Physical Properties Affecting Toilet Paper Disintegration Time

A Major Qualifying Project

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By

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Abstract

The goal of this study was to determine which properties affect the disintegration time of toilet paper. The disintegration time was measured by performing spin tests on fourteen papers from both France and the United States. The fiber density, turbidity, and roughness of each paper were analyzed, and their relationship with disintegration time was studied. It was concluded that a toilet paper with a high fiber density and smooth surface should have the fastest disintegration time.

Acknowledgements

We would like to acknowledge Dr. Marie-Nöelle Pons at the École Nationale Supérieure des Industries Chimiques (ENSIC) for allowing us to use her lab in the Reactions and Chemical Engineering Laboratory to perform this research, as well as for her guidance and support throughout the project. We would also like to thank Professor Stephen Kmiotek at Worcester Polytechnic Institute (WPI) for his guidance, as well as the opportunity to complete our Major Qualifying Project at ENSIC in Nancy, France.

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Executive Summary

Sanitary sewer overflows (SSOs) occur when the level of water in sewers rises during wet weather conditions. If toilet paper does not disintegrate quickly enough, it is expelled from overflowing sewers along with other untreated waste. This has a variety of health and environmental consequences. Although toilet paper is not the only waste component of these overflows, this study focuses on which properties influence the disintegration of toilet paper and compares various brands.

Multiple tests were performed on fourteen different toilet papers from France and the United States. First, the disintegration time of each toilet paper was measured by performing spin tests, where a sheet of toilet paper was clipped to a blade rotating in water. Each toilet paper was tested nine times, and the average disintegration time was calculated. The turbidity of one, two, and three g/L of toilet paper in water was measured using a Hach Lange Sc1000 Transmetteur. In addition, the fiber density of each toilet paper was analyzed under a Zeiss Axio Imager A1 Microscope. Twenty pictures were taken of a single sheet of each type of toilet paper. Visilog 6 software was then used to calculate the percentage of light that shone through the toilet paper from the microscope. This percentage was inversely related to the fiber density. In addition, the three-dimensional structures of the toilet papers were observed using a scanning electron microscope (SEM). The texture was quantified using an image analysis software to calculate the roughness coefficient, where a greater coefficient corresponded to a rougher surface. Finally, the correlations between the disintegration time, fiber density, turbidity, and roughness coefficient were analyzed.

The average disintegration time for each toilet paper is shown in Figure 1, below. The figure excludes Winny, Goddard, and Solo Douceur toilet papers because they did not disintegrate in under seven hours.

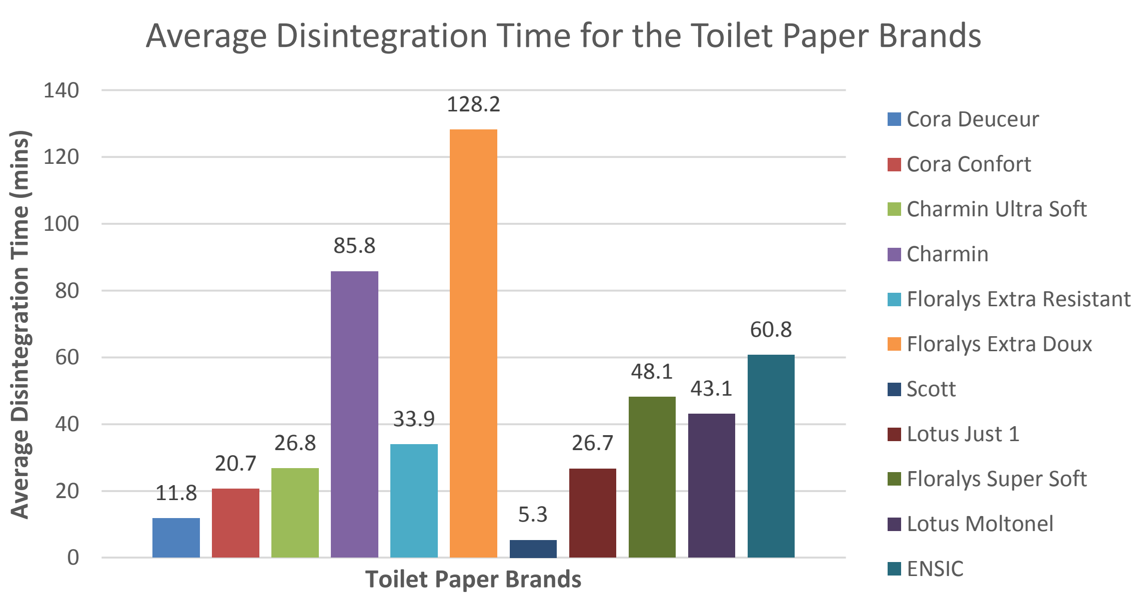

Figure 1: The average disintegration time for each toilet paper.

The turbidity of each toilet paper in water at three concentrations was measured and studied for any trends. A summary of the results from seven of the brands is shown in Figure 2, below.

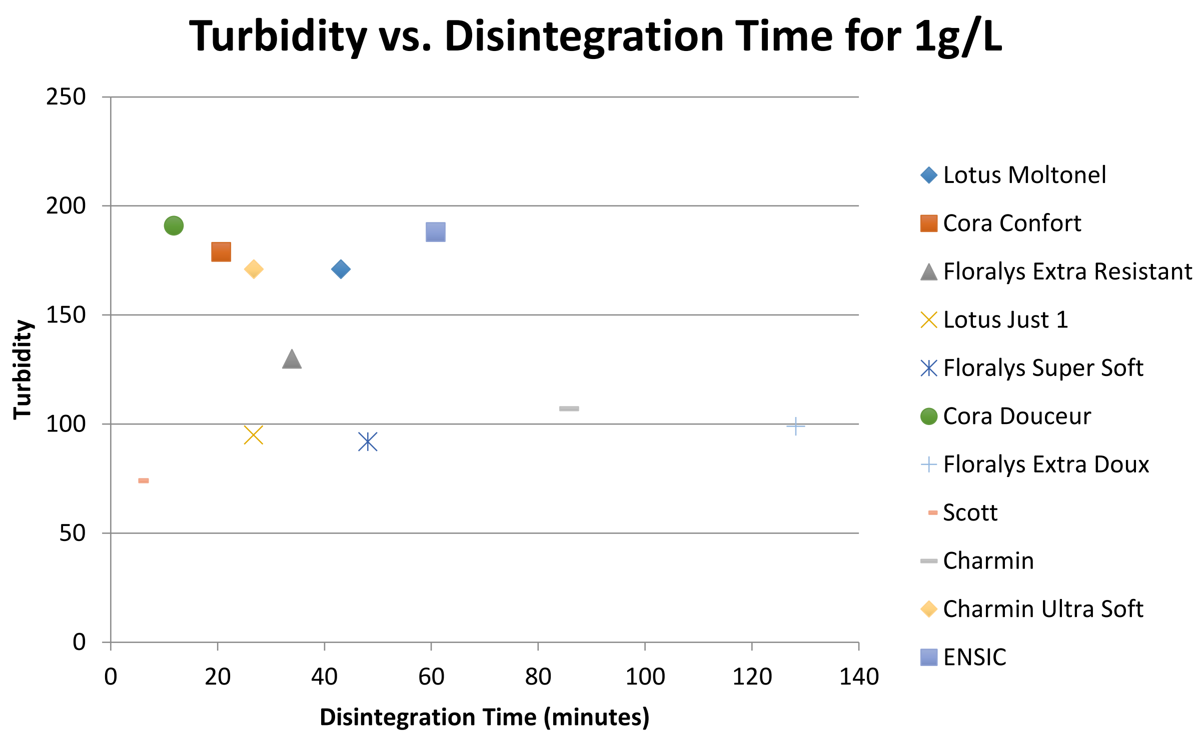

Figure 2: Disintegration time versus turbidity for 1g/L for the toilet papers.

Figure 2 does not illustrate any trends between the turbidity and disintegration time.

The fiber density was analyzed by calculating the percentage of light that shone through the toilet paper from the microscope. A lower percentage of light indicates denser fibers, as less light is able to shine through the paper. A summary of the percentage for each paper is shown in Figure 3, below, with the standard deviation shown above each bar.

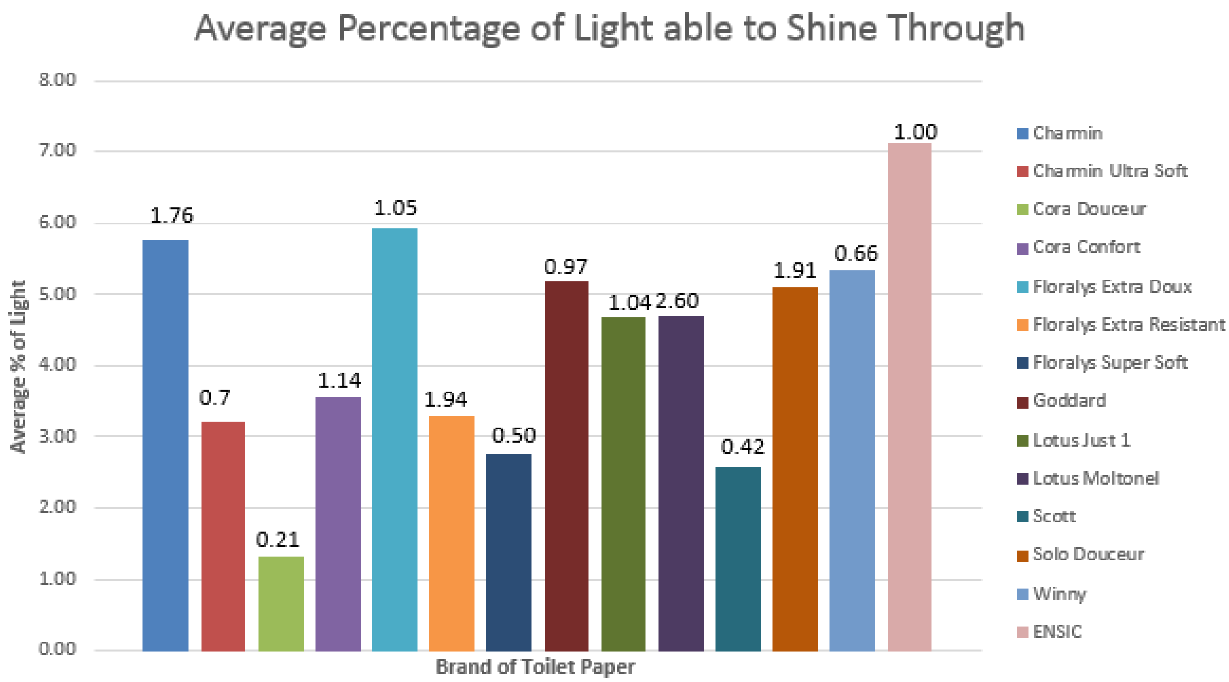

Figure 3: The average percentage of light able to shine through each toilet paper brand.

The ENSIC toilet paper had the highest percentage of light shining thorough and Cora Douceur had the lowest. It is important to note that a higher percentage of light corresponds with lower fiber density. A general trend was observed that denser fibers had faster disintegration times. This relationship can be observed in Figure 4, below.

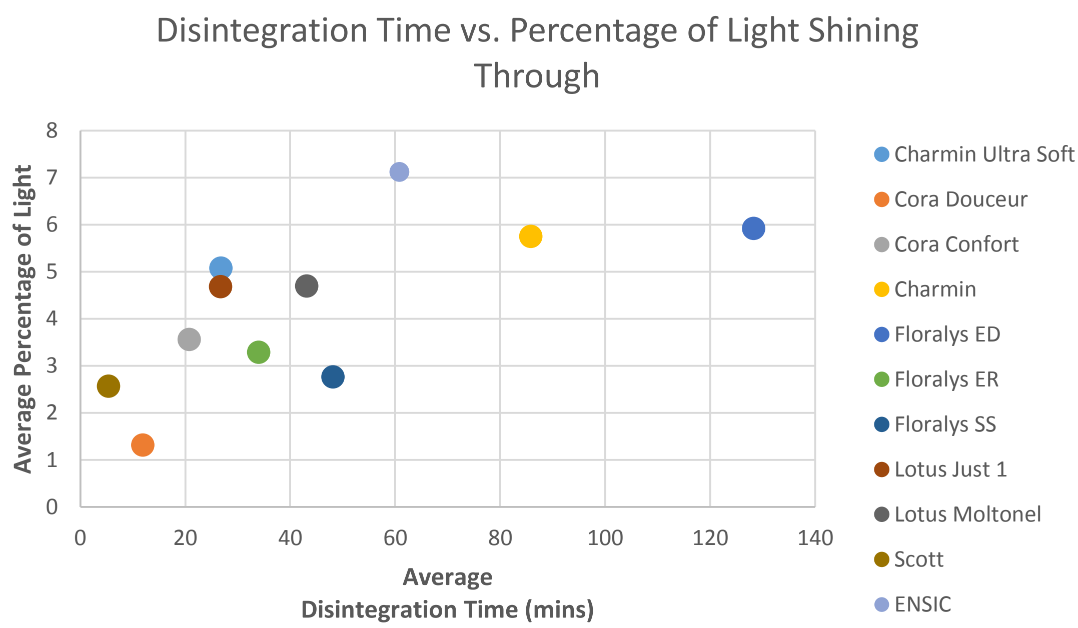

Figure 4: The relationship between the average disintegration time of the toilet papers and their average light percentage.

A scanning electron microscope was used to analyze the three-dimensional structure of the toilet paper fibers. An image analysis software was used to calculate the roughness coefficient, where a higher coefficient corresponded with rougher toilet paper. After graphing the roughness coefficients versus disintegration time and fiber density, a slight positive correlation was observed. Toilet papers with rough surfaces tended to disintegrate slower, as shown in Figure 5.

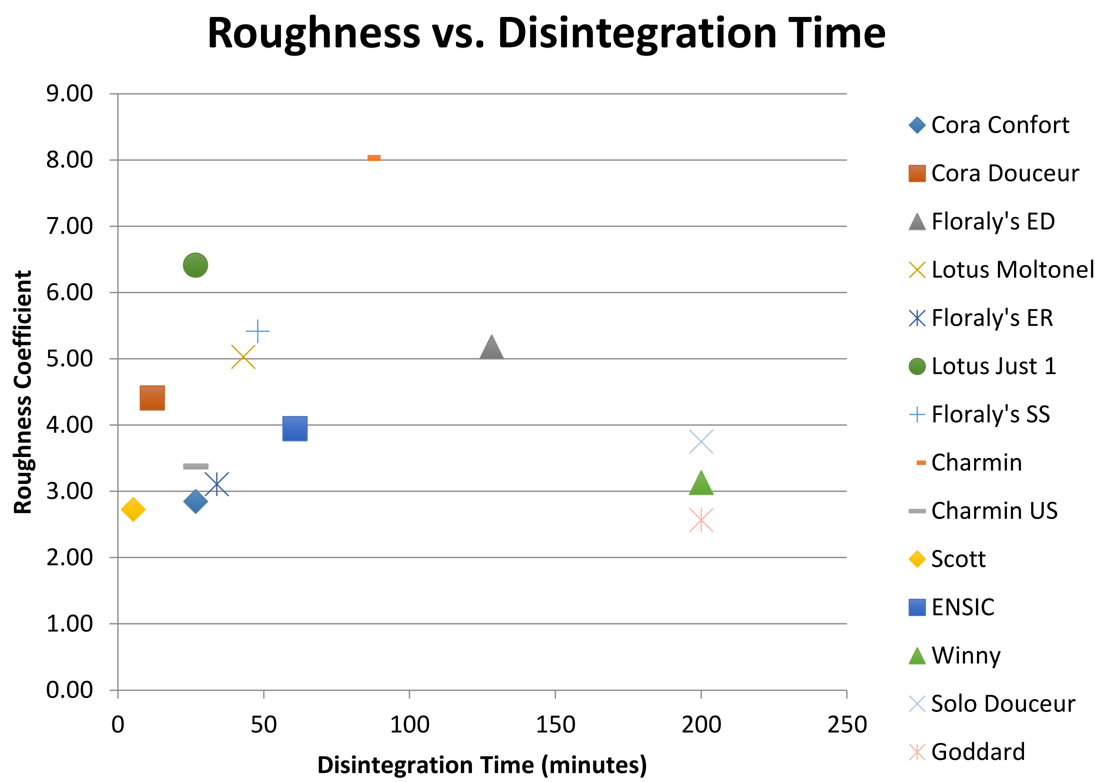

Figure 5: The roughness versus disintegration time for all toilet papers.

Winny, Goddard, and Solo Douceur did not disintegrate in less than seven hours but were plotted above as disintegrating in 200 minutes. This was chosen to reduce the scale of the axis. These three papers had similar surface roughness to Scott and ENSIC yet had a much longer disintegration time. This indicates that roughness is not a dominant factor that affects disintegration.

After analyzing the results and correlations between each of the tests, it was determined that in general, a toilet paper with a high fiber density and a smooth surface should have the fastest disintegrate time and that roughness is not a major factor affecting disintegration. Since no conclusions were drawn from the turbidity tests, more experimentation is needed to determine the effect of turbidity on disintegration time.

Introduction

The disintegration of toilet paper is essential to the proper function of modern day sewer systems. If toilet paper does not disintegrate quickly enough and the sewer overflows, it can result in a multitude of consequences. A sewer overflow can have negative impacts on both the environment and health of the surrounding community. To mitigate the risk of a sewer overflow, it is necessary to find a toilet paper that can disintegrate and move quickly through the sewer system.

There are a number of factors that may affect how quickly a specific toilet paper disintegrates. Some of these factors include the fiber density and roughness of the toilet paper, as well as how turbid the toilet paper is when dissolved in water. In this study, fourteen different brands of toilet paper from both France and the United States were tested.

In addition to finding a toilet paper that disintegrates quickly, it is important to keep the consumer in mind. Consumers prefer specific toilet paper qualities and they will not necessarily buy a toilet paper that disintegrates more quickly if it does not have those qualities. The goal of this study was to determine the ideal qualities that a toilet paper should have in order to disintegrate the fastest, keeping in mind that the qualities may not appeal to consumers.

Background

Consequences of Sewer Overflows

Combined sewers collect both storm runoff and sanitary sewage. During dry weather conditions, these sewers transport wastewater directly to sewage treatment centers. During wet weather conditions, these sewers are designed to overflow into bodies of water if the level of wastewater rises. This overflow, known as a sanitary sewer overflow (SSO), contains wastewater and untreated human and industrial waste (Fleming & Slack, 2001). This industrial waste is partially comprised of toilet paper fibers. Although toilet paper is not the singular component of SSOs, this study only focused on toilet paper.

Ideally, toilet paper breaks down in a septic tank or sewer and travels smoothly through wastewater infrastructure (InspectAPedia, 2014). If toilet paper does not disintegrate quickly enough and is expelled from a sewer, there are multiple consequences. A major consequence of an SSO is that the subsurface water carries solid waste containing pathogens into drinking water sources, leading to community health issues. According to the United States Environmental Protection Agency (USEPA), 40,000 SSOs occur each year, discharging pathogens into various bodies of water (Arnone & Walling, 2007).

Health Consequences

The World Health Organization (WHO) estimates that waterborne infections cause 13 million deaths each year. In the United States (US) alone, 900,000 cases of illnesses and 900 deaths occur every year due to microbial contamination of drinking water. These pathogens can affect the body through skin contact or ingestion. For example, *Giardia* and *Cryptosporidium* are two pathogens that have been found to cause illness from drinking contaminated water. Effects of *Giardia* and *Cryptosporidium* are diarrhea, nausea, indigestion, and can be fatal. SSOs are not only harmful to human health, but they can also negatively impact the agriculture and aesthetics of an area.

Environmental and Social Consequences

Sewage damages the ecosystem in bodies of water such as lakes or streams. Sewer overflows kill fish, devastate wildlife habitats, and ruin the aesthetic value of the land (Fleming & Slack, 2001). Additionally, sewer overflows can greatly affect people's wellbeing, as overflows can occur in homes or buildings. Septic systems also have the potential to overflow into yards. This negatively impacts the aesthetic of the area and requires time and financial resources to rectify the problem. Using toilet paper that breaks down easily in sewers would contribute to fewer SSOs, thus preserving ecosystems and the health and wellbeing of the community.

Prevention of Sewer Overflows

Various qualities of toilet paper brands may make it disintegrate more quickly and therefore pose less risk for SSOs and their associated consequences. However, creating an environmentally friendly toilet paper can be complicated because it must be appealing for consumer use to make a difference in sewer overflow problems. Studies have shown that other attempts to make toilet paper more environmentally friendly, by including recycled materials, have not been successful.

In a study conducted by Hanyu et al, German and Japanese communities blindly tested recycled versus virgin toilet paper products, and the virgin products received higher satisfaction ratings (Hanyu, Kishino, Yamashita & Hayashi, 2007). The virgin products cause environmental harm because they are made from the fibers of standing trees rather than recycled paper products (Kaufman, 2009). Of the German and Japanese participants rating the papers, only 30% and 15%, respectively, stated that "good for the Earth" was an important quality that they considered when buying toilet paper for their homes. Less than half of all people were willing to switch to a more expensive brand, and most recycled products were pricier than their virgin counterparts.

People generally found the virgin products more desirable because they are softer than the recycled papers. Despite their positive environmental impact, only 2% and 20% of commercial toilet papers are made entirely of recycled components in the US and European Union (EU), respectively (Kaufman, 2009). In Kaufman's study on toilet paper use in the US and EU, it was determined that people who claimed to be concerned about the environment still did not want to buy recycled toilet paper because it was not soft enough (Kaufman, 2009).

It is evident that simply creating a toilet paper that degrades more quickly cannot solve the issue of sewer backups. The toilet paper must degrade rapidly but also maintain the quality and price that consumers expect. For this study, fourteen varieties of toilet paper from both the US and France were tested to study qualities that affected the disintegration rate. It was necessary to study the specific qualities of toilet papers on the market that lead to a faster rate of disintegration and use that knowledge to find a balance.

Methodology

Toilet Papers Tested

Fourteen different brands of toilet paper from the US and France were tested for various properties that may affect disintegration rate. The toilet papers were chosen from popular brands in both countries based on what was readily available. The brand, country of origin, and number of plies of each paper are summarized in Table 1, below. The table is ordered from the greatest to least number of plies.

Name	Country	# of Plies
Lotus Moltonel	France	4
Lotus Just 1	France	4
Floralys Super Soft (SS)	France	4
Cora Confort	France	3
Solo Douceur	France	3
Floralys Extra Doux (ED)	France	3
Floralys Extra Resistant (ER)	France	3
Cora Douceur	France	2
Winny	France	2
ENSIC	France	2
Charmin Ulta Soft (US)	United States	2
Charmin	United States	2
Goddard	United States	1
Scott	United States	1

Table 1: Summary of toilet paper brands tested in this study.

Spin Test

A spin test was used to quantify the rate of disintegration of the various toilet papers. Fisher Bioblock Scientific's Floculator 10409 with six rotating blades was used to spin a single sheet of toilet paper in 600mL of water at 150rpm. A single sheet of toilet paper was folded over each blade and held in place using two small binder clips, as shown in Figure 6.

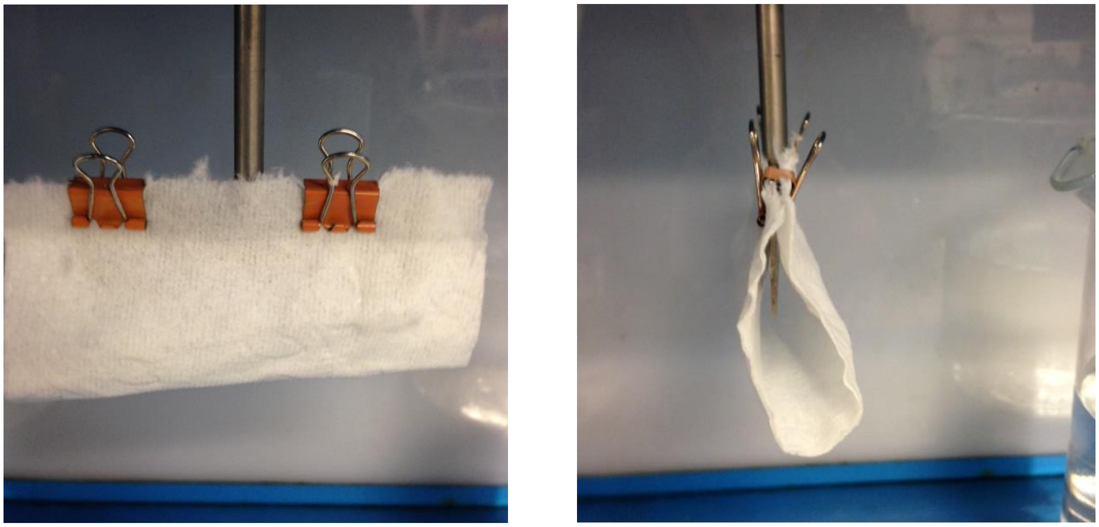

Figure 6: Demonstration of a sheet of paper folded around the blade.

The paper was then lowered into the beaker of water so that the bottom of the blade was resting on the water surface, as shown in Figure 7 below. A timer was started once the papers began spinning, and the time was recorded once each paper disintegrated.

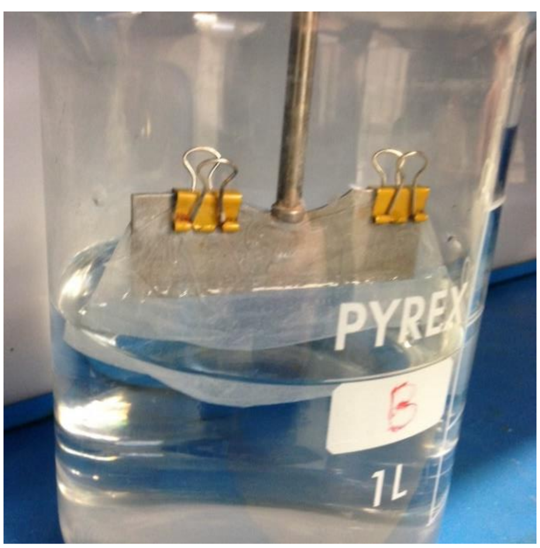

Figure 7: Demonstration of the blade lowered into the water before turning on the floculator.

The toilet paper was considered disintegrated once the beaker contained large fragments of paper with minimal paper hanging below the blade. An example of disintegrated paper is shown in Figure 8.

Figure 8: Example of toilet paper that is considered disintegrated.

The rate of disintegration was initially measured three times for each paper to establish a general knowledge of each disintegration rate. Three samples that disintegrated in an hour or less were tested twelve times, and the standard deviation and average disintegration time were calculated after each run. The number of tests after which the standard deviation and average remained constant was used as baseline for the number of times to test other brands.

Once each brand was tested an appropriate number of times, an average and standard deviation of disintegration time were calculated. It was then possible to correlate the rate of disintegration with other properties of each toilet paper.

Turbidity Test

The turbidity of the various toilet papers in water was measured using a Hach Lange Sc1000 Transmetteur and a Solitax SC to study the correlation with the rate of disintegration. Turbidity is a measurement of cloudiness, so a more turbid solution suggests a greater number of toilet paper fibers in the water. A standard of a known turbidity in water was first used to calibrate the Solitax SC, and a trash bag was wrapped around the equipment to block the light and give a more accurate turbidity reading. The trash bag also mimicked the lighting in sewers. An example of measuring the turbidity without the trash bag can be seen in Figure 9 below.

Figure 9: Testing the turbidity of DI water.

The toilet paper suspensions were prepared in water, at concentrations of one, two, and three g/L. A hand blender, the Proline Pied Mixeur, was used to grind the toilet paper to help it dissolve more rapidly. The turbidity of each suspension was measured and used to study the correlation between turbidity and disintegration rate.

Fiber Density Test

All fourteen varieties of toilet paper were placed under a Zeiss Axio Imager A1 Microscope to observe the fibers more closely. The purpose of this test was to measure the percentage of light that shone through a sheet of toilet paper to study the fiber density. It was then determined whether there was any correlation between fiber density and disintegration rate. For multi-ply papers, only one ply was placed under the microscope, so the fibers could be easily distinguished, as shown in Figure 10, below.

Figure 10: Peeling one ply of toilet paper to analyze under the microscope.

A magnification lens of 2.5X was used for all samples, and the amount of light used varied depending on the variety of toilet paper. The light was adjusted for each sample so that it was possible to distinguish individual fibers against the light that was shining through from the microscope. For each of the fourteen samples, twenty pictures were taken of different areas from a single sheet because the fibers are not uniform throughout, as shown in Figure 11, below. Taking multiple pictures from a variety of areas allowed for an average to be calculated so that the data was more representative of the brand as a whole.

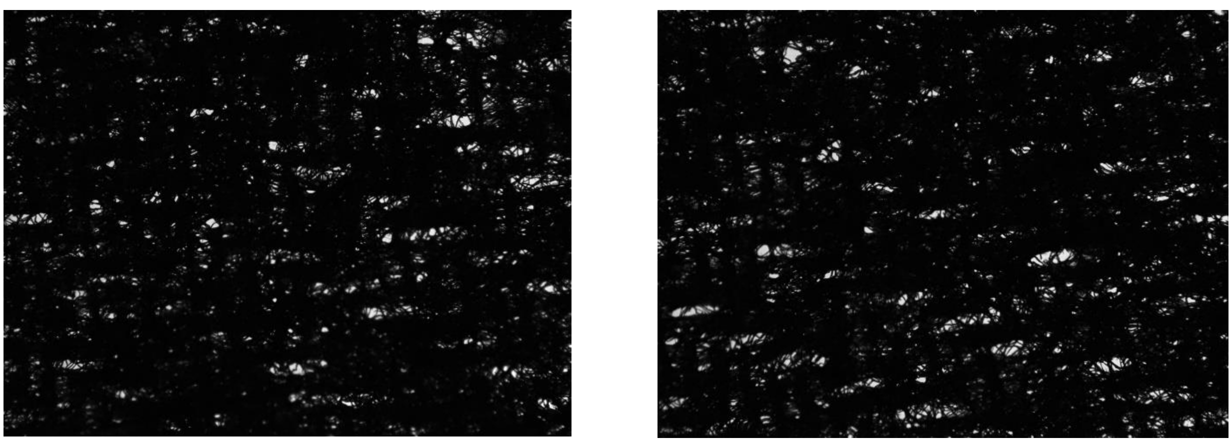

Figure 11: Two different images of Cora Confort toilet paper under the Zeiss Axio Imager A1 Microscope.

Light Percentage Calculations

The percentage of light from the microscope that shone through a single ply was calculated using an image analysis software, Visilog 6. The threshold was a number that corresponded with a color on the microscope image that would be considered "white" versus "black". In this instance, "white" would be spaces where light was shining through the paper, and "black" would be where the fibers were blocking the light. The threshold was automatically set for each of the microscope images. The Visilog 6 software then calculated the total number of pixels in the image that were considered to be "white". This was the number of pixels that represented light shining through the paper. The software also provided the dimensions of the image, which was the total number of pixels in the image. Dividing the number of pixels under the threshold by the total number of pixels resulted in the fraction of light shining through the sample. A larger percentage of light shining through a sample meant that there were more spaces between fibers, so the fibers were less dense. This data was later used to correlate the fiber density of each brand with its disintegration time calculated from the spin tests.

SEM Microscope

A scanning electron microscope (SEM) was used to analyze the three-dimensional structure of the toilet paper fibers. To prepare the samples, one ply of each paper was adhered to a round metal disk using carbon black tape, as shown in Figure 12.

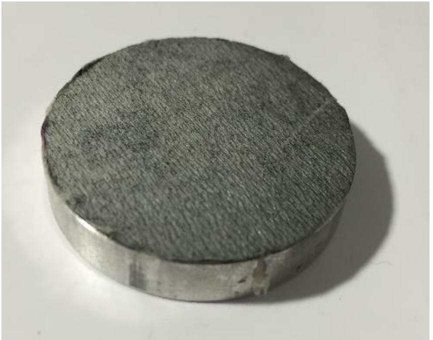

Figure 12: One ply of toilet paper adhered to a metal disk using carbon black tape.

To prepare the samples for the SEM, each disk was put into a Jeol Fine Coat Ion Sputter JFC-1100 to be coated with a palladium and gold alloy. This made the samples electrically conductive and allowed imaging in the SEM.

Multiple pictures of each sample were taken in the SEM at a magnification of 100X. It was observed that the toilet paper samples had different textures. Some areas appeared smooth and individual fibers were not obvious, indicating that they were glued tightly together. In other areas, the individual fibers were obvious or there were gaps between them, making the surface appear rough.

An image analysis software was used to quantify the texture of the images. The coefficient of roughness of each image was then used to calculate an average for each toilet paper. A higher roughness coefficient corresponds to a rougher surface. This data was then used to relate the roughness of the toilet paper to the disintegration time and fiber density.

Results and Discussion

Spin Test

The first step in conducting the spin tests was determining the appropriate number of times to test each brand of paper. Each paper was preliminarily tested three times to find a baseline for how long it took to dissolve. The preliminary testing for each brand is summarized in Table 2, below.

Name	Average Disintegration Time (min)
Lotus Moltonel	42
Lotus Just 1	102
Floralys Super Soft	66
Cora Confort	12
Solo Douceur	342
Floralys Extra Doux	48
Floralys Extra Resistant	90
Cora Douceur	30
Winny	420
Charmin Ultra Soft	60
Charmin	90
Goddard	420
Scott	48

Table 2: Average disintegration time of three preliminary spin tests for each brand of paper.

Using this baseline, three papers with shorter disintegration times were selected to be tested twelve times each, and the average and standard deviation were plotted over the number of trials. This information was then used to determine how many times the other papers should be tested. Cora Douceur, Cora Confort, and Charmin Ultra Soft were selected because they each had average disintegration times of one hour or less. It was important to choose papers with shorter disintegration times to complete the testing more efficiently. Testing the shorter papers multiple times was less time consuming than testing the longer papers.

The graphs of the average and standard deviation of the three chosen papers were used to determine how many times subsequent brands should be tested. After a certain number of trials, it was expected that the average and standard deviation would stop fluctuating and begin to remain constant. The number of trials after which this occurred would be the number of trials conducted on all other brands of toilet paper. Cutting down the number of trials on the brands that took longer to disintegrate saved a significant amount of time. The results from the twelve trials on Cora Douceur, Cora Confort, and Charmin Ultra Soft are summarized in Figures 13 - 15 below.

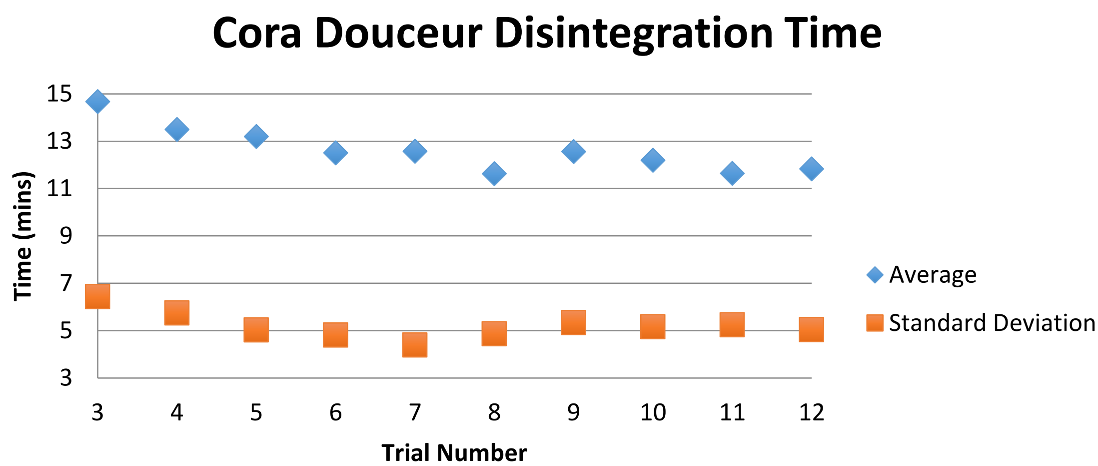

Figure 13: The average and standard deviations for the disintegration times of Cora Douceur.

The Cora Douceur results showed a steady decrease in both the average and the standard deviation of the disintegration time until trial seven. After this trial, the results begin to stabilize.

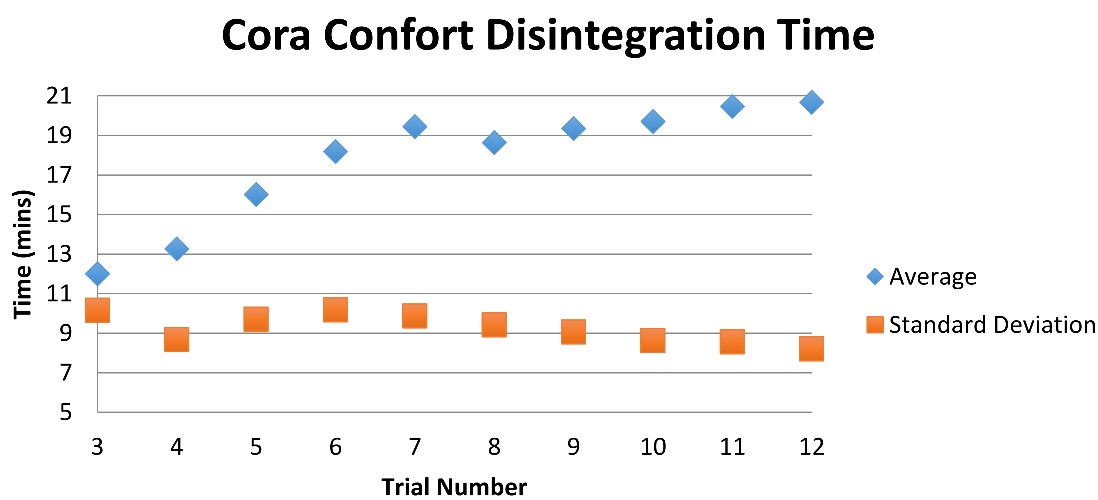

Figure 14: The average and standard deviations for the disintegration times of Cora Confort.

There is a sharp increase in the values until trial seven for Cora Confort, after which they begin to stabilize.

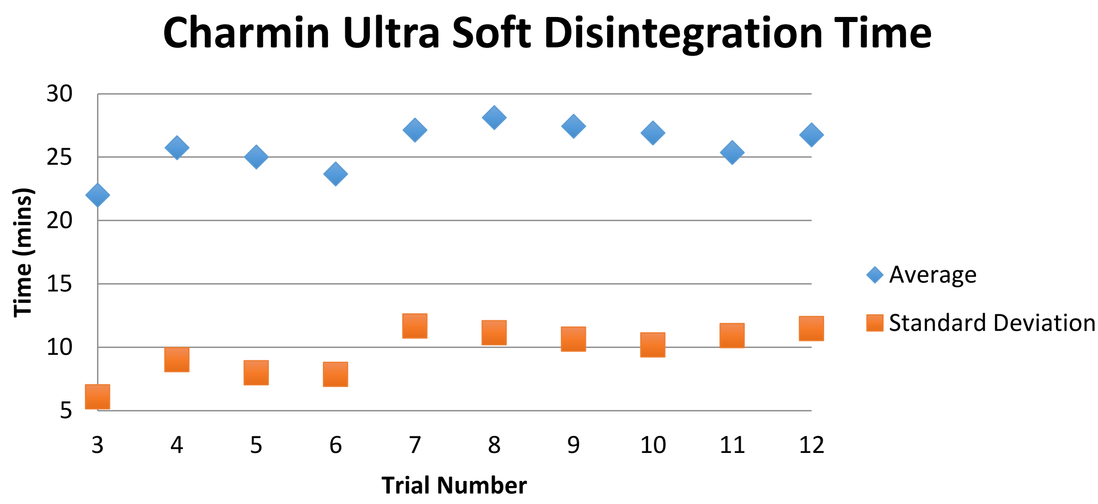

Figure 15: The average and standard deviations for the disintegration times of Charmin Ultra Soft.

The results fluctuate greatly until trial seven for Charmin Ultra Soft, after which they begin to stabilize. Since the values generally began to stabilize after trial seven, it was determined that nine trials would be an appropriate number of times to test the remaining brands. This number would allow for the average and standard deviation to be more accurate and testing nine times instead of eight accounted for error.

After preliminary testing was completed on three toilet paper brands, each toilet paper was tested nine times to measure the average disintegration time. The average disintegration time in minutes for each brand is shown in Figure 16, below.

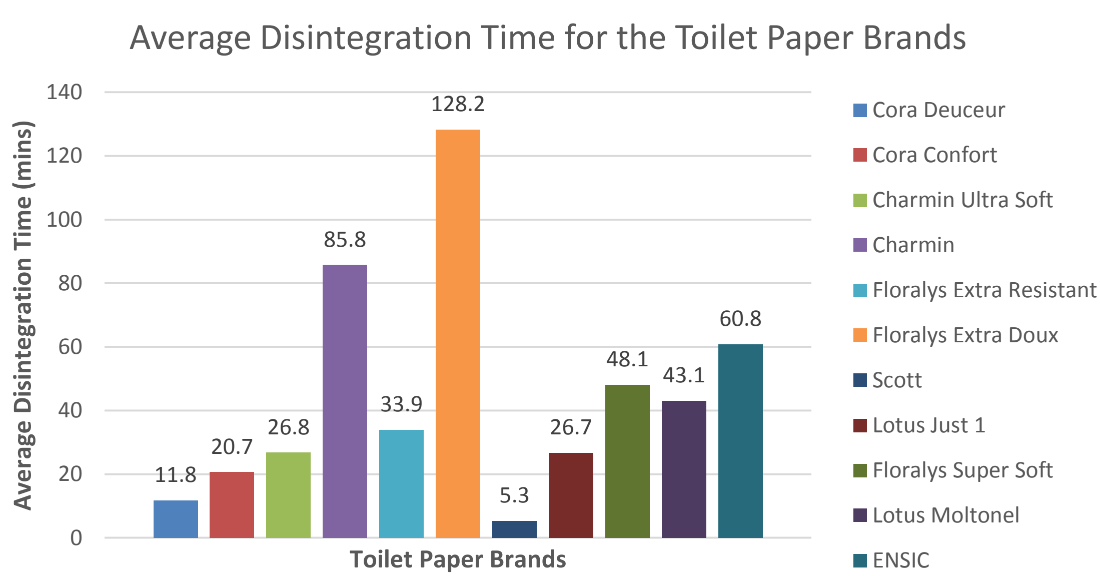

Figure 16: The average disintegration time in minutes of each toilet paper.

Goddard, Winny, and Cora Douceur were omitted from the figure above because they did not disintegrate after seven hours of testing. As a result, they were not tested nine times. Figure 16 shows that Floralys Extra Doux had the slowest disintegration time of 128 minutes, and Scott had the fastest disintegration time of 5 minutes. This data was then used to study the trends between other properties and disintegration time to determine if there were any correlations.

Turbidity Test

A suspension of toilet paper in water was made at concentrations of one, two, and three g/L for each brand. The turbidity of each suspension was then measured using a Hach Lange Sc1000 Transmetteur that was wrapped in a trash bag to imitate sewer lighting. It was expected that as the concentration increased, the turbidity of each brand would also increase because the water would be cloudier with more toilet paper. A summary of the results from seven of the brands is shown below in Figure 17. The seven brands were chosen at random to display to reduce the number of data points on the graph. Showing seven brands rather than all fourteen allowed for trends to be displayed more clearly.

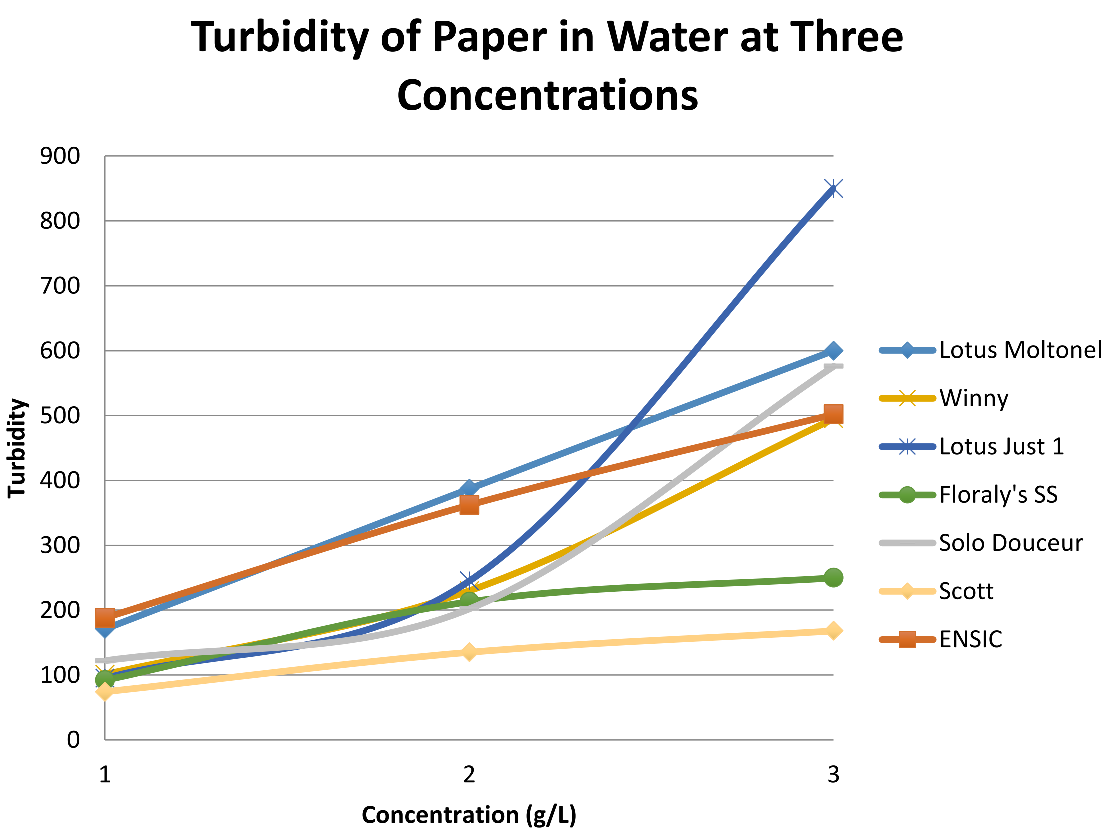

Figure 17: The turbidity of toilet papers in water at three different concentrations.

It can be noted that the turbidity increases with increased concentration, but the amount by which it increases varies greatly between brands. For example, the turbidity of Lotus Moltonel appears to increase nearly linearly with each change in concentration, but Lotus Just 1 displays a sharp increase in turbidity when the concentration is increased from two to three g/L. It can also be noted that at a concentration of one g/L, the turbidity of each brand is very similar, and falls between 50 and 200. As the concentration increases, there is much more variance between the turbidity of each brand.

The turbidity measurements and the average disintegration time at various concentrations are plotted together in Figure 18, below, to study the correlation between these two properties. Toilet papers that did not disintegrate after seven hours were not included in these graphs to reduce the axis scale and study the trends more clearly.

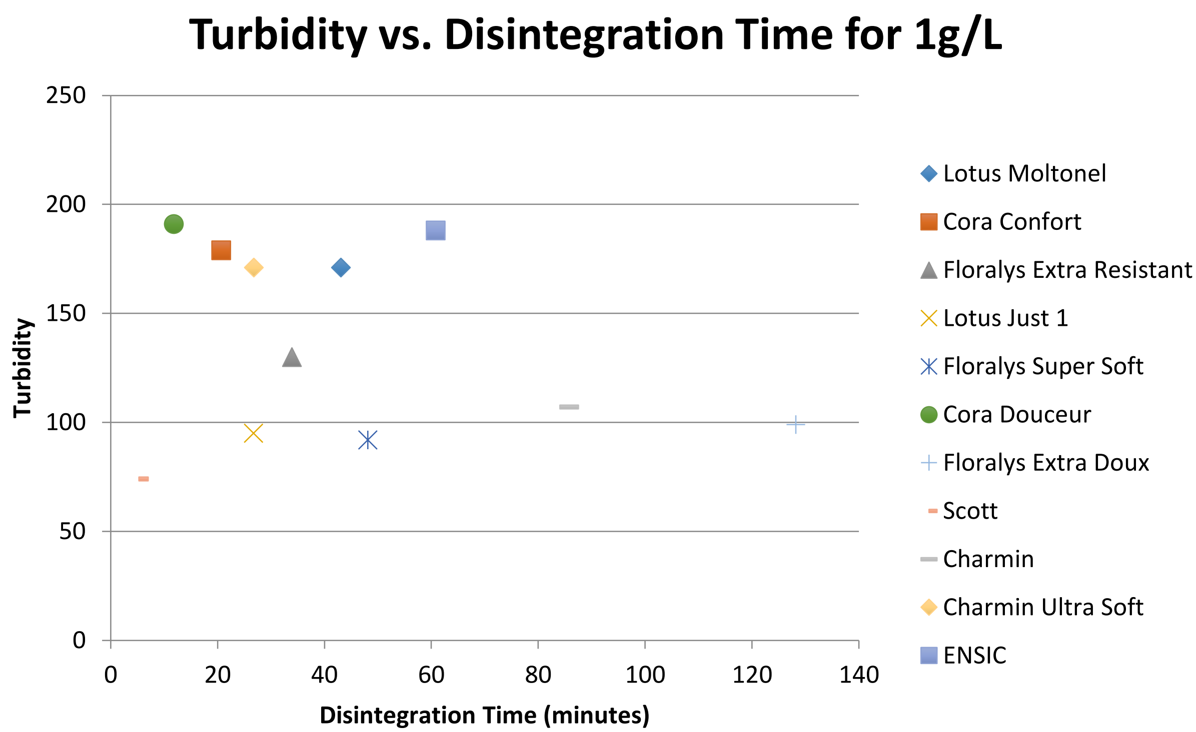

Figure 18: Disintegration time versus turbidity for 1g/L for the toilet papers.

At a concentration of one g/L, there is no obvious correlation between the disintegration time and turbidity of each brand.

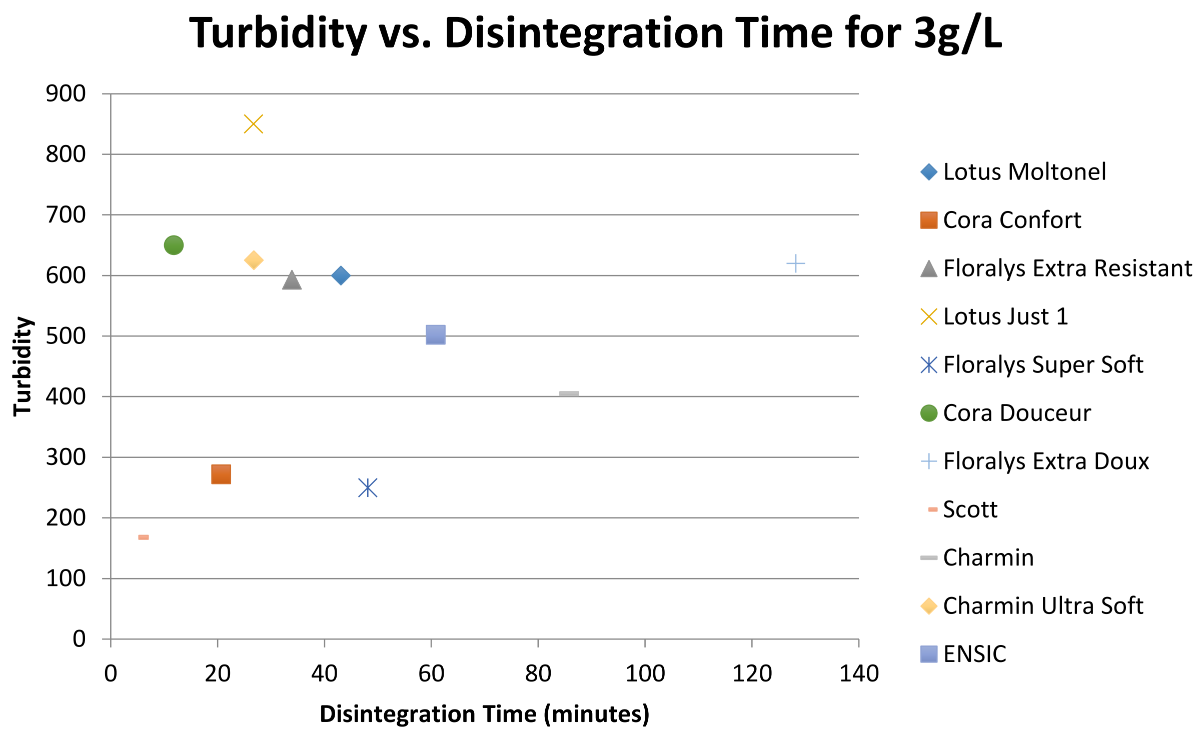

Figure 19: Disintegration time versus turbidity for 1g/L for the toilet papers.

At a concentration of three g/L, there appears to be a negative correlation between half of the points, but since the other half do not follow the trend, no conclusions can be drawn. From this data it cannot be concluded whether the turbidity of a toilet paper brand has any effect on its disintegration time. Additional testing was done to examine the effect of partial size and shape on the turbidity measurements. This case study is discussed in Appendix B.

Fiber Density Test

Once the percentage of light from the microscope shining through each sample was determined, an average was calculated for each of the fourteen brands of toilet paper. A greater percentage of light shining through the paper meant that there were more spaces between the fibers, so they were less dense. Essentially, measuring the percentage of light shining through the paper was the equivalent of measuring the percentage of empty spaces between the fibers. The purpose of measuring this physical characteristic was to evaluate any correlation between the fiber density and the disintegration time. The results for the average percentage of light shining through each paper are shown in Figure 20, below, with the standard deviation shown above each bar. It is important to note that the percentage of light shining through the paper is inversely related to fiber density.

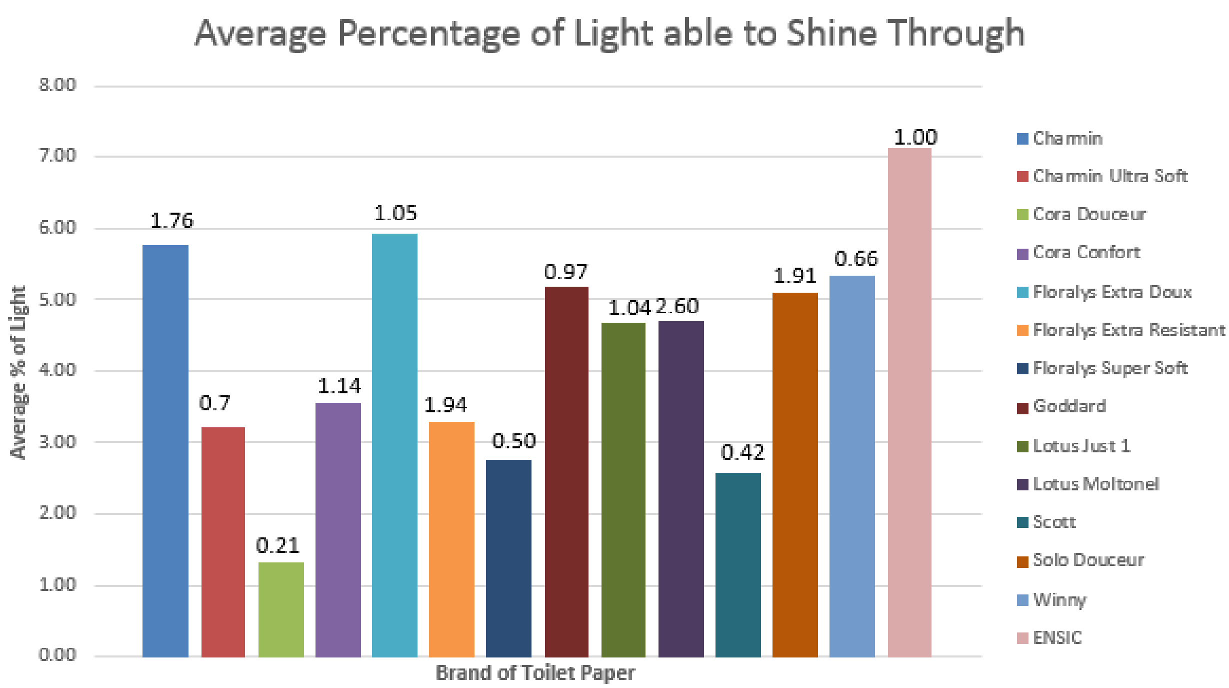

Figure 20: The average percentage of light fable to shine through each toilet paper brand with the standard deviation shown above each bar.

The toilet papers had a wide range of fiber densities. The percentage of light shining through each paper ranged from 1.32% for Cora Douceur to 7.12% for ENSIC. Based on this measurement alone, Cora Douceur has the greatest fiber density, and ENSIC has the most spaces and holes between fibers.

An overall trend was observed between the fiber density and the disintegration time of each sample, as shown in Figure 21, below. Winny, Goddard, and Solo Douceur are excluded from this graph because they did not disintegrate in under seven hours. Eliminating these points significantly reduces the scale of the axis, making the trend easier to study.

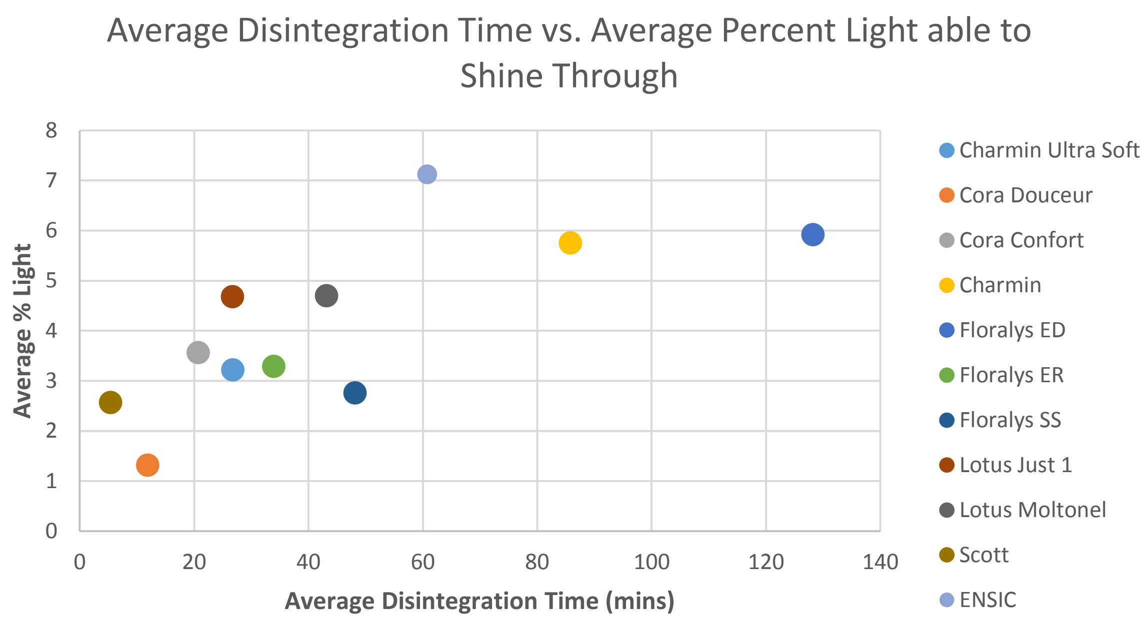

Figure 21: The relationship between the average disintegration time of the toilet papers and their average light percentage.

There is a positive correlation between the disintegration time and the average amount of light shining through each paper, so there is a negative correlation between disintegration time and fiber density. In general, the toilet papers that required more time to disintegrate had lower fiber densities since more light was able to shine through the paper. Since the trend is not completely linear, the disintegration time also depends on additional factors.

In Figure 22, below, the three toilet papers that did not disintegrate are added to the graph. These papers have been assigned a disintegration time of 200 minutes to reduce the size of the axis scale.

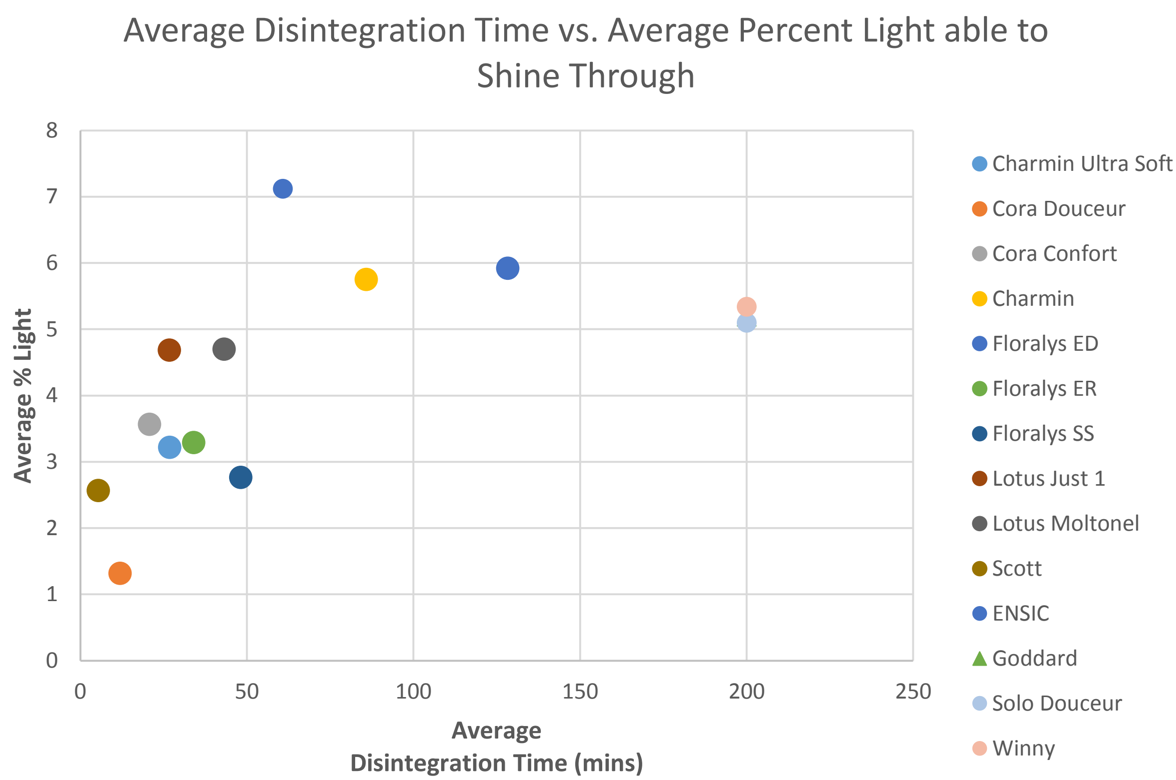

Figure 22: The average disintegration time versus percentage of light for all toilet papers.

It can be noted that the points for Winny, Goddard, and Solo Douceur are nearly overlapping because they have very similar fiber densities. They still follow the general trend that a greater percentage of light able to shine through corresponds with a longer disintegration time. However, the points for the three papers that did not disintegrate have lower percentages of light able to shine through than some of the other papers tested. This suggests that after a certain point, there is a maximum percentage of light that is able to shine through, or a minimum fiber density that is reached.

SEM

An SEM was used to take approximately twenty pictures of each of the fourteen toilet paper brands. Using an image analysis software, the texture of the paper in each image was quantified and assigned a coefficient of roughness. A paper with a higher coefficient has a rougher surface, meaning that the fibers are less attached to one another. A lower coefficient of roughness means that the paper surface is smoother, suggesting that the fibers are more thoroughly glued together. Examples of rough and smooth papers can be seen in Figure 23, below. The photo on the left shows an image of Charmin that has a roughness coefficient of 8.03. The photo on the right shows Goddard with a roughness coefficient of 2.56.

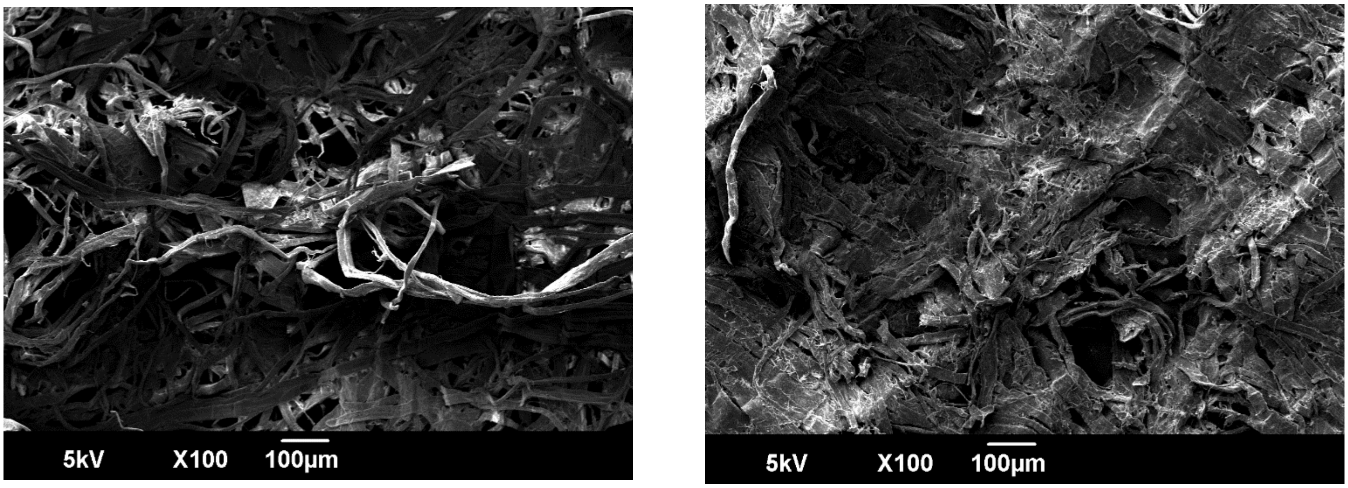

Figure 23: Photos of rough paper (left), and smooth paper (right).

An average coefficient of roughness was calculated for each of the papers. This average was then plotted against the disintegration time to study the potential correlation between the two properties. The relationship is shown in Figure 24, below. It can be noted that Solo Douceur, Winny, and Goddard are not shown on the plot. This is because their disintegration times were longer than seven hours, so removing them from the plot reduced the scale of the axis, making the trend easier to study.

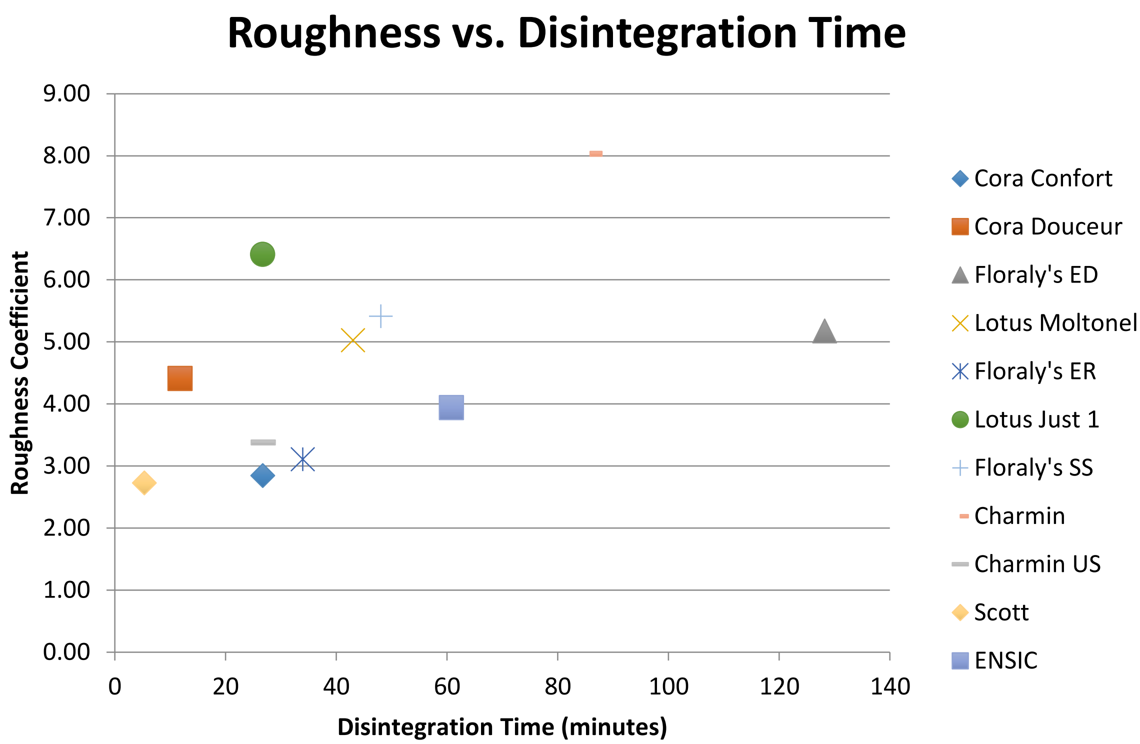

Figure 24: Relationship between the roughness coefficient and disintegration time.

There is a slight positive correlation between the roughness coefficient and the disintegration time of the toilet papers. This means that papers with rougher surfaces tend to take longer to disintegrate. Therefore, the papers that are more glued together, with smoother surfaces, disintegrate more quickly.

Figure 25, below, is the same plot including Winny, Goddard, and Solo Douceur. These papers did not disintegrate in less than seven hours but were plotted below as disintegrating in 200 minutes, which was chosen to reduce the scale of the axis.

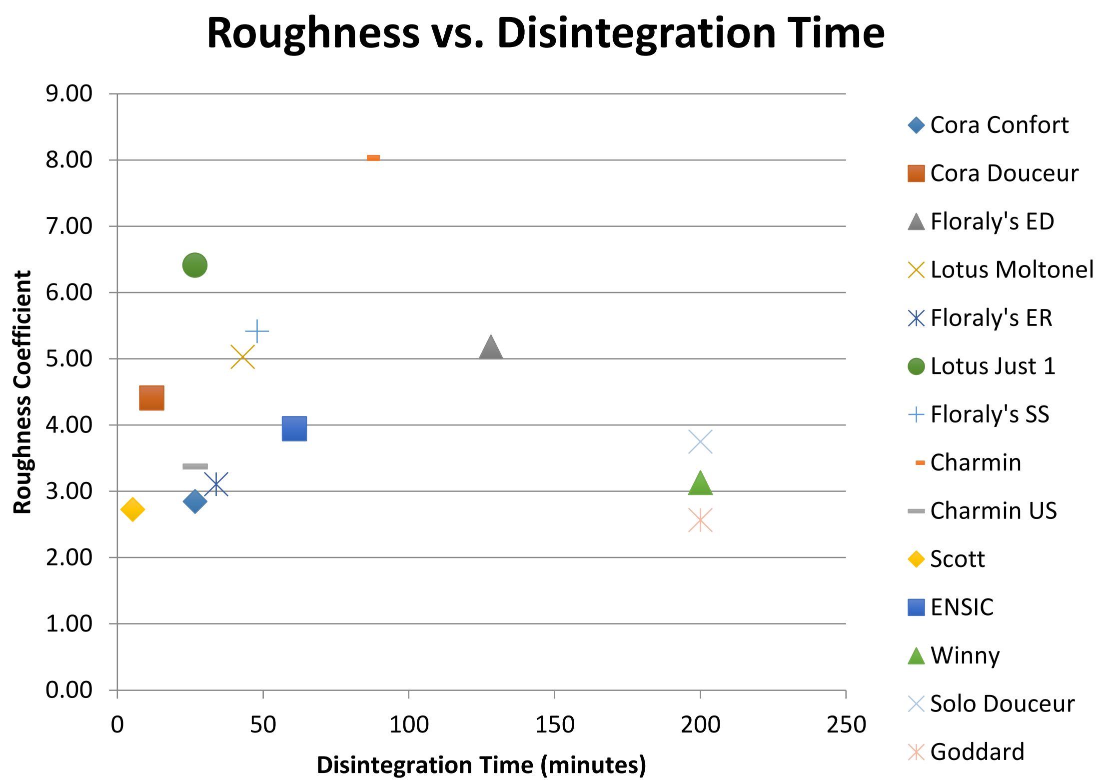

Figure 25: The roughness versus disintegration time for all toilet papers.

These three toilet papers have similar roughness coefficients to Scott and ENSIC despite their longer disintegration time. This indicates that roughness is not a dominant factor affecting the disintegration time. In general, a smoother surface disintegrates more quickly, but there are other properties that have a stronger effect on the disintegration. There were multiple sources of error when analyzing the SEM data that may have skewed the roughness coefficient. These potential errors are discussed later on.

Error Analysis

Spin Tests

Throughout experimentation, there were various sources of error that may have skewed the data. When conducting the spin tests, four different blades on the floculator were used simultaneously, and it was noted that the paper on the first blade usually disintegrated first, and paper on the third blade usually took the longest to disintegrate. This suggests that the different blades may have been spinning at inconsistent speeds. The third blade also rocked back and forth slightly as it was spinning which subjected that toilet paper to different movements compared to the other blades. The blades would also occasionally sink into the water, so they would need to be lifted back into position. This movement may have caused some of the samples to break off of the blade more quickly than if they had been undisturbed.

Another source of error during the spin tests was that the water used in the beakers was not at a consistent temperature. They were subjectively filled with room-temperature water, but the temperature was not confirmed with a thermometer. The disintegration time may have been faster or slower depending on the temperature of the water used during testing.

The various brands also had toilet paper sheets of different dimensions. In order to fit the toilet paper into the beaker, the perforations were sometimes parallel and sometimes perpendicular to the blade. It is possible that the uneven edges of the perforations being in different orientations may have also had an effect on the disintegration times across brands.

Turbidity

It is important to note that the Solitax SC reads turbidity at values between 0 and 4000. At the beginning of each day, the turbidity of deionized water was measured, and it varied from day to day. It was expected that the turbidity of water would be zero since it should be clear, but the machine registered it inaccurately. A summary of the dates and deionized water turbidities is displayed in Figure 26, below.

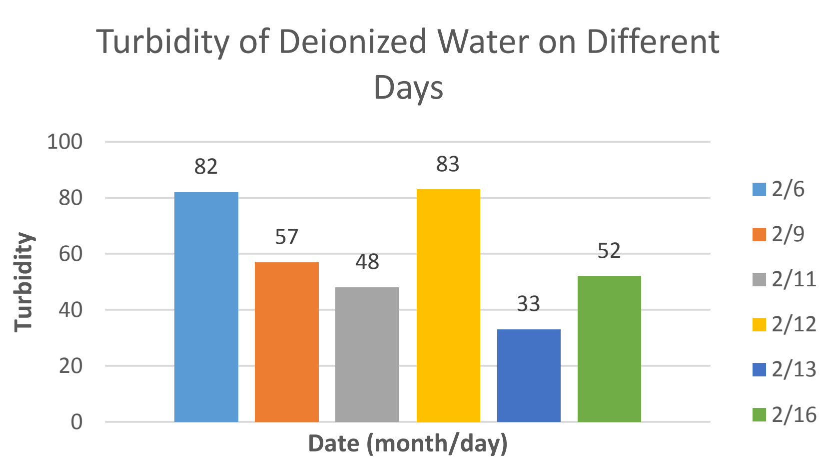

Figure 26: The turbidity of deionized water on different days of testing.

Since the turbidity was measured on a scale of 0 to 4000 the variation shown in Figure 26 is considered to be "noise". There was sometimes a change of less than 100 between the turbidity of toilet paper at different concentrations. It is unclear how much of that variation can be attributed to "noise" versus an actual change in turbidity.

The size and shape of the fibers being measured may have also affected the turbidity measurements. As previously mentioned, a case study on this effect can be found in Appendix B.

A trash bag was also used to block the light during the turbidity measurements, but this was not a perfect method, and there may have been some light that skewed the sample readings.

Fiber Density

A source of error when measuring the fiber density was that all twenty microscope pictures were taken of the same sheet of toilet paper. Taking twenty pictures accounted for variation in different areas of that specific sheet, but it did not account for variation throughout the roll. It is possible that sheets from the beginning, middle, and end of the roll may have had different fiber densities, so this was a source of error in measuring this property.

SEM Coefficient of Roughness

The image analysis software was not perfect, and the measurements of roughness are highly dependent on the clarity and lighting in the SEM images. Therefore, the image analysis software itself was a source of error when calculating the roughness coefficient of each brand.

Conclusions and Recommendations

The goal of this study was to determine how various properties impact the disintegration time of toilet paper to reduce the consequences of sewer overflows. Spin tests were used to quantify the rate of disintegration of fourteen brands of toilet paper from France and the US. This data was used to study correlations between disintegration time, fiber density, turbidity, and roughness.

It was noted that there were various sources of error when conducting the spin tests, so in future experiments there should be some improvements made to the testing method. Each of the blades should be calibrated to ensure that the speed readout on the floculator matches the speed of each individual blade. If time allowed, the accuracy of the disintegration time measurements could also be improved by using the same blade for each trial. It is also recommended that the water temperature be measured to ensure that it is consistent between spin test trials. Finally, it is recommended that wider beakers be used so that the toilet paper can be folded over the blade with the perforations in the same orientation each time. With these improvements, some outside factors affecting the disintegration time would be eliminated, providing more accurate results.

As expected, there was an increase in turbidity for each brand as the concentration increased because the water became cloudier as more toilet paper was added. At concentrations of one and three g/L, there were no obvious trends between the disintegration time and turbidity of each brand of paper. Therefore, no conclusions can be drawn without further testing.

Due to time constraints, each brand was tested at each concentration only once, so it is recommended that more measurements be taken in future experiments. Taking an average of multiple measurements would provide more accurate data. In order to further improve the measurements, it is recommended that the Solitax SC be calibrated more thoroughly. The machine displayed "noise" when measuring the turbidity of deionized water each day, so it was not a reliable instrument when analyzing the toilet paper solutions. It is also recommended that the Hach Lange Sc1000 Transmetteur be placed in a darkroom during future experimentation. Since light skews the turbidity measurements, a trash bag was placed around the instrument, but a darkroom would be a more effective method of blocking all light.

To measure the fiber density of each brand of toilet paper, the percentage of light able to shine through a single ply was calculated using Visilog software. It was concluded that as the percentage of light able to shine through the paper increased, the disintegration time also increased. Therefore, toilet papers with greater fiber densities have lower disintegration times.

When measuring the percentage of light that shone through each toilet paper, the microscope pictures were all from the same sheet. In future experiments it is recommended that the pictures be taken from sheets from the beginning, middle, and end of the roll to account for variation.

The roughness coefficients of SEM photos were calculated using an image analysis software. It was concluded that papers with rougher surfaces took longer to disintegrate. This means that papers that are more glued together, and therefore have smoother surfaces, have faster disintegration times. However, when studying the papers that did not disintegrate, it became clear that roughness is not a dominant factor affecting disintegration time. In the future, additional properties should be studied to determine which properties have a stronger impact on disintegration.

With the exception of the spin tests, the toilet paper plies had to be peeled apart for all experiments. It was noted during sample preparation that some plies were easier to pull apart compared to other toilet papers. It is possible that their ease of separation may have a significant contribution to disintegration time. This was not quantified or analyzed in this study, but it may be a useful property to examine in future experiments.

Overall, it was concluded that toilet papers with faster disintegration times generally have denser fibers and smoother surfaces. Without further experimentation, there can be no conclusions made regarding the turbidity. These properties coincide with what customers generally look for when buying paper for their homes, so the potential for creating an environmentally friendly toilet paper is promising.

Nomenclature

Charmin US: Charmin Ultra Soft

ENSIC: Toilet paper taken from the École Nationale Supérieure des Industries Chimiques's bathroom

EU: European Union

Floraly's ED: Floraly's Extra Doux

Floraly's ER: Floraly's Extra Resistant

Floraly's SS: Floraly's Super Soft

Goddard: Toilet paper taken from the Goddard Hall building on the Worcester Polytechnic Institute campus

SEM: Scanning Electron Microscope

SSO: Sanitary Sewer Overflow

US: United States

USEPA: United States Environmental Protection Agency

WHO: World Health Organization

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Appendix A: Aqua Tube ™ Case Study

Aqua Tube ™ is a flushable and biodegradable toilet paper tube developed by Georgia-Pacific. Replacing the traditional cardboard tube, Aqua Tube ™ is advertised to disintegrate in the drainpipe when flushed down the toilet and does not require a separate flush. The tube contains wood pulp from certified suppliers, which allows for rapid disintegration (Aqua Tube).

A case study was done to determine the disintegration time of Aqua Tube ™ to test if it performed as advertised. The tube was also analyzed with an SEM to study its three-dimensional structure and the roughness coefficient.

The Aqua Tube ™ was cut in half and attached to the floculator blades to measure the disintegrate time, as shown in Figure 27.

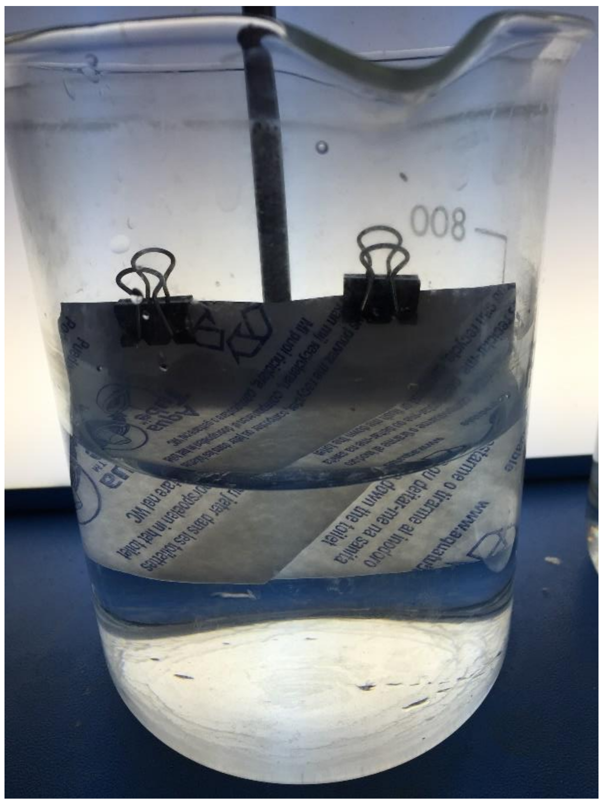

Figure 27: Aqua Tube ™ spin test.

Once the blades began spinning, it was observed that the tube disintegrated almost instantaneously after being lowered into the water. It was not possible to state an exact time that it took to disintegrate, so the disintegration time is summarized as being less than five seconds.

This disintegration time is significantly faster than that of any toilet paper tested in this study. The technology used in the tube is therefore useful to study when characterizing how toilet paper properties affect disintegration. It was not possible to test the fiber density of the tube since it does not have plies. Therefore, it was not possible to compare the density of the tube to see if it followed the trend that denser fibers disintegrate more quickly. In the future, it is recommended that a similar test be developed for testing the fiber density of the tube.

The turbidity of the tube in water was also not tested. There was no correlation between turbidity and disintegration time found when testing the papers, so it was not useful to study this property of the tube.

Finally, SEM pictures were taken of the tube, and the image analysis software was used to determine that the average roughness coefficient was 3.45. This roughness coefficient falls on the lower end compared to the toilet papers measured, adhering to the trend that a smoother surface correlates with a lower disintegration time.

In the future it is recommended to further study the properties of the Aqua Tube ™ compared to those of the toilet papers to determine other properties that may affect disintegration time. This technology could be used to eventually create a new toilet paper that disintegrates more quickly in sewer systems, preventing sewer overflows.

Appendix B: Case Study on Additional Factors Affecting Turbidity

The turbidity of each brand of toilet paper was measured at concentrations of one, two, and three g/L in water, and no conclusions were drawn from the collected data. As an additional case study, the turbidity of four other solids were measured at the same three concentrations and compared to the toilet papers. The purpose of this study was to examine the potential that other factors affect the turbidity reading on the Hach Lange Transmetteur.

The turbidities of kieselguhr, corn starch, rice starch, and potato starch are shown at each concentration in Figure 28, below. Three toilet papers were arbitrarily chosen to also be represented on the graph as a basis of comparison. Only three papers are shown rather than all fourteen to reduce the number of data points and make the trends easier to study. The three toilet papers are represented by dotted lines, while the three starches and the kieselguhr are represented by solid lines.

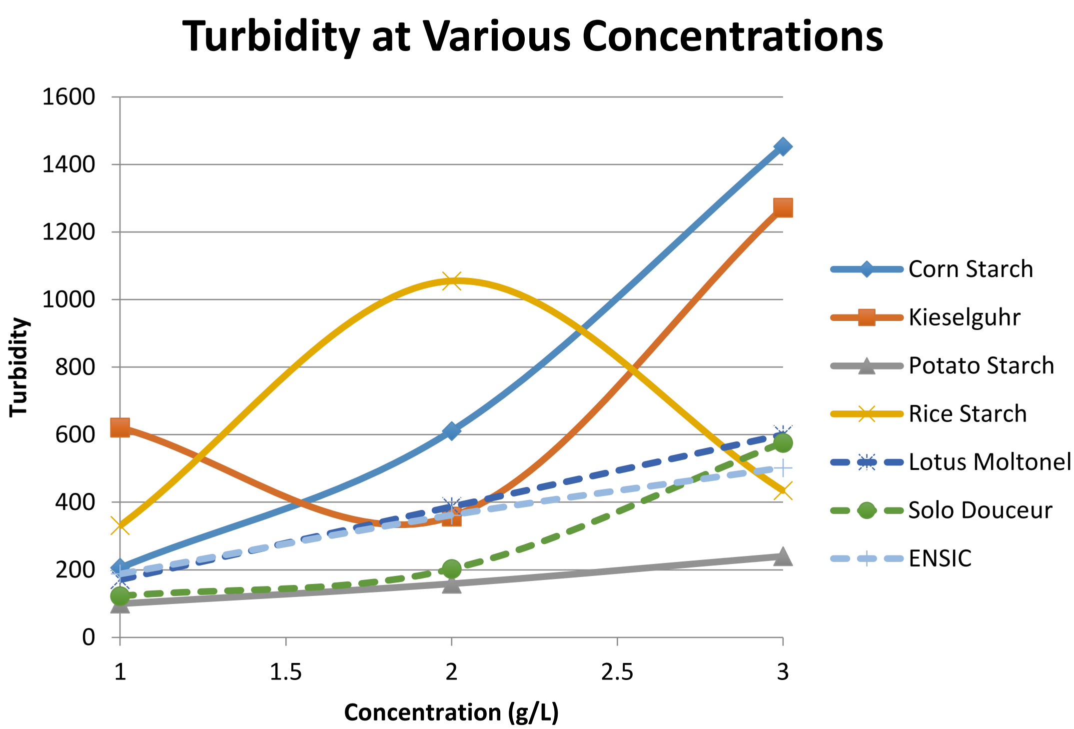

Figure 28: The turbidity of three toilet papes and other solids at various concentrations.

As the concentration of each substance increases, the turbidity is also expected to increase because the water should be cloudier. The toilet papers, potato starch, and corn starch all follow this trend, but the kieselguhr and rice starch do not. It can be noted that the turbidity of rice starch decreases as the concentration increases from two to three g/L, and there is a similar phenomenon for the kieselguhr between one and two g/L. This suggests that there is an additional factor affecting the measurements because the results do not make physical sense.

It can also be noted that the amount by which the turbidity changes between concentrations varies greatly for each substance. A potential explanation for this observation is that the transmetteur registers the turbidity differently for particles of different shapes and sizes.

It can be seen on the graph that the three toilet papers, represented by dotted lines, are closer to each other than to the other solids on the graph. This could mean that the transmetteur registers the toilet paper fibers in a different way than it registers other particles.

A possible explanation for the sharp changes between some of the concentrations, as well as the fact that two data points show a decreased turbidity with increased concentration, is that particles could be sticking to the sensor. If a particle sticks to the sensor or blocks it in some way, then the transmitteur will not be able to accurately meaure the turbidity of the solution.

In the future it recommended that more experimentation to be done to further examine the magnitude of these effects on the turbidity readings. A deeper understanding would allow for alterations to be made to the testing method so that more accurate data could be collected and conclusions could be drawn on the effect of turbidty on toilet paper disintegration time.

Appendix C: Raw Data

Spin Test Data

Cora Deuceur			
Trial	Time (mins)	Average	Standard Deviation
1	12	x	
2	10	x	
3	22	14.67	6.43
4	10	13.5	5.74
5	12	13.2	5.02
6	9	12.5	4.81
7	13	12.57	4.39
8	5	11.62	4.87
9	20	12.55	5.34
10	9	12.2	5.16
11	6	11.64	5.24
12	14	11.8	5.04

Cora Confort			
Trial	Time (mins)	Average	Standard Deviation
1	3	x	
2	23	x	
3	10	12	10.15
4	17	13.25	8.65
5	27	16	9.69
6	29	18.17	10.17
7	27	19.43	9.86
8	13	18.62	9.4
9	25	19.33	9.05
10	23	19.7	8.61
11	28	20.45	8.55
12	23	20.7	8.18

Charmin Ultra Soft			
Trial	Time (mins)	Average	Standard Deviation
1	29	x	
2	18	x	
3	19	22	6.08
4	37	25.75	8.99
5	22	25	7.97
6	17	23.67	7.84
7	48	27.14	11.65
8	35	28.125	11.14
9	22	27.44	10.62
10	22	26.9	10.16
11	10	25.36	10.90
12	42	26.8	11.45

Charmin			
Trial	Time (mins)	Average	Standard Deviation
1	87	x	
2	103	x	
3	117	102.33	15.01
4	82	97.25	15.92
5	110	99.8	14.92
6	63	93.67	20.10
7	83	92.14	18.78
8	82	90.88	17.75
9	32	84.33	25.71
10	60	81.9	25.43
11	90	82.64	24.25
12	120	85.8	25.51

Floralys ER			
Trial	Time (mins)	Average	Standard Deviation
1	3	x	
2	5	x	
3	29	12.33	14.47
4	9	11.5	11.93
5	5	10.2	10.73
6	43	15.67	16.48
7	26	17.14	15.54
8	9	16.12	14.67
9	10	15.44	13.87
10	180	31.9	53.66
11	30	31.73	50.91
12	58	33.9	49.12

Floralys ED			
Trial	Time (mins)	Average	Standard Deviation
1	104	x	
2	98	x	
3	106	102.67	4.16
4	96	101	4.76
5	135	107.8	15.75
6	61	100	23.74
7	168	109.71	33.62
8	182	118.75	40.27
9	204	128.2	47.19

Scott			
Trial	Time (mins)	Average	Standard Deviation
1	4		
2	3		
3	8	5	2.64
4	10	6.25	3.30
5	1	5.2	3.70
6	2	4.67	3.56
7	9	5.28	3.64
8	10	5.88	3.76
9	1	5.3	3.87

Lotus Just 1			
Trial	Time (mins)	Average	Standard Deviation
1	16		
2	19		
3	40	25	13.08
4	33	27	11.40
5	25	26.6	9.91
6	27	26.67	8.87
7	19	25.57	8.60
8	31	26.25	8.19
9	30	26.7	7.76

Floralys SS			
Trial	Time (mins)	Average	Standard Deviation
1	89		
2	94		
3	70	84.33	12.66
4	34	71.75	27.21
5	33	64	29.25
6	25	57.5	30.63
7	7	50.28	33.85
8	25	47.13	32.59
9	56	48.1	30.63

Lotus Moltonel			
Trial	Time (mins)	Average	Standard Deviation
1	42		
2	17		
3	8	22.33	17.62
4	46	28.25	18.63
5	78	38.2	27.48
6	63	42.33	26.58
7	51	43.57	24.49
8	48	44.12	22.72
9	35	43.1	21.47

ENSIC			
Trial	Time (mins)	Average	Standard Deviation
1	38		
2	57		
3	71	55.33	16.56
4	73	59.75	16.15
5	48	57.40	14.94
6	36	53.83	15.97
7	135	65.43	33.96
8	77	66.88	31.71
9	12	60.78	34.85

Turbidity Test Data

Brand	Concentration (g/L)	Turbidity
Lotus Moltonel	1	171
Lotus Moltonel	2	387
Lotus Moltonel	3	600
Cora Confort	1	179
Cora Confort	2	338
Cora Confort	3	272
Floraly's ER	1	130
Floraly's ER	2	425
Floraly's ER	3	593
Winny	1	101
Winny	2	230
Winny	3	495
Lotus Just 1	1	95
Lotus Just 1	2	245
Lotus Just 1	3	850
Floraly’s SS	1	92
Floraly’s SS	2	213
Floraly’s SS	3	250
Cora Douceur	1	191
Cora Douceur	2	261
Cora Douceur	3	650
Floraly’s ED	1	99
Floraly’s ED	2	335
Floraly’s ED	3	620
Solo Douceur	1	122
Solo Douceur	2	202
Solo Douceur	3	576
Scott	1	74
Scott	2	135
Scott	3	168
Goddard	1	270
Goddard	2	230
Goddard	3	762
Charmin	1	107
Charmin	2	321
Charmin	3	405
Charmin US	1	171
Charmin US	2	296

Charmin US	3	625
ENSIC	1	188
ENSIC	2	362
ENSIC	3	502
Kieselguhr	1	621
Kieselguhr	2	358
Kieselguhr	3	1272
Potato Starch	1	100
Potato Starch	2	159
Potato Starch	3	240
Corn Starch	1	206
Corn Starch	2	611
Corn Starch	3	1453
Rice Starch	1	331
Rice Starch	2	1055
Rice Starch	3	435

Fiber Density Test Data

Charmin

#	Threshold	# of Blue Pixels	% Light
1	64	99839	6.92
2	67	112502	7.79
3	69	95285	6.60
4	67	110114	7.63
5	65	69053	4.78
6	68	114497	7.93
7	66	84865	5.88
8	70	76868	5.33
9	68	61687	4.27
10	57	68617	4.75
11	71	58661	4.06
12	65	72017	4.99
13	69	59904	4.15
14	70	14651	1.01
15	71	109729	7.60
16	62	68720	4.76
17	60	119052	8.25
18	70	84286	5.84
19	64	100523	6.96
20	66	80847	5.60
		Average Light %	5.76

Charmin Ultra Soft

#	Threshold	# of Blue Pixels	% Light
1	65	48571	3.36
2	68	64109	4.44
3	69	43167	2.99
4	78	38958	2.70
5	66	48868	3.39
6	69	31853	2.21
7	78	31780	2.20
8	67	43210	2.99
9	75	43183	2.99
10	86	29673	2.06
11	66	42698	2.96
12	65	49265	3.41
13	72	44819	3.10
14	73	39631	2.75
15	57	53260	3.69
16	70	66771	4.63
17	70	57878	4.01
18	66	595474	41.25
19	68	46842	3.24
20	71	46219	3.20
		Average	5.08

Cora Douceur

#	Threshold	# of Blue Pixels	% Light
1	72	19975	1.38
2	78	16928	1.17
3	75	22852	1.58
4	69	20957	1.45
5	68	18291	1.27
6	71	23037	1.60
7	76	18471	1.28
8	68	20571	1.43
9	81	22850	1.58
10	81	16637	1.15
11	78	17396	1.21
12	76	16379	1.13
13	72	19850	1.38
14	72	23082	1.60
15	80	16768	1.16
16	76	20908	1.45
17	79	17393	1.20
18	64	10345	0.72
19	75	18889	1.31
20	74	19266	1.33
		Average	1.32

Cora Confort

#	Threshold	# of Blue Pixels	% Light
1	61	50209	3.48
2	70	50687	3.51
3	69	56963	3.95
4	68	69076	4.79
5	69	57595	3.99
6	69	51142	3.54
7	66	46716	3.24
8	75	45536	3.15
9	84	38596	2.67
10	62	61340	4.25
11	67	62505	4.33
12	66	63208	4.38
13	56	46781	3.24
14	70	66938	4.64
15	65	55290	3.83
16			0.00
17	64	47753	3.31
18	61	30503	2.11
19	69	49799	3.45
20	65	79195	5.49
		Average	3.57

ENSIC

#	Threshold	# of Blue Pixels	% Light
1	62	91497	6.34
2	57	96535	6.69
3	60	79063	5.48
4	60	135566	9.39
5	60	88917	6.16
6	57	103550	7.17
7	60	112933	7.82
8	70	119229	8.26
9	61	116215	8.05
10	57	103923	7.20
11	58	86039	5.96
12	57	94615	6.55
13	55	116988	8.10
14	55	98180	6.80
15	57	97331	6.74
16	57	105132	7.28
17	55	107601	7.45
18	57	122628	8.50
19	56	89895	6.23
20	60	88336	6.12
		Average	7.12

Floraly's Extra Doux

#	Threshhold	# of Blue Pixels	% Light
1	76	100046	6.93
2	65	102339	7.09
3	66	95805	6.64
4	66	102313	7.09
5	64	93083	6.45
6	57	84463	5.85
7	70	86217	5.97
8	76	95856	6.64
9	70	89758	6.22
10	70	61626	4.27
11	65	79605	5.51
12	71	67199	4.66
13	70	63023	4.37
14	66	61821	4.28
15	75	80249	5.56
16	69	65939	4.57
17	71	89577	6.21
18	61	98826	6.85
19	65	80564	5.58
20	65	111889	7.75
		Average	5.92

Floraly's Extra Resistant

#	Threshold	# of Blue Pixels	% Light
1	69	46419	3.22
2	79	29103	2.02
3	60	46219	3.20
4	60	40538	2.81
5			0.00
6	76	48872	3.39
7			0.00
8	63	70019	4.85
9	67	87550	6.07
10	63	65719	4.55
11	58	61838	4.28
12	60	76117	5.27
13	62	72590	5.03
14	63	68476	4.74
15	59	56969	3.95
16			0.00
17	67	70858	4.91
18	65	63538	4.40
19			0.00
20	61	45842	3.18
		Average	3.29

Floraly's Super Soft

#	Threshold	# of Blue Pixels	% Light
1	70	42814	2.97
2	68	33483	2.32
3	70	29236	2.03
4	69	38223	2.65
5	70	42827	2.97
6	67	52251	3.62
7	66	32993	2.29
8	67	39007	2.70
9	67	36586	2.53
10	65	44192	3.06
11	68	57741	4.00
12	69	47700	3.30
13	64	31228	2.16
14	67	36031	2.50
15	69	37933	2.63
16	68	46408	3.21
17	65	36061	2.50
18	70	34963	2.42
19	70	44334	3.07
20	67	34524	2.39
		Average	2.77

Goddard

#	Threshold	# of Blue Pixels	% Light
1	57	63497	4.40
2	67	61937	4.29
3	53	77030	5.34
4	68	58358	4.04
5	56	90703	6.28
6	67	56051	3.88
7	56	77239	5.35
8	54	108341	7.51
9	62	71817	4.98
10	65	86532	5.99
11	67	94755	6.56
12	64	57413	3.98
13	54	92725	6.42
14	57	71611	4.96
15	61	71583	4.96
16	55	79515	5.51
17	65	72405	5.02
18	67	61249	4.24
19	58	75245	5.21
20	58	70696	4.90
		Average	5.19

Lotus Just 1

#	**Threshold**	**# of Blue Pixels**	**% Light**
1	73	97239	6.74
2	71	80273	5.56
3	65	59570	4.13
4	64	72822	5.04
5	66	62381	4.32
6	72	82470	5.71
7	67	68380	4.74
8	71	66850	4.63
9	67	54953	3.81
10	66	70628	4.89
11	75	82660	5.73
12	68	80443	5.57
13	62	76678	5.31
14	63	75289	5.22
15	68	58520	4.05
16	76	36126	2.50
17	76	43642	3.02
18	69	66691	4.62
19	66	44996	3.12
20	64	72143	5.00
		Average	4.69

Lotus Moltonel

#	Threshold	# of Blue Pixels	% Light
1	60	85904	5.95
2	61	90519	6.27
3	68	78706	5.45
4			0.00
5	72	103854	7.19
6	63	87052	6.03
7	61	66489	4.61
8	68	126513	8.76
9			0.00
10			0.00
11			0.00
12	60	82351	5.70
13	66	57409	3.98
14	61	84891	5.88
15	65	72125	5.00
16	66	80881	5.60
17	63	85985	5.96
18	64	81486	5.64
19	65	76884	5.33
20	68	96477	6.68
		Average	4.70

Scott

#	Threshold	# of Blue Pixels	% Light
1	74	35632	2.47
2	71	35292	2.44
3	66	41610	2.88
4	66	29239	2.03
5	66	30286	2.10
6	59	47933	3.32
7	68	35772	2.48
8	72	34099	2.36
9	67	43411	3.01
10	64	32743	2.27
11	61	43008	2.98
12	70	26601	1.84
13	65	39108	2.71
14	65	42754	2.96
15	69	37613	2.61
16	70	32791	2.27
17	70	34451	2.39
18	66	40829	2.83
19	69	31210	2.16
20	60	47611	3.30
		Average	2.57

Solo Douceur

#	Threshold	# of Blue Pixels	% Light
1	75	87812	6.08
2	62	116842	8.09
3	59	93809	6.50
4	70	78892	5.47
5	67	76828	5.32
6	66	67276	4.66
7	64	81058	5.62
8	68	69667	4.83
9	57	78527	5.44
10			0.00
11	62	92708	6.42
12	58	71130	4.93
13	62	75225	5.21
14	60	76944	5.33
15	60	85922	5.95
16	65	67983	4.71
17	68	83732	5.80
18			0.00
19	59	82030	5.68
20	61	86251	5.98
		Average	5.10

Winny

#	Threshold	# of Blue Pixels	% Light
1	68	83511	5.79
2	69	66177	4.58
3	71	74369	5.15
4	66	72398	5.02
5	65	70101	4.86
6	64	59235	4.10
7	66	88274	6.12
8	61	84555	5.86
9	66	78199	5.42
10	72	69506	4.82
11	69	79922	5.54
12	66	83913	5.81
13	64	85765	5.94
14	67	60543	4.19
15	70	90442	6.27
16	67	85807	5.94
17	72	89595	6.21
18	68	72207	5.00
19	65	80414	5.57
20	66	67649	4.69
		Average	5.34

SEM Data

Charmin

No_Img	Mean_Variation
1	13.77
2	9.49
3	11.09
4	10.71
5	9.20
6	7.34
7	6.75
8	6.67
9	7.10
10	6.86
11	6.41
12	5.88
13	6.58
14	6.47
15	6.11
Average	8.03
St. Dev.	2.31

Charmin Ultra Soft

No_Img	Mean_Variation
1	4.98
2	5.48
3	5.30
4	4.87
5	5.14
6	4.73
7	4.22
8	4.27
9	3.01
10	2.19
11	2.66
12	2.47
13	2.01
14	2.08
15	2.25
16	2.16
17	2.59
18	2.44
19	2.30
20	2.32
Average	3.38
St. Dev.	1.30

Cora Confort

No_Img	Mean Variation
1	3.25
2	3.28
3	3.21
4	3.03
5	2.98
6	3.11
7	2.87
8	2.91
9	2.90
10	2.89
11	2.7
12	2.59
13	2.82
14	2.60
15	2.67
16	2.57
17	2.58
18	2.56
19	2.54
Average	2.85
St. Dev.	0.25

Cora Douceur

No_Img	Mean_Variation
1	6.30
2	5.89
3	5.82
4	5.35
5	5.72
6	4.70
7	4.57
8	4.69
9	4.82
10	4.87
11	4.64
12	4.61
13	4.46
14	3.27
15	1.70
16	1.94
17	2.16
18	4.08
19	4.11
Average	4.41
St. Dev.	1.31

ENSIC

No_Img	Mean_Variation
1	2.00
2	3.62
3	3.67
4	3.91
5	3.77
6	3.73
7	3.86
8	4.44
9	4.43
10	4.29
11	3.96
12	3.98
13	4.19
14	4.10
15	4.25
16	4.70
17	4.36
18	4.63
19	3.65
20	3.81
21	3.41
Average	3.94
St. Dev.	0.57

Floraly's Extra Doux

No_Img	Mean_Variation
1	7.19
2	6.93
3	6.31
4	6.43
5	5.54
6	5.53
7	5.68
8	5.65
9	4.59
10	4.49
11	5.03
12	3.81
13	2.92
14	3.38
15	4.52
16	4.82
Average	5.18
St. Dev.	1.22

Floraly's Extra Resistant

No_Img	Mean_Variation
1	3.22
2	3.79
3	3.73
4	3.70
5	3.57
6	3.64
7	3.61
8	3.57
9	2.66
10	2.81
11	2.99
12	3.16
13	2.86
14	2.48
15	2.48
16	3.17
17	2.34
18	2.15
Average	3.10
St. Dev.	0.53

Floraly's Super Soft

No_Img	Mean_Variation
1	6.67
2	5.69
3	6.18
4	5.99
5	5.65
6	5.45
7	5.35
8	5.16
9	5.28
10	5.40
11	4.52
12	4.63
13	4.55
14	5.69
15	5.41
16	5.03
Average	5.42
St. Dev.	0.58

Goddard

No_Img	Mean_Variation
1	3.39
2	3.46
3	3.41
4	3.29
5	3.38
6	3.33
7	1.63
8	1.12
9	1.45
10	2.33
11	2.22
12	2.19
13	2.46
14	2.32
15	2.65
16	2.37
Average	2.56
St. Dev.	0.76

Lotus Just 1

No_Img	Mean_Variation
1	8.11
2	6.53
3	6.77
4	6.18
5	6.95
6	5.64
7	5.52
8	5.58
9	7.34
10	6.28
11	5.81
12	5.77
13	6.94
14	6.28
Average	6.41
St. Dev.	0.756

Lotus Moltonel

No_Img	Mean_Variation
1	5.63
2	5.17
3	5.63
4	6.60
5	5.08
6	4.9
7	4.85
8	4.80
9	5.01
10	4.70
11	5.42
12	4.86
13	5.02
14	2.72
Average	5.03
St. Dev.	0.83

Scott

No_Img	Mean_Variation
1	1.97
2	2.03
3	2.36
4	2.39
5	2.19
6	3.54
7	1.81
8	2.99
9	2.94
10	3.26
11	3.20
12	3.48
13	3.37
14	3.10
15	2.52
16	2.64
17	2.53
18	2.75
Average	2.73
St. Dev.	0.54

Solo Douceur

No_Img	Mean_Variation
15	3.76
16	3.78
17	4.17
18	5.18
19	3.90
20	3.16
21	3.36
22	4.34
23	4.97
24	3.07
25	3.01
26	2.30
Average	4.75
St. Dev.	1.38

Winny

No_Img	Mean_Variation
1	2.14
2	5.94
3	5.83
4	4.75
5	4.16
6	4.20
7	4.35
8	2.65
9	2.85
10	2.84
11	3.04
12	3.25
13	2.20
14	2.30
15	2.25
16	1.90
17	2.07
18	1.87
19	2.06
20	2.01
Average	3.13
St. Dev.	1.30

Aqua Tube ™

No_Img	**Mean_Variation**
1	3.09
2	3.11
3	3.35
4	3.91
5	4.21
6	3.52
7	3.28
8	3.41
9	3.11
10	3.54
11	3.12
12	3.20
13	3.38
14	3.66
15	3.63
16	3.80
17	3.54
18	3.58
19	3.07
Average	3.45
St. Dev.	0.312