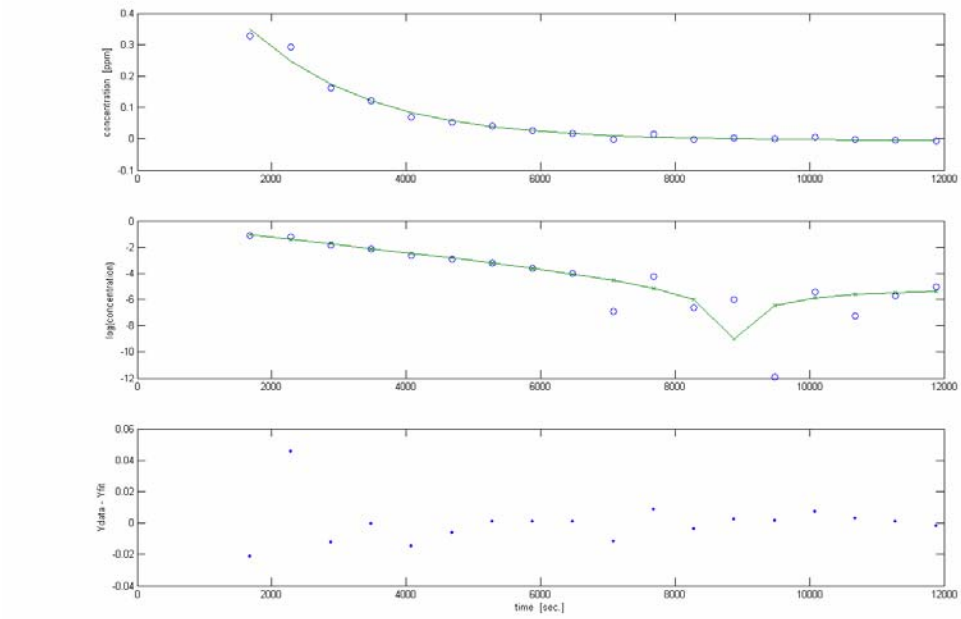
Appendix D

Calculations of measurement 1

Channel 1

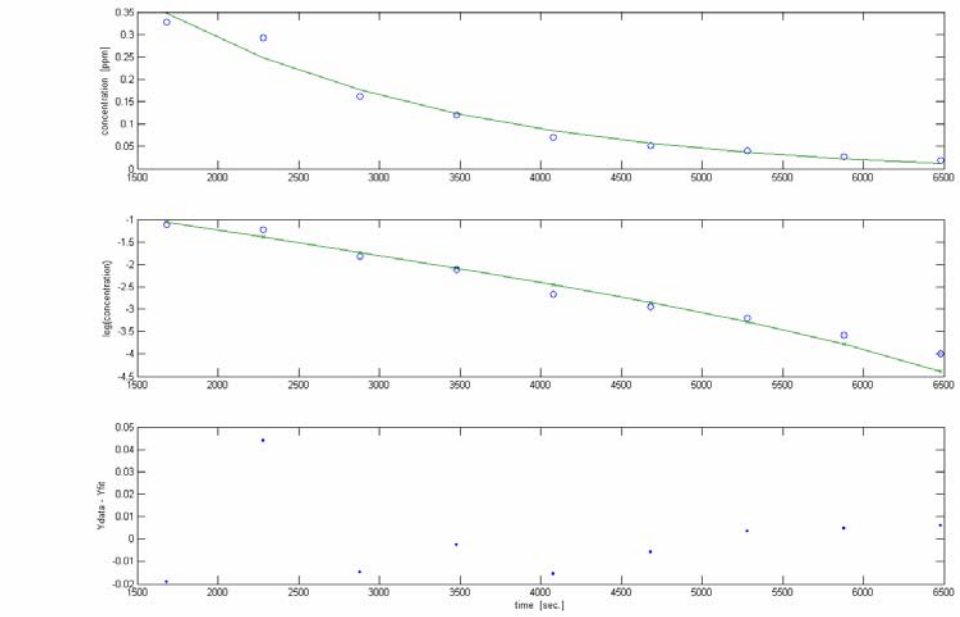
Using Matlab-file between t1= 1680 and t2= 11880 s.

Result: n= 2.06 h^{-1}



Using Matlab-file between t1= 1680 and t2= 6480 s.

Result: n= 1.91 h^{-1}

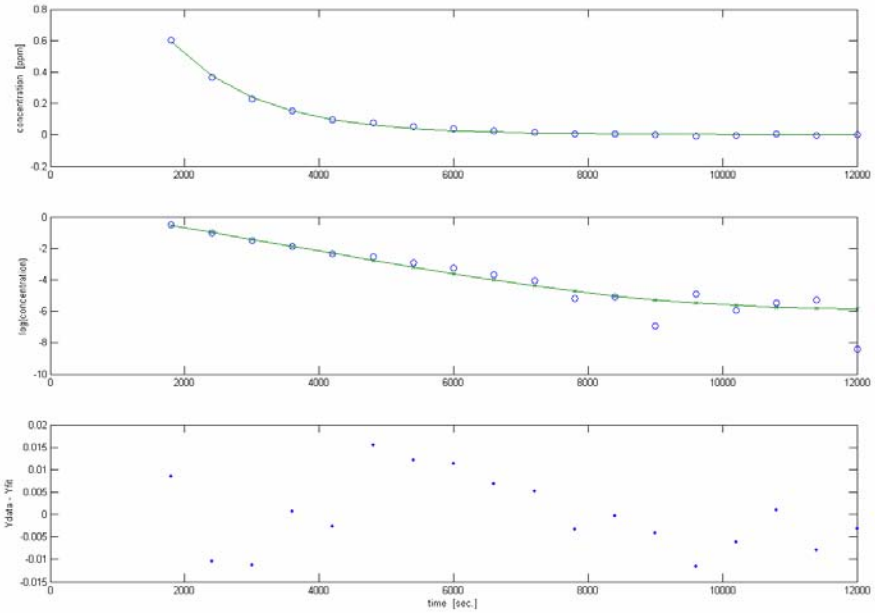


By hand between t1=1680 and t2=10080 sec.: $n = \frac{\ln(0.0043) - \ln(0.3280)}{2\frac{1}{3}}$ = 1.86 h^{-1}

Channel 2

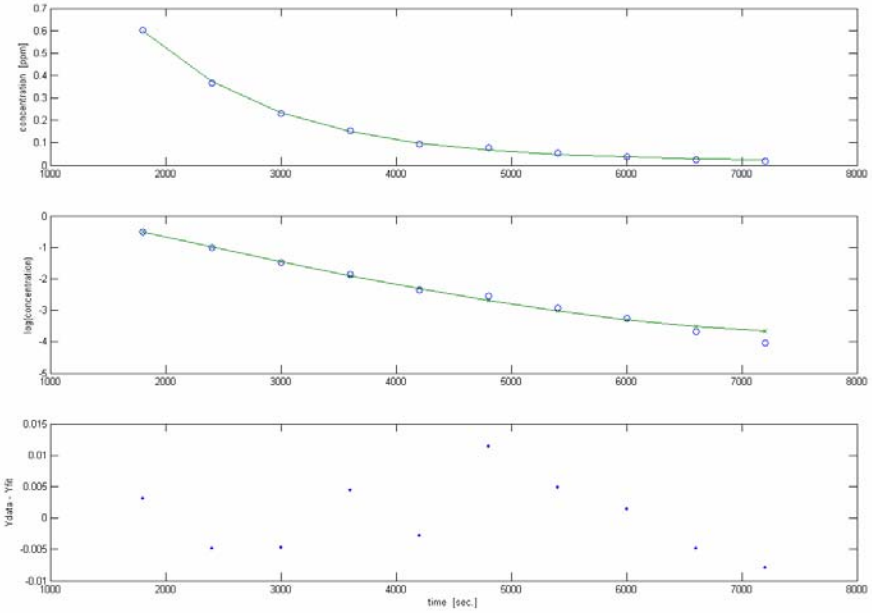
Using Matlab-file between t1= 1800 and t2= 12000 s.

Result: n= 2.73 h^{-1}



Using Matlab-file between t1= 1800 and t2= 7200 s.

Result: n= 2.98 h^{-1}

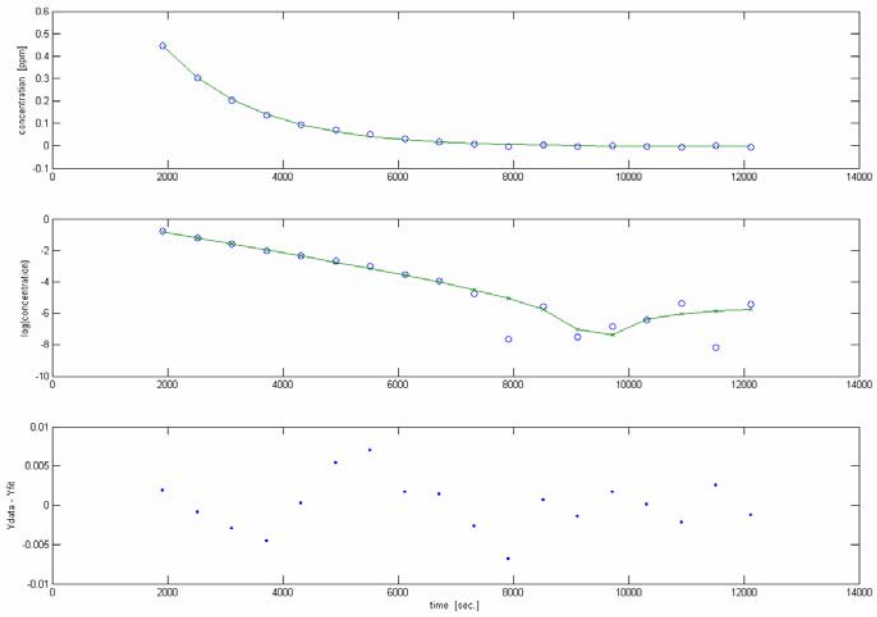


By hand between t1= 1800 and t2= 10800 s: $n = \frac{\ln(0.0042) - \ln(0.6020)}{2\frac{1}{2}} = 1.99\ h^{-1}$

Channel 3

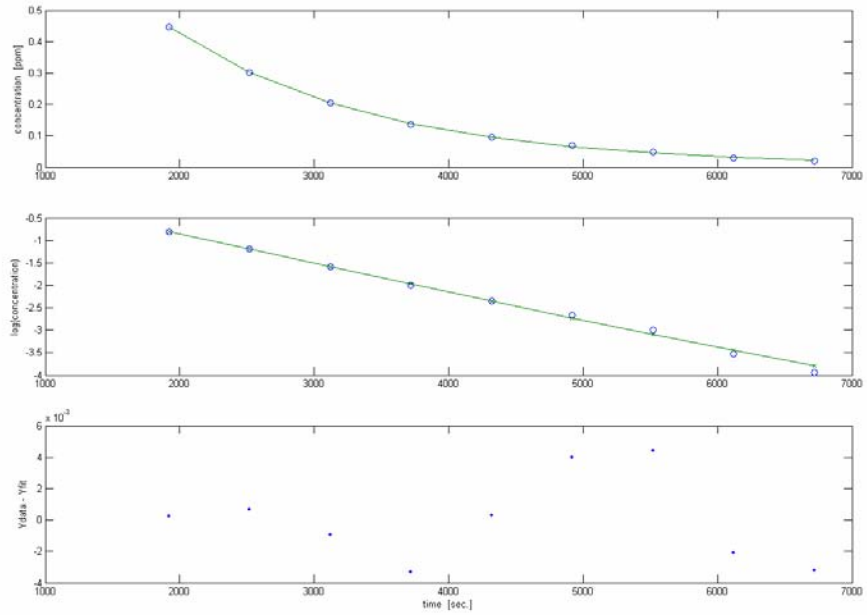
Using Matlab-file between t1= 1920 and t2= 12120 s.

Result: n= 2.27 h^{-1}



Using Matlab-file between t1= 1920 and t2= 6720 s.

Result: n= 2.37 h^{-1}

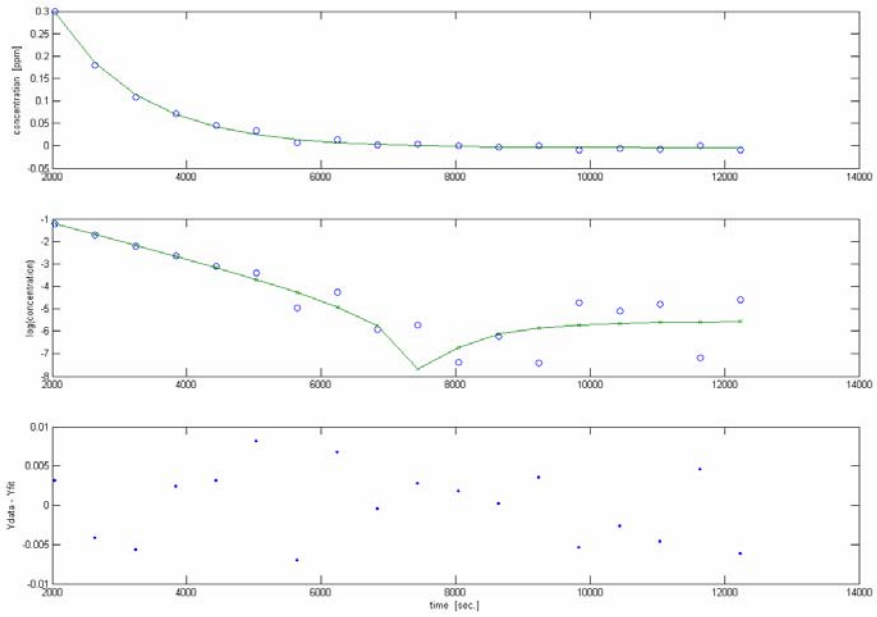


By hand between t1= 1920 and t2= 9720 s: $n = \frac{\ln(0.0011) - \ln(0.4470)}{2\frac{1}{6}} = 2.77\ h^{-1}$

Channel 4

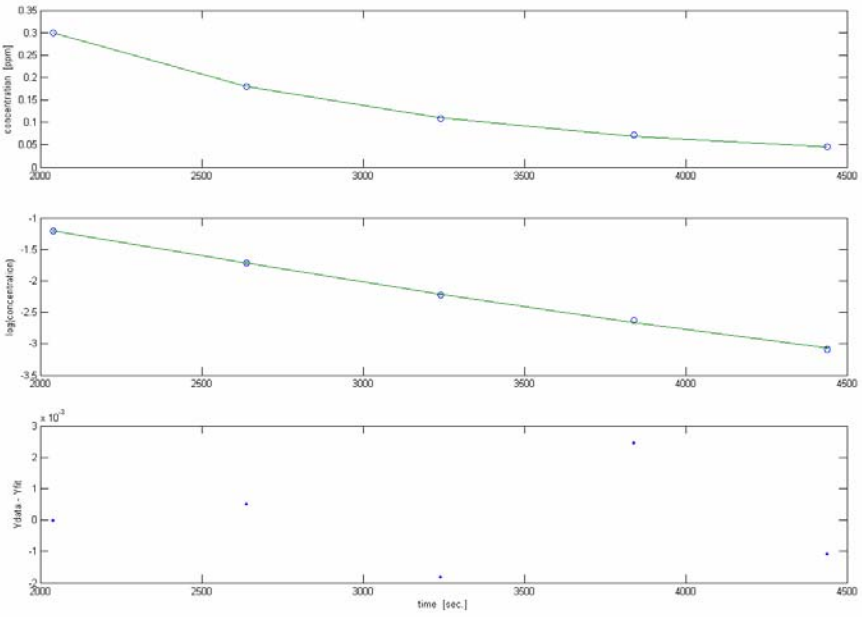
Using Matlab-file between t1= 2040 and t2= 12240 s.

Result: n= 2.82 h^{-1}



Using Matlab-file between t1= 2040 and t2= 4440 s.

Result: n= 3.29 h^{-1}

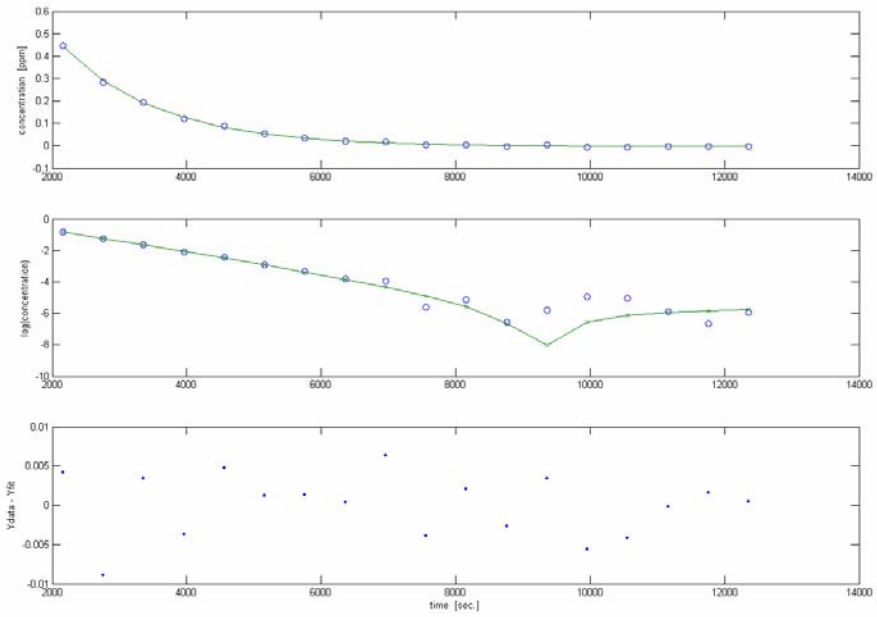


By hand between t1= 2040 and t2= 11640 s: $n = \frac{\ln(0.00076) - \ln(0.30000)}{2\frac{2}{3}} = 2.24\ h^{-1}$

Channel 5

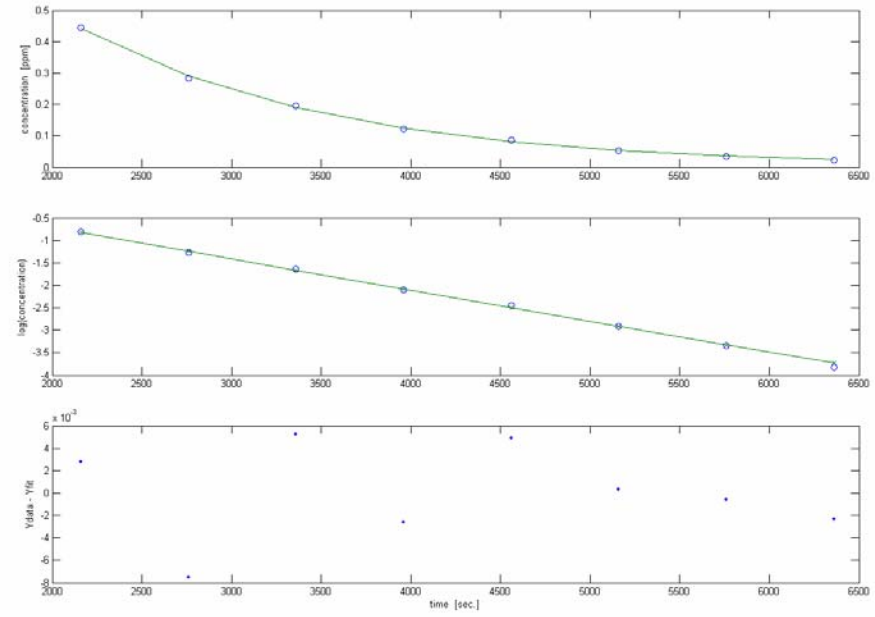
Using Matlab-file between t1= 2160 and t2= 12360 s.

Result: n= 2.47 h^{-1}



Using Matlab-file between t1= 2160 and t2= 6360 s.

Result: n= 2.55 h^{-1}



By hand between t1= 2160 and t2= 9360 s: $n = \frac{\ln(0.003) - \ln(0.445)}{2} = 2.50\ h^{-1}$

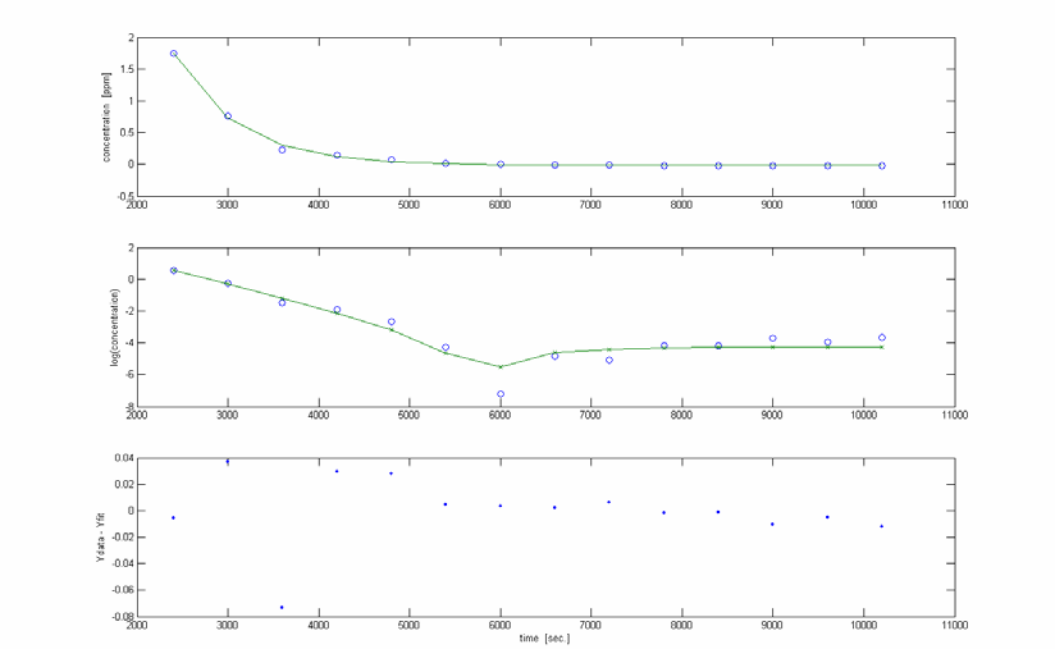
Appendix E

Calculations of measurement 2

Channel 1

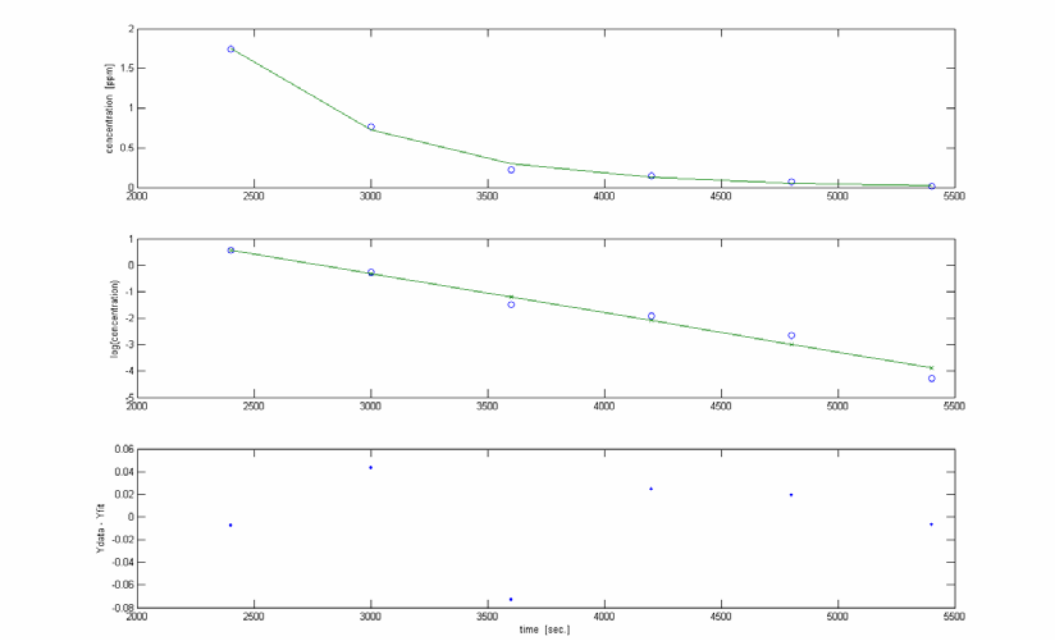
Using Matlab-file between t1= 2400 and t2= 10200 s.

Result: n= 5.17 h^{-1}



Using Matlab-file between t1= 2400 and t2= 5400 s.

Result: n= 5.29 h^{-1}

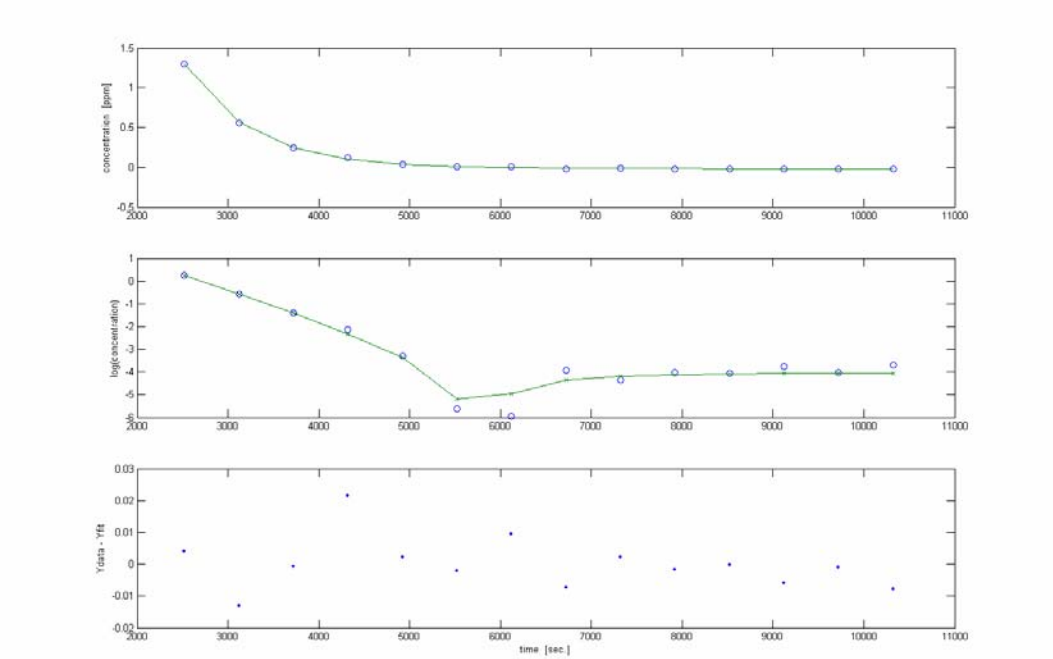


By hand between t1=2400 and t2=5400 s: $n = \dfrac{\ln(0.0139) - \ln(1.7400)}{\dfrac{5}{6}} = 5.80\ h^{-1}$

Channel 2

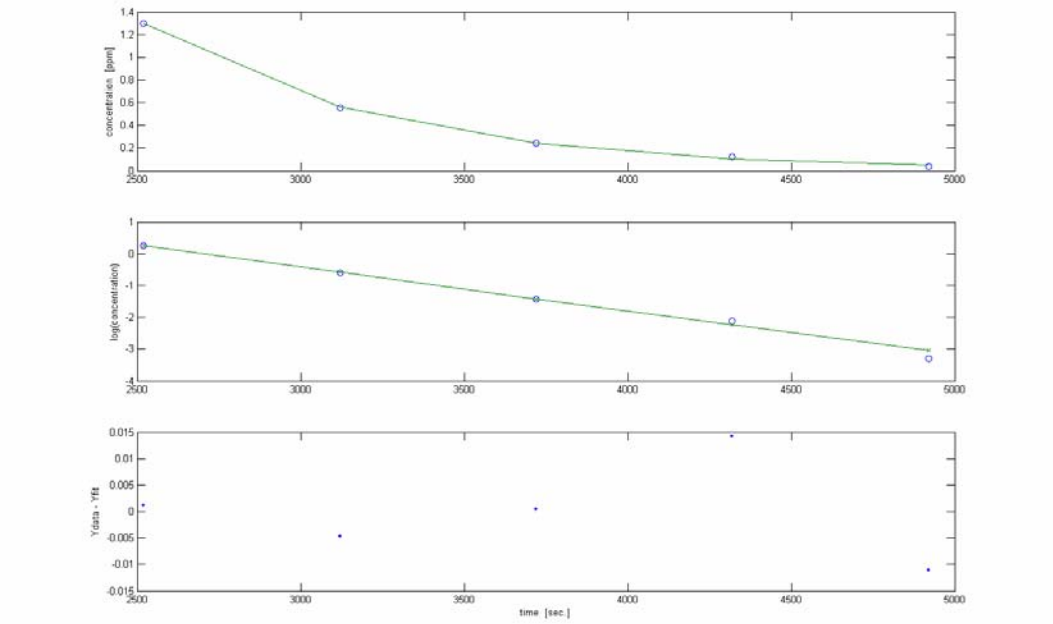
Using Matlab-file between t1= 2520 and t2= 10320 s.

Result: n= 4.86 h^{-1}



Using Matlab-file between t1= 2520 and t2= 4920 s.

Result: n= 5.09 h^{-1}

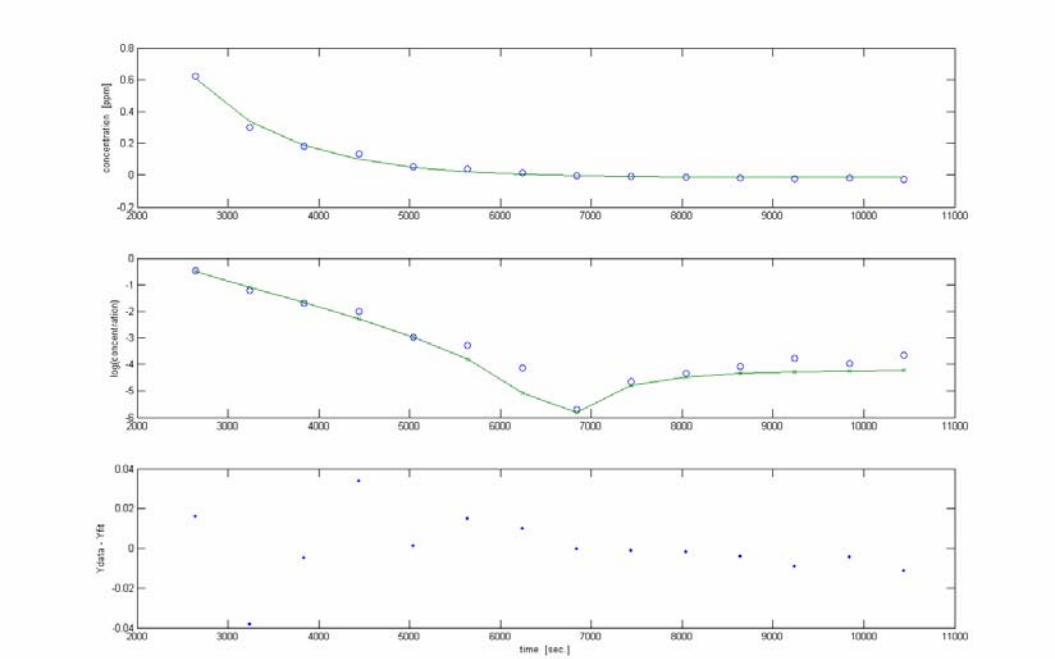


By hand between t1= 2520 and t2= 6120 s: $n = \frac{\ln(0.0026) - \ln(1.3000)}{1} = 6.21\ h^{-1}$

Channel 3

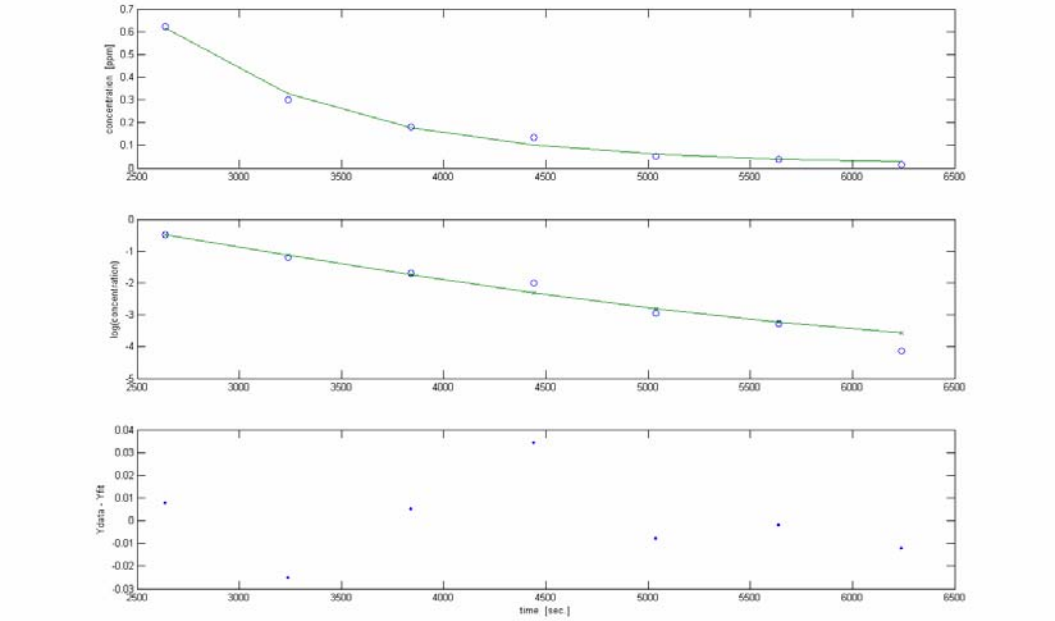
Using Matlab-file between t1= 2640 and t2= 10440 s.

Result: n= 3.37 h^{-1}



Using Matlab-file between t1= 2640 and t2= 6240 s.

Result: n= 3.95 h^{-1}

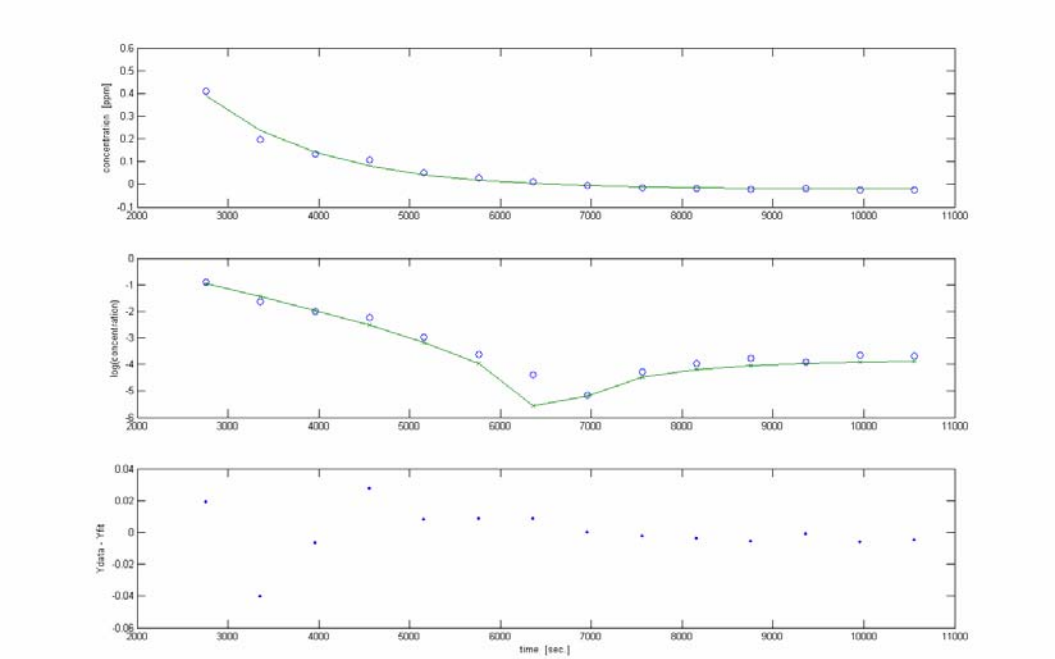


By hand between t1= 2640 and t2= 6240 s: $n = \frac{\ln(0.0161) - \ln(0.6220)}{1} = 3.65\ h^{-1}$

Channel 4

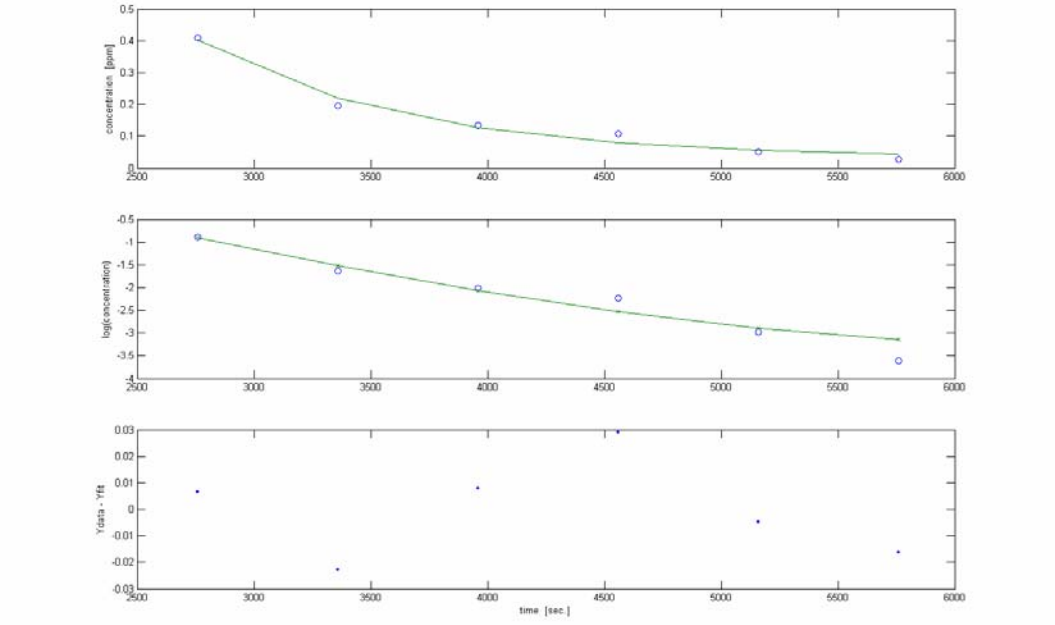
Using Matlab-file between t1= 2760 and t2= 10560 s.

Result: n= 2.79 h^{-1}



Using Matlab-file between t1= 2760 and t2= 5760 s.

Result: n= 4.08 h^{-1}

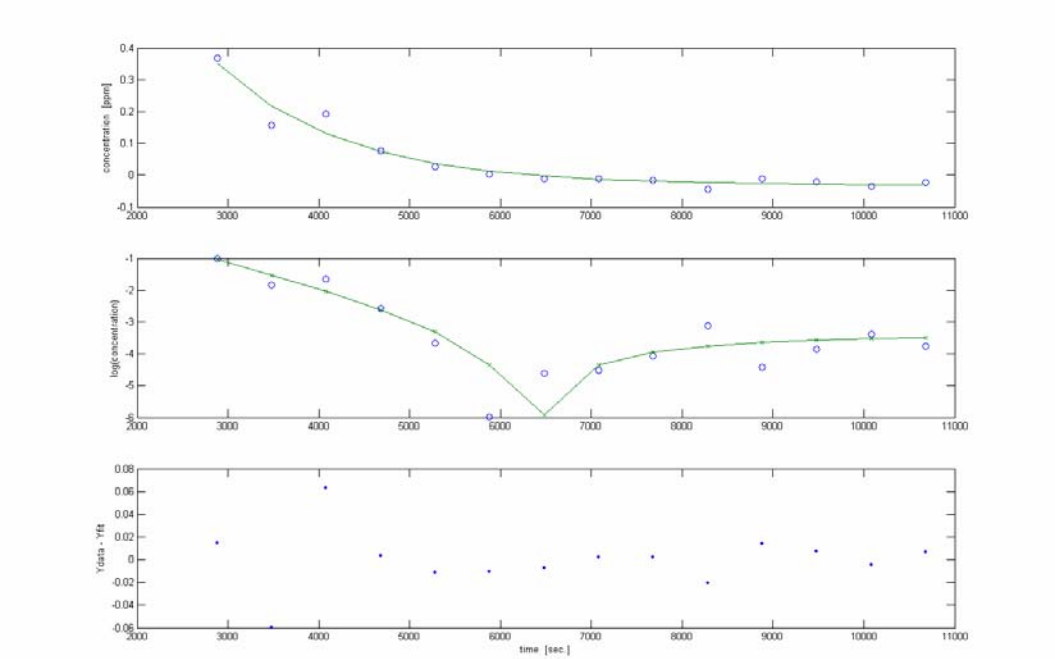


By hand between t1= 2760 and t2= 5760 s: $n = \frac{\ln(0.0270) - \ln(0.4080)}{1} = 3.49\ h^{-1}$

Channel 5

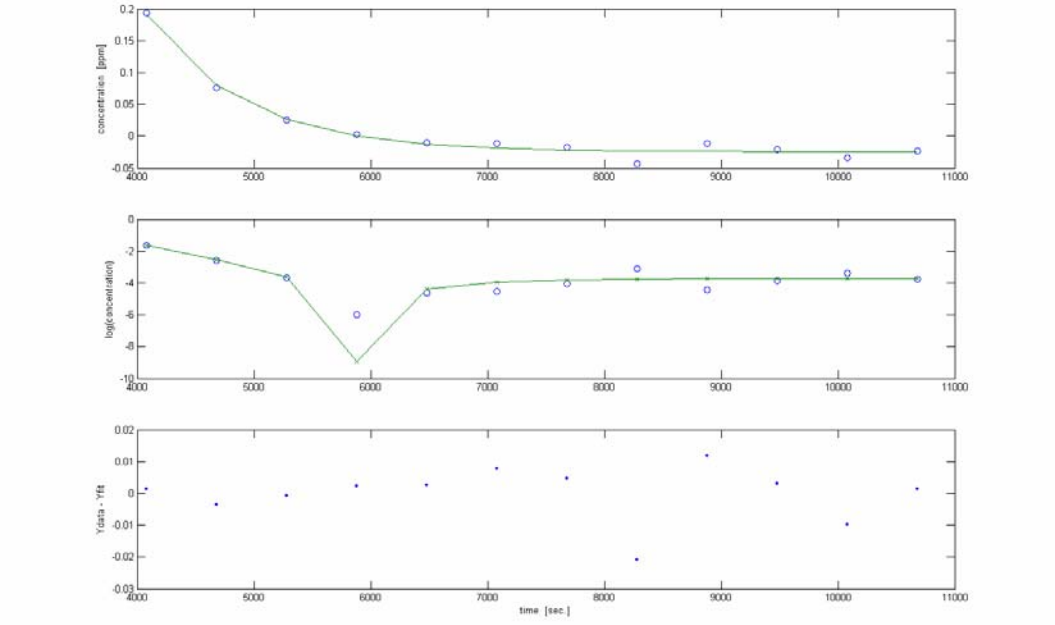
Using Matlab-file between t1= 2880 and t2= 10680 s.

Result: n= 2.60 h^{-1}



Using Matlab-file between t1= 4080 and t2= 10680 s.

Result: n= 4.35 h^{-1}



By hand between t1= 2880 and t2= 5280 s: $n = \dfrac{\ln(0.0256) - \ln(0.3670)}{\dfrac{2}{3}} = 3.99\ h^{-1}$

Appendix F

Calculations of measurement 3

Channel 1

By hand between t1=13200 and t2=15000 s: $n = \frac{\ln(0.0072) - \ln(0.1540)}{\frac{1}{2}} = 6.13\ h^{-1}$

By hand between t1=12600 and t2=15000 s: $n = \frac{\ln(0.0072) - \ln(1.4300)}{\frac{2}{3}} = 7.93\ h^{-1}$

Channel 2

By hand between t1= 12720 and t2= 15720 s: $n = \frac{\ln(0.0142) - \ln(0.4680)}{\frac{5}{6}} = 4.91\ h^{-1}$

By hand between t1= 12120 and t2= 14520 s: $n = \frac{\ln(0.0109) - \ln(1.4800)}{\frac{2}{3}} = 7.37\ h^{-1}$

Channel 3

By hand between t1= 12840 and t2= 15240 s: $n = \frac{\ln(0.0283) - \ln(0.5820)}{\frac{2}{3}} = 4.54\ h^{-1}$

By hand between t1= 12240 and t2= 15240 s: $n = \frac{\ln(0.0283) - \ln(1.4500)}{\frac{5}{6}} = 4.72\ h^{-1}$

Channel 4

By hand between t1= 12960 and t2= 15360 s: $n = \frac{\ln(0.0040) - \ln(0.5810)}{\frac{2}{3}} = 7.47\ h^{-1}$

By hand between t1= 12360 and t2= 15360 s: $n = \frac{\ln(0.0040) - \ln(1.0700)}{\frac{5}{6}} = 6.70\ h^{-1}$

Channel 5

By hand between t1= 13080 and t2= 15480 s: $n = \frac{\ln(0.0070) - \ln(0.3600)}{\frac{2}{3}} = 5.90\ h^{-1}$

By hand between t1= 12480 and t2= 15480 s: $n = \frac{\ln(0.0070) - \ln(0.5630)}{\frac{5}{6}} = 5.26\ h^{-1}$