International Summer Water Resources Research School
Dept. of Water Resources Engineering, Lund University

Treatment of dye wastewater with ozone solution

By
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Abstract
The textile industry annually produces large amounts of waste water which contains several different compounds from the production. There are several ways to treat waste water from textile factories in order to remove the remains of the dyes. The most common ways are physical, chemical and biological treatment. One efficient way that does not contribute to any secondary pollution has improved to be ozone oxidation. This project will focus on making a small-scale equipment and optimizing some parameters in the treatment process of the waste water. The parameters to be determined are the pH, oxygen flow rate and the mixing ratio between waste water and ozone solution. An experimental setup consisting of an oxygen source, ozone generator, tubes, pumps and a spectrophotometer are to be used. The results showed that the most efficient pH was the original pH of the waste water, 8.43. The best flow rate of the oxygen was 1600 mL/min and the most appropriate speed of the pump controlling the ozone solution was 420 mL/min.

Key words: dye wastewater, oxidation, ozone, decolourization, small-scale equipment
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1. Introduction
The textile industry in China is the largest in the world and it uses enormous amounts of water for bleaching, sizing, desizing, mercerizing and dyeing. Around 0.2-0.5 m³ water is required for every kilo finished textile goods. The textile industry as well as many other industries like pharmaceutical, food and paper use over 30 000 different kinds of dyes with 8 000 different chemical structures. The chemicals are used to treat the products in many different ways and are very often released in the waste water (D. Glasser, 2010)

The dye residue from the textile industries results in large amounts of dye wastewater that is spread in streams and whole rivers can be found to be completely coloured. Textile wastewater is considered to be one of the industrial wastewaters that is most difficult to treat due to the components being hardly biodegradable (T.Y. Chen, 2009). The dye wastewater from the textile industries is characterized by deep colour, high chemical oxygen demand (COD) and a pH varying between 2 and 12 (LIU Jia-le, 2007). The water also has a high concentration of organic carbon (Jiangning Wu, 1998). Chemical reagents and biological methods have been used for a long time to treat the waste water, though it has resulted in further pollution. A more efficient way to handle dye wastewater is to use ozone. Thanks to its strong oxidation properties, ozone has approved to be appropriate when treating waste water. The use of ozone in wastewater treatment is a relatively environmentally friendly way to deal with the waste water (D. Glasser, 2010).

In this experiment ozone is used to oxidize dye wastewater from the textile industry in order to treat it. Synthetic waste water will be used as well as real waste water from a textile industry. Different parameters, such as pH, oxygen flow rate and the mixing ration between oxygen solution and dye waste water, are to be determined in order to optimize the oxidation process.

1.1 Aim
The purpose with this project is to determine different parameters in order to optimize the process of treating dye wastewater. The parameters that will be analyzed are the flow rate of oxygen, mixing ratio between ozone solution and dye water and finally the pH-value of the mixed solution.

2. Background
2.1 Dye wastewater
Waste water from the textile industry is characterized by the dye remains in the water. The dyes affect the transparency of the water and often contain toxic and carcinogenic compounds making them harmful to the environment (Jiangning Wu, 2008). Due to incomplete dye fixation on fibres 5 – 80 % of the initial dye can be found in the waste water (Arlindo C. Gomesa, 2010). When dyeing cotton so called reactive dyes are commonly used. Usually 30 % of the dye remains in the waste water when using this kind of dye. Dyes were intentionally designed to resist degradation and how they affected the environment was not considered to be very important. Biological treatment has earlier been used to treat dye wastewater. These methods consider the degradation compounds but are ineffective in removing the colour (Jiangning Wu, 2008). The dyes used in the textile industry are highly structured molecules with two key components, cromophore and the functional group. Cromophore constitutes the colours and the functional group bonds the dye to the textile fibre (Arlindo C. Gomesa, 2010). The composition of dye chromophores is characterized by double bonds between carbon and nitrogen and aromatic and heterocyclic rings containing oxygen, nitrogen and sulphur. Those rings can absorb UV light at different wavelengths resulting in the characteristic colours of waste water from textile industries (LIU Jia-le, 2007). The amount of dyes used only in the textile industry is about 10 000 and every year 7105 tons of dyes are used. So called azo dyes are the most common and stands for over 50 % of the dyes used. Azo
dyes are chemical stable and are carcinogenic. Most of them are not biodegradable and biological treatment has proved not to be efficient enough in order to treat them (Arlindo C. Gomesa, 2010). Regarding the structure of the dyes

In this experiment Red 3BS 93050-79-4 has been used. The molecular structure of the dye used can be seen in figure 1. The molecule has five functional groups consisting of sulphur with two double bonded oxygen atoms and one sodium oxygen group. These functional groups enable the dye to dissolve in water.

![Molecular structure of Red 3BS 93050-79-4](image)

**Figure 1 Molecular structure of Red 3BS 93050-79-4**

### 2.2 Oxidation

Oxidation is a chemical reaction at which a substance gives one or more electrons away. The electrons are taken up by another substance since they cannot exist on their own. When a substance is oxidized its oxidation number increases. Oxidizing is an efficient method in waste water treatment, e.g. for decolourization, and other kinds of cleaning.

### 2.3 Ozone

Ozone is a very reactive gas with strong oxidation properties. It is unstable, explosive and is recognised by its special smell. It is toxic even in small concentrations and the density is about 1.5 times higher than the density of air. The solubility of ozone in water is much higher than the solubility of oxygen. Ozone occurs in the atmosphere where it protects the earth from the UV-radiation from the sun (Elding, 2013). Thanks to its strong oxidation properties (only F₂ is stronger oxidation reagent) it is an effective agent to decolourize dye wastewater. It can also be used to prepare biorefractory dyes for biological treatment. The mass transfer of ozone from the gas-phase to the liquid-phase is the rate-limiting step when using ozone to oxidize dye wastewater. The driving force for the mass transfer is the difference between the equilibrium ozone concentration at the gas-liquid interface and the concentration of the dissolved ozone. This driving force varies with water quality and hence the efficiency of ozone treatment of dye wastewater depends on the water quality as well. The efficiency also depends on the characteristics and the concentration of the dye. Ozone is relatively easy to produce and does not contribute to any secondary pollution when used in waste water treatment (Jiangning Wu, 2008). When ozone is to be used in larger amounts the gas is often created by an ozone generator. An ozone generator was constructed at the first time in 1857 and it uses oxygen to form ozone. The ozone passes an electrical discharge where electrons with much energy break the bonds in the O₂-molecules. An oxygen molecule then reacts with an oxygen atom and creates ozone. The gas produced in an ozone generator can contain an amount of 15 % ozone (Elding, 2013). There are many different ways to make the ozone dissolve in water. In this experiment bubbling balls will be used since it was considered the most suitable way. The reason why ozone is suitable in decolourisation is due to its property to break the conjugated double bonds that are common in the dye chromophores (LIU Jia-le, 2007). Ozone has also been used in combination with UV radiation in order to treat wastewater. This method has proved to be very efficient (G. Tezcanli-Güyer, 2004).
2.4 COD
COD, Chemical Oxygen Demand, is an index of the organic material in a water sample. To decide
the COD of a water sample an oxidation reagent is added making the organic material oxidize. How much
they oxidize depends on which oxidation reagent that is used. The more oxidizable compounds the
sample contains the higher COD value (Nationalecyklopedin, 2013). To prepare a COD analysis some
chemicals are added to the water sample and then it is heated for two hours. See detailed information in
paragraph 3.1.

2.5 Spectrophotometer
A spectrophotometer is used to measure the absorbance of electromagnetic waves of a solution. It can be
used to determine the composition and the purity of a sample. A low absorbance means that the sample is
clean and with a low concentration of solid compounds. The wavelength of the spectrophotometer
depends on the colour of the sample (Nationalecyklopedin, 2013).

3. Method and materials
A small-scaled equipment was set up and used in this experiment. The ozone used was produced from
oxygen by an ozone generator and then dissolved into water (15 L) by bubbling bolls. 1 g of Red 3BS
from a textile factory was dissolved into tap water (10 L) to prepare the so called synthetic waste water.
Two pumps were used to mix the ozone solution and the waste water in a tube with a length of 10 m. The
experimental equipment is shown in figure 2 and a picture of the equipment can be seen in figure 3.
Samples were taken every fifth minute and the absorbance was measured with a spectrophotometer. The
results were arranged in diagrams and then analyzed.
A smaller amount of real waste water from a textile factory was available for this experiment. It was, however, not enough to be used through the whole experiment and synthetic waste water was prepared and used instead. The synthetic waste water was used in every part of the experiment except when it is mentioned that real waste water was used. When different pH values were needed NaOH was used to increase the pH in the waste water and HCl was used to decrease the pH.

3.1 COD analysis
When testing the COD-concentration in the waste water, pure potassium hydrogen phthalate (KHP, $C_8H_5K_4O_4$) was used to prepare solutions of standard curve. The molecular structure of KHP is shown in figure 3. To prepare the COD-experiment, 2.1274 g KHP was dissolved into 500 mL water. The solution was then put in 10 different test tubes with different concentrations. 5 mL of every sample were added in smaller test tubes together with some other chemicals according to the formula below:

$$5 \text{ mL sample} + 1 \text{ mL H}_2\text{SO}_4 + 1 \text{ mL K}_2\text{Cr}_2\text{O}_7 + 5 \text{ mL H}_2\text{SO}_4 - \text{CuSO}_4$$

The test tubes were then put in a heater (figure 4) where they were heated for two hours. The absorbances of the samples were then measured in the spectrophotometer.

![Figure 3. Molecular structure of KHP.](image)

![Figure 4. COD-samples in the heater.](image)

4. Result
The accurate values for the figures below can be seen in Appendix.

The unit of the pumps used in these experiments is revolutions per minute, rpm. Experiments were carried out in order to convert the unit of the speed of the pump to mL/min. The result can be seen in table 1. In the rest of the report mL/min will be used.
Table 1: Convert table for the speed of the pump.

<table>
<thead>
<tr>
<th>Speed of the pump</th>
<th>mL/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>rpm</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>298</td>
</tr>
<tr>
<td>100</td>
<td>414</td>
</tr>
<tr>
<td>125</td>
<td>529</td>
</tr>
<tr>
<td>150</td>
<td>645</td>
</tr>
</tbody>
</table>

4.1. Effect of pH on treatment

The change in absorbance at different pH-values can be seen in figure 5. The flow rate is 1600 mL/min and the speed of the pump for the ozone solution is 645 mL/min. Without adding any chemicals to the waste water the pH was 8.43. The pH of the real waste water was 8.08.

![Figure 5: Absorbance at different pH-values.](image-url)

4.2 Effect of oxygen flow rate on treatment

The change in absorbance at different oxygen flow rates can be seen in figure 6. The pH is 8.43 and the speed of the pump for the ozone solution is 645 mL/min.
4.3 Effect of mixing ratio on treatment

The change in absorbance at different speeds of the pump for the ozone solution can be seen in the figures below. The pH is 8.43 and the oxygen flow rate is 1600 mL/min in all cases.

The absorbance (dilution and oxidation) when the speed of the pump is 298 mL/min can be seen in figure 7.

Figure 6. Absorbance at different oxygen flow rates (mL/min).

Figure 7. Absorbance at a pump speed of 298 mL/min.
The absorbance (dilution and oxidation) when the speed of the pump is 414 mL/min can be seen in figure 8.

![Figure 8. Absorbance at a pump speed of 414 mL/min.](image)

The absorbance (dilution and oxidation) when the speed of the pump is 529 mL/min can be seen in figure 9.

![Figure 9. Absorbance at a pump speed of 529 mL/min.](image)
The absorbance (dilution and oxidation) when the speed of the pump is 645 mL/min can be seen in figure 10.

![Graph showing absorbance over time for dilution and oxidation with a speed of 645 mL/min.]

Figure 10. Absorbance at a pump speed of 645 mL/min.

### 4.4. Result of COD analysis

After determining the optimized parameters the experiment was to be carried out with real waste water (pH=8.08). When testing the COD of the real waste water the results were found to be strange and unusable. Because of this the results from the COD measurements were decided not to be included in this report. Different concentrations of KHP and different wavelengths corresponding to the colour of the sample were used in the spectrophotometer. However, none of the results were able to use.

### 5. Discussion

#### 5.1 Effect of pH on treatment

The experiment was carried out at four different pH-values to see where the oxidation effect was most efficient. As seen in figure 5 the difference in absorbance between the different pH-values is not very large. The highest and the lowest pH tested resulted in a small decrease of the absorbance compared to the pH-values close to 7. Since the difference is quite small it seems reasonable not to decrease or increase the pH in order to get a more efficient oxidation effect. Measurements were carried out at even higher pH-values than 11.13 but then the colour of the samples changed so much that they could not be studied at the same wavelength as the samples with lower pH. Since the real waste water will probably never reach such high pH-values as 11 or 12 further measurements were not done at higher pH-values. Since a change in pH did not result in a large decrease of the absorbance the best pH is 8.43 which is the pH of the synthetic waste water without adding any chemicals to it.

#### 5.2 Effect of oxygen flow rate on treatment

The experiment was carried out at five different flow rates in order to decide the most efficient one. The more oxygen that is converted to ozone and dissolved in the water, the higher oxidation effect and hence lower absorbance. As seen in figure 6 the absorbance decreases with increasing flow rate. The flow rate was increased by 320 mL/min every time but the decrease in absorbance seems to be smaller as the flow rate increases. A higher flow rate results in a lower absorbance but since the difference in absorbance between the two highest flow rates was very small 1600 mL/min was decided to be the best flow rate. The use of even more oxygen was considered not necessary compared to the small gain in decreased absorbance.

#### 5.3 Effect of mixing ratio on treatment

The mixing ratio was regulated by the speed of the pump for the ozone solution. The higher speed of the pump the more ozone solution is mixed with the dye water. Also the dilution increases as more ozone
solution is mixed with the dye water. As seen in figures 7-10 a higher speed of the pump leads to a stronger oxidation effect which is shown as lower absorbance. Another aspect of the higher speed of the pump is the amount of water needed in the process. A pump speed of 645 mL/min clearly results in a stronger oxidation effect but the increased amount of water needed was regarded to be too large. Taking both the oxidation effect and the necessary amount of water into consideration, the pump speed of 414 mL/min was regarded to be the most appropriate one. At every speed of the pump the oxidation gives lower absorbance than the cases when only dilution was used. During the dilution only a certain amount of water is mixed with the dye water. This decreases the absorbance since the amount of dye is lower per volume unit. When the same amount of ozone solution is mixed with the dye water the absorbance decreases significantly since the dye, to a certain extent, is oxidized. When the speed of the pump is higher the amount of water mixed with the dye water is larger as well. The decrease in absorbance is hence due to both oxidation and dilution to a larger extent when the speed of the pump is high. The steep slope between 0 and 5 minutes in figure 7-10 is due to the dilution with the ozone solution. The first value, at t=0 min, is the absorbance only for the waste water without any dilution and therefore this value is large compared to the rest. The largest cause to the decrease in absorption is the dilution while the oxidation is a smaller part.

As seen in figure 8 and 9 the absorbance at 30 min is higher than the values before. When the two pumps were turned on, the one controlling the waste water was turned on first. Since the reaction tube was not very efficient the waste water could have been transported in the tube without mixing with the ozone solution. This would result in a higher absorbance. Further experiments were carried (without being a part of the large experiment) when both pumps were turned on at the same time. This resulted in no increase of the absorbance at the last measurement.

Some other ways to interpret the results from this part of the experiment were investigated as well. E.g. the slope of the absorbance graphs was plotted in a diagram to see the difference between the different speeds. However, these ways did not show a clear difference between the different speeds and were excluded from the results.

5.4 COD
Unfortunately the results from the COD experiment were not able to be used. Probably the concentration of KHP was too large to receive accurate values and the samples should be further diluted before tested. Another reason is that the waste water was not completely mixed with the ozone solution in the reaction tube. While testing the real waste water, the ozone solution probably broke the large carbon particles in the water while smaller compounds were still in the water resulting in high absorbance. The time was not enough to continue this part of the experiment.

5.5 Limitations
Experiments like this always have many limitations. The time reserved to this experiment was only four weeks and the plan was to finish the experiment during this time. Some parts of it did not turn out well and some of the results were not useful. The COD experiments did not give any good results and more time would have been necessary to do those experiments again and find suitable concentration and wavelength intervals. Another limitation was that the amount of real waste water available was only some litres. It would perhaps have been more accurate to use real waste water throughout the whole experiment. It would also have been interesting to consider more parameters like the components in the water and the temperature at which the process is most efficient. Even here the time was limited.
5.6 Sources of error

The results from these experiments can be inaccurate due to several different aspects. The experiments should rather be carried out several times, not only once, to get more accurate values. Since the time was limited it was not possible to do the experiments more than once. Parameters like the pH, the oxygen flow rate and the mixing ration have been tested but it would also be interesting to consider the composition and the temperature of the water. The temperature is for example determining for how much ozone that could be dissolved in the water. To consider more parameters would give a broader view of the waste water and how to optimize the treatment with ozone solution.

When all the parameters were decided the experiment was carried out with the real waste water. This water was collected at a textile factory but it is not sure that the water is absolute waste water. The factory could have treated it already in order to hide what compounds they actually add to their products and also to the water. The results of this experiment could have been different if the waste water would not have been treated at all. The real waste water was also stored for some weeks before it was used. It would perhaps be more accurate to do the experiments with fresh waste water.

Using tap water for the experiment could be misleading since it contains chlorine which has to be removed before the COD is to be tested. This could affect the water in such a way that it is inappropriate to be used in this kind of experiment. In real waste water there are a lot of organic compounds and it is difficult to specify which compounds it contains and compare the synthetic waste water to this. The synthetic waste water was perhaps not as similar to the real waste water as expected.

5.7 Improvements

To improve a similar experiment in the future one suggestion is to use another reactor tank. The reaction tank in the experimental setup was simply a plastic tube with a length of 10 m. In order to make the dye water and the waste water to mix completely a tank with a box shape would preferably be used. Another aspect is the time for the experiment. The dye water and the ozone solution were mixed for 30 minutes but a longer reaction time could have increased the oxidation effect. In figure 5-10 it is though seen that the absorbance levels out as the time increases. The oxidation decreases as the ozone concentration decreases. To further optimize the process the reaction time would have to be considered further as well. A more appropriate time would be around one hour. Another suggestion to increase the efficiency is to let the ozone dissolve in the water for a longer time before mixing it with the waste water.

5.8 Conclusion

Even though waste water treatment with ozone solution does not contribute to any secondary pollution it needs large amount of water for the ozone to dissolve in. Also, the ozone has to be produced. The method is, however, seen as an appropriate and environmental friendly way to handle the waste water. Due to the time limitation it is difficult to draw any final conclusions from this experiment. Waste water treatment with ozone solution is efficient and relatively environmental friendly. To increase the efficiency more experiments have to be done and the process parameters further optimized. The final parameters that were considered to be the most appropriate are pH=8.43, oxygen flow rate=1600 mL/min and the speed of the pump of the ozone solution = 100 rpm.

6. Acknowledgement

The author would like to thank Professor Dongxing Yuan, the supervisor for this project, for nice guidance and interesting discussions. A special thank to Rui Zhang, who have spent a lot of time on this project, for explanations and discussions during the experiments. Also to my project colleagues Wenxin Deng and Yuzhou Wang I would like to say thank you. Thank you for great discussions in the laboratory.
about cultural differences and many other interesting subjects.

Further I would like to thank everyone involved in this cooperation between Lund University and Xiamen University that made the 7th Lingfeng Summer Research School possible. Finally I would like to thank Sweco for their contribution to making this exchange possible.

7. References


8. Appendix

8.1. Effect of pH on treatment

The change in absorbance at different pH-values can be seen in table 1. The flow rate is 1600 mL/min and the speed of the pump for the ozone solution is 645 mL/min.
Table 1 Absorbance at different pH-values.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>pH 3.52</th>
<th>pH 6.52</th>
<th>pH 8.43</th>
<th>pH 11.13</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.638</td>
<td>1.62</td>
<td>1.776</td>
<td>1.444</td>
</tr>
<tr>
<td>5</td>
<td>0.548</td>
<td>0.664</td>
<td>0.631</td>
<td>0.489</td>
</tr>
<tr>
<td>10</td>
<td>0.439</td>
<td>0.492</td>
<td>0.457</td>
<td>0.413</td>
</tr>
<tr>
<td>15</td>
<td>0.362</td>
<td>0.426</td>
<td>0.383</td>
<td>0.354</td>
</tr>
<tr>
<td>20</td>
<td>0.33</td>
<td>0.376</td>
<td>0.357</td>
<td>0.333</td>
</tr>
<tr>
<td>25</td>
<td>0.314</td>
<td>0.363</td>
<td>0.338</td>
<td>0.316</td>
</tr>
<tr>
<td>30</td>
<td>0.305</td>
<td>0.354</td>
<td>0.327</td>
<td>0.306</td>
</tr>
</tbody>
</table>

8.2. Effect of oxygen flow rate on treatment

The change in absorbance at different oxygen flow rates can be seen in table 2. The pH is 8.43 and the speed of the pump for the ozone solution is 645 mL/min.

Table 2 Absorbance at different flow rates.

<table>
<thead>
<tr>
<th>Flow rate (mL/min)</th>
<th>Time (min) 640</th>
<th>Time (min) 960</th>
<th>Time (min) 1280</th>
<th>Time (min) 1600</th>
<th>Time (min) 1920</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.776</td>
<td>1.776</td>
<td>1.776</td>
<td>1.776</td>
<td>1.776</td>
</tr>
<tr>
<td>5</td>
<td>0.747</td>
<td>0.712</td>
<td>0.629</td>
<td>0.631</td>
<td>0.502</td>
</tr>
<tr>
<td>10</td>
<td>0.71</td>
<td>0.559</td>
<td>0.527</td>
<td>0.457</td>
<td>0.417</td>
</tr>
<tr>
<td>15</td>
<td>0.629</td>
<td>0.536</td>
<td>0.462</td>
<td>0.383</td>
<td>0.364</td>
</tr>
<tr>
<td>20</td>
<td>0.582</td>
<td>0.491</td>
<td>0.429</td>
<td>0.357</td>
<td>0.341</td>
</tr>
<tr>
<td>25</td>
<td>0.548</td>
<td>0.456</td>
<td>0.401</td>
<td>0.338</td>
<td>0.328</td>
</tr>
<tr>
<td>30</td>
<td>0.524</td>
<td>0.434</td>
<td>0.396</td>
<td>0.327</td>
<td>0.325</td>
</tr>
</tbody>
</table>

8.3. Effect of mixing ratio on treatment

The change in absorbance at different speeds of the pump for the ozone solution can be seen in the tables below. The pH is 8.43 and the oxygen flow rate is 1600 mL/min in all cases.

The absorbance (dilution and oxidation) when the speed of the pump is 298 mL/min can be seen in table 3.

Table 3 Absorbance for dilution and oxidation, speed of pump is 298 mL/min.

<table>
<thead>
<tr>
<th>298 mL/min</th>
<th>Time (min) Dilution</th>
<th>Oxidation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.776</td>
<td>1.776</td>
</tr>
<tr>
<td>5</td>
<td>1.102</td>
<td>0.987</td>
</tr>
<tr>
<td>10</td>
<td>1.102</td>
<td>0.955</td>
</tr>
<tr>
<td>15</td>
<td>1.108</td>
<td>0.854</td>
</tr>
<tr>
<td>20</td>
<td>1.108</td>
<td>0.839</td>
</tr>
<tr>
<td>25</td>
<td>1.119</td>
<td>0.799</td>
</tr>
<tr>
<td>30</td>
<td>1.097</td>
<td>0.807</td>
</tr>
</tbody>
</table>
The absorbance (dilution and oxidation) when the speed of the pump is 414 mL/min can be seen in table 4.

Table 4 Absorbance for dilution and oxidation, speed of pump is 414 mL/min.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Dilution</th>
<th>Oxidation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.776</td>
<td>1.776</td>
</tr>
<tr>
<td>5</td>
<td>0.971</td>
<td>0.851</td>
</tr>
<tr>
<td>10</td>
<td>0.967</td>
<td>0.733</td>
</tr>
<tr>
<td>15</td>
<td>0.967</td>
<td>0.66</td>
</tr>
<tr>
<td>20</td>
<td>0.943</td>
<td>0.618</td>
</tr>
<tr>
<td>25</td>
<td>0.86</td>
<td>0.599</td>
</tr>
<tr>
<td>30</td>
<td>1</td>
<td>0.6</td>
</tr>
</tbody>
</table>

The absorbance (dilution and oxidation) when the speed of the pump is 529 mL/min can be seen in table 5.

Table 5 Absorbance for dilution and oxidation, speed of pump is 529 mL/min.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Dilution</th>
<th>Oxidation</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.666</td>
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<tr>
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<td>0.783</td>
<td>0.457</td>
</tr>
<tr>
<td>30</td>
<td>0.917</td>
<td>0.453</td>
</tr>
</tbody>
</table>

The absorbance (dilution and oxidation) when the speed of the pump is 645 mL/min can be seen in table 6.

Table 6 Absorbance for dilution and oxidation, speed of pump is 645 mL/min.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Dilution</th>
<th>Oxidation</th>
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