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The Impact of Environmental Degradation on the Analysis of Manufactured Fibers

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ABSTRACT

The analysis of fiber evidence involves the ability to link a questioned fiber back to its known source. But before the collection and analysis of questioned fibers, they could be potentially exposed to various environmental conditions for an extended period of time. There has been little research on how manufactured fibers are affected by various environments and if this interaction affects the ability to link a questioned fiber back to its known source. Changes to the manufactured fibers are essential to be aware of, in order to avoid the possibility of erroneous exclusions when performing fiber comparisons. A six-month time study was performed to determine how ten different environmental conditions would affect the physical, optical, and chemical properties of four manufactured fibers.

Fabric swatches of the nylon, acrylic, rayon, and polyester were exposed to solid conditions including sand, potting soil, chicken and cow manure and were also exposed to liquid conditions such as motor oil and winter road pretreatment fluids. Squares of each fabric type were placed in glass containers, each containing a different environment and stored for six months. Every two weeks fibers were subsampled from each environment and analyzed microscopically and instrumentally, using a bright-field and polarized light microscope, a Fourier-Transform Infrared Spectrometer, a Raman Spectrometer, and an UV-Visible Microspectrophotometer for fluorescence analysis. Comparisons back to the control fibers were used to determine if the fiber's analytical data was measurably altered over time to a point where they were inconsistent with the known source.

Due to the increased strength and resilience of the manufactured fibers, there were no changes to the analytical data significant enough that the manufactured fibers could not be related back to their known source, except in the cases of complete degradation. Viscose rayon

completely degraded in certain conditions but remained unaltered in others, while polyester remained unchanged in all conditions. The other fabric types, nylon and acrylic, were slightly altered but were still able to be related back to their known source. The only significant change that occurred, to all of the manufactured fibers, was the fiber's fluorescence over time, but at this time the cause of these changes is uncertain. Further work needs to be conducted to determine the causes of the changes in fluorescence, but these results did not impact the fibers identification or inhibit the ability to link the fiber back to its known source. These results indicate that forensic fiber comparison analysis can be logically preformed on fibers that have been exposed to various environments, since the fiber's structural, optical and physical properties remain stable over time.

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CHAPTER I

1.1 Introduction

Criminals who commit homicides often attempt to hide the body or evidence so that there is a delay in discovery. Therefore, evidence may be left in a variety of environmental conditions until the body is discovered. Once the body and the evidence are collected, the evidence is placed in storage until a forensic analyst is able to examine the evidence. The time period between collection and analysis varies between laboratories dependent on their backlog. Due to a combination of these two situations, it may be months to a year before evidence from the crime is analyzed. The Office of Legislative Research reported in 2010 that the average time it takes to process trace evidence in the United States is approximately two months, with some labs taking up to one year [1]. During that time, before the evidence is discovered, fiber evidence may be exposed to different environmental conditions. These conditions may include being buried in soil or exposed to contaminated water, which may interact with the fabric and thus alter the analytical results of the analysis.

Fibers are a common form of forensic evidence that can be found at crime scenes and may be used to place a suspect or victim at the crime scene, as well as establish a link between a suspect, victim, weapon and location. This is established by Edmond Locard's principle of exchange, which states that contact between two people or surfaces, no matter how brief, leaves a trace [2]. Forensic fiber analysis involves determining the presence of links or exclusions between a questioned fiber and a known source. When analysts examine fibers, they compare the physical, optical and chemical characteristics of the fibers to determine if two or more fibers could share a common source. A common source is when two fibers may have originated from the same textile material. If there are significant differences between fibers, they are concluded

to have different sources. Fibers that are brought into a laboratory are not always in pristine condition. The fiber evidence could be covered in different fluids or particulates due to being exposed to different environmental conditions for varying periods of time. The point in question is whether or not this environmental exposure affects the microscopic or spectral data of fibers. If the analytical data of a fiber is altered over time, then there is a possibility for erroneous or false negative results during analysis. Thus, this research focused on analyzing changes in manufactured fiber's analytical data over time after exposure to a variety of different environmental conditions.

Previous research has focused on discovering the most efficient methods for fiber analysis as well as the analysis of natural fibers after exposure to various environmental conditions. Little research has been conducted to determine how class characteristics of manufactured fibers are affected by the exposure to different environmental conditions. Due to the exposure, there is a possibility that exclusions of fibers from a known source could be made, when in reality the fiber had been affected by the exposure to environmental contamination. This research delved into the spectroscopic and microscopic analysis process to see if, as fibers are exposed to contaminants, discernable differences are apparent over time. The goal of this research is to determine how different environmental conditions alter the class characteristics of manufactured fibers and if the alterations are enough to cause a fiber to be inconsistent with its known source.

The manufactured fabrics selected for this research were exposed to a variety of different substances and environmental conditions, including both solid and liquid conditions. The fabrics were left in these conditions for six months and analyzed every two weeks using a combination of microscopic and spectroscopic examinations. Since all permutations of fabric type and

environmental conditions are impossible to fit into the allotted time frame, some restrictions must be placed upon this study. This study only focused on non-dyed, manufactured fabrics; nylon, polyester, acrylic and rayon.

The conditions that the fibers were exposed to did not involve altering the temperature or the humidity present. Fabric was placed in the conditions and then stored in a closed cabinet so that light, temperature, and humidity are controlled for the duration of the experiment. Fibers were analyzed using a combination of microscopic and spectroscopic analysis to determine the extent of the changes from different conditions. If it is proven that the analytical data of fibers are significantly impacted by environmental conditions, then comparisons of known and questioned fibers in laboratories should be examined more critically to ensure that false negative results are not reported.

1.2 Literature Review

1.2.1 Research of natural fiber degradation

While there has been little research conducted on analyzing changes to manufactured fibers within environmental conditions, there has been work done analyzing natural fibers. Research by Canetta et al. examined the morphological changes to cotton, wool, and viscose rayon on a nanoscopic level when exposed to soil, pond water, and sea water for six weeks [3]. This research used atomic force microscopy (AFM) to analyze the surface texture parameters over the course of a six-week period. AFM allowed the surface of the fibers to be examined at a nanoscopic level to distinguish damage created due to environmental exposure. They concluded that they were able to distinguish between environmental conditions due to the damage that was present on the fiber at a nanoscopic scale [3]. This information could provide more probative value to the fiber evidence once the fiber is collected and properly identified. Their research was

limited in the number of environmental conditions that were examined and the time period of exposure. This research focused purely on the changes to the surface texture of the fibers after contact with the environments, but they do not focus on the classification of the fibers post-exposure. If a fiber is unable to be properly classified, then the probative value established based on damage conditions would be futile. This study has room for growth and future experimentation and it also provided a starting point for the methodology development that could be used for exposing fibers to different environmental stresses.

Another study determined how the stiffness of flax fibers is affected when the fabric is submerged in water for two months [4]. The examination used a scanning electron microscope (SEM) as well as biochemical analysis. The researchers were investigating the varying levels of sugar and uronic acid produced by the fibers after being exposed to water. To examine this phenomenon the fibers were placed in distilled water for the duration of the experimentation. Flax, being a natural plant fiber, has a cell wall which gives the fiber a level of stiffness. Fibers were examined using the SEM for cracks in the cell wall that would contribute to a loss of stiffness in the fiber. This research demonstrated that there are changes to natural fibers after exposure to water that can affect the durability of the fibers over time. While this research involved measuring the changes that occurred after exposure to an environmental condition, the researchers only examined the fiber using two methods and only used distilled water. There are many contaminants present in water that could affect the results of the exposure. This experimental design only works for natural fibers that have a cell wall, and therefore would only be relevant for plant-based fibers and not synthetic fibers.

Research by Payne et al. examined how cellulosic wood-based fibers take up oil in different conditions [5]. The researchers focused on how the mass of fibers changed as they took

up oil. The main goal of this research was to determine if placing cellulosic fibers into areas where oil has been introduced into the environment can assist in the oil clean-up process. For this experiment the researchers utilized deionized water and contaminated the sample with oil. It was determined that the fibers were able to absorb up to four times their weight in oil, thus changing the morphology of the fiber over time [5]. This research only focused on the amount of oily water a fiber could intake and thus how the mass of the fiber changed. For a forensic investigation, microscopic analysis of the fiber could be used to determine if the fibers were structurally altered as the fibers absorbed oil and were thus unable to be properly classified.

1.2.2 Research on manufactured fiber degradation

There has been research done by Lowe et al. investigating how natural and manufactured fibers are affected by the presence of decomposition of buried bodies as well as soil texture[6]. A 100% cotton shirt and underwear comprised of 50% cotton and 50% polyester were buried in different soil textures as well as in direct contact with a decomposing pig. This study showed that the cotton was better preserved when in contact with the decomposing remains rather than when it was just in contact with the soil. They hypothesized that this was due to the presence of bacteria in the decomposition fluid that was unable to break down the cellulose structure [6]. The mixture of natural and manufactured fibers was not prone to degradation and still remained in the same condition after being buried for 14 months. This study demonstrated that manufactured fibers, in soil and decomposition fluid, are less prone to degradation over time [6]. This study focused on one natural fiber type and a fiber mixture of natural and synthetic fibers. This brings up the question on how other manufactured fibers, including regenerated fibers, would hold up in similar conditions.

There is one research study that delves into the examination of manufactured fibers to determine if there are significant changes to the fibers after exposure to various environmental conditions. Research done by Brinsko et al. analyzed the viscose rayon, azlon and polylactic acid by exposing them to freshwater, saltwater, heat, cold, ultraviolet light, and composting conditions for a period of two years [7]. The analysis of the fibers was done with polarized light microscopy, infrared spectroscopy, and solubility and melting point analysis. They found that, except for when the fibers completely degraded, the fibers were all able to be correctly identified back to their control source [7]. In their study viscose rayon was the most prone to degradation while the other regenerated fibers were more resilient. This study examined multiple regenerated fabric types in vast number of conditions, but one sample type this research did not examine was synthetic fibers, such as polyester or nylon. This is one of few studies that has been performed on regenerated fibers in conditions that would commonly occur at a crime scene and is thus relevant to verifying that exposure to environmental conditions does not affect the identification of regenerated manufactured fibers.

Overall, most of the previous research done on fibers in different environmental conditions has singularly focused on the surface changes to natural fibers. Natural fibers are, by their nature, weaker than manufactured fibers due to their structural make up. Natural plant fibers are composed of cellulose or animal hair. Manufactured fibers are composed of stable polymers that cause the fibers to be more difficult to damage. While the idea that manufactured fibers are not prone to degradation is logical, it has rarely been studied under controlled conditions. Therefore, the aim of this research is to analyze if there are any changes to a manufactured fiber's analytical data after exposure to different environmental conditions.

1.3 Fibers

1.3.1 Fiber Basics

Fibers are a common form of forensic trace evidence because they are prevalent in daily life. Individuals are in continuous contact many forms of fibers, such as clothing, furniture, carpet, car seats and other accessories. A textile fiber is the smallest unit of a completed textile product, such as clothing, and is comprised of raw materials [8]. The next largest unit of fabric composition is a piece of yarn/thread, these are "continuous strands of textile fibers… entwining to form a textile fabric" [8]. And finally, the construction of a piece of fabric is designed by various connectivity of the yarn. The fibers that create our fabric and other items that we are surrounded by daily, fall into two main classes; natural fibers and manufactured fibers[9]. Natural fibers can further be subdivided into two main types plant/cellulosic and animal/protein fibers. Cellulosic fibers are those that are grown, fibers that are produced from cellulose such as cotton. While protein fibers are those that are collected from an animal, such as wool from a sheep or silk from a worm.

Manufactured fibers are also sub-divided into two main categories; regenerated fibers and synthetic fibers [8]. Regenerated fibers are created from natural materials, such as rayon which is a semi-synthetic polymer composed of a regenerated cellulose [9]. Fibers are composed of polymers which are comprised of monomers; in the case of most regenerated fibers the monomer is cellulose. Regenerated fibers, such as viscose rayon, are made by dissolving the cellulose portion of wood pulp and then reforming the dissolved fluid into a fiber by a wet or dry spinning process [9]. This fiber type has a similar chemical structure, and therefore similar physical and chemical properties, to cotton because it is primarily composed of cellulose.

Man-made/synthetic fibers are composed of synthetic polymers, a repeating molecule or group of molecules that are bonded together during the manufacturing process [9]. There are many classes of synthetic fibers which are distinguished based on the monomer of which the polymer is comprised. Each class of synthetic fiber has a number of subclasses as well as a set of unique characteristics, which will be discussed later. There are three processes to form polymers into manufactured fibers; melt spinning, dry (solvent) spinning, and wet spinning [8]. During the melt spinning process, thermoplastic polymers are melted down to a molten state and then pushed through a spinneret. A spinneret is a thimble shaped piece of metal that has many small holes, that can be many shapes, in which the polymer solution is pushed through to create the fiber. This spinneret is designed to create the desired shape of the cross section, as the molten fiber passes through it solidifies in the air and in its fibrous form.

The dry spinning process involves dissolving the polymer in a solvent. The dissolved material is then pushed through a spinneret. The solvent is then evaporated off leaving only the fiber remaining. This process is used when the polymer of interest is heat sensitive at high temperatures. Finally, the wet spinning process is similar to the dry spinning process, the polymer is dissolved into solution and then pushed through a spinneret [8]. The fiber after it is exiting the spinneret is placed into a liquid bath where the polymer coagulates into a solid. Each manufacturing process creates the desired polymer structure for the manufactured fibers. The polymers that make up manufactured fibers are extremely stable due to the types of bonding that occur between the polymers, and therefore are theoretically not easily prone to degradation.

After the fibers have been created, they then can go through the process of being dyed. The dye can interact with all manufactured fibers differently based on dye and fiber type, and the temperature and length of exposure to the dye. Most fibers that are discovered at crime scenes

are dyed, a process that impregnates the textile fiber with color [8]. The temperature, how long the fibers are exposed to the dye, and the dye type are important factors to determine how the dye interacts with the fiber. The bonds and bond types that are present between fibers and dyes are variable, depending on the dye and fiber type [10]. The dyeing process creates another variable that must be accounted for when exposing the fibers to different environmental conditions. Therefore, dyed fibers were not examined for this research.

Another variable that needs to be controlled for is the coating present on fibers. During the manufacturing process coatings may also be added to fibers to make them more stable, stiffer, increase their thermal stability, to make them water resistance, etc. These coatings may cause different interactions between the fiber and the environmental conditions, perhaps do the formation of a barrier by the coating. Thus, it is important to know if a coating is present on the fiber.

In the year of 2017, there were approximately 105 million megatons of fibers produced globally [11]. Figure 1 shows a graph of the common fiber types produced in 2017 [11]. This figure indicates that, of the manufactured fibers, polyester was the most produced, followed by manmade cellulosics (such as rayon), other synthetics (such as acrylic), and nylon. Based on the

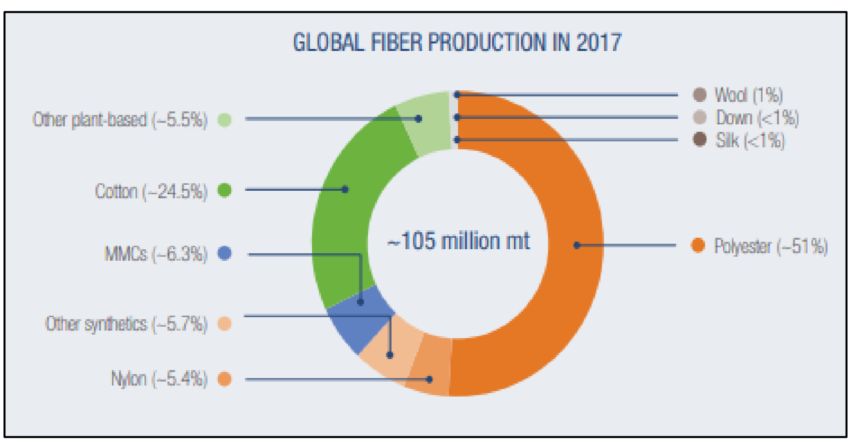

Figure 1: Commonly produced fibers types in 2017

global fiber production report a representative selection of fibers where chosen for this research. Since these four types of fibers are the most commonly found used in everyday textiles, it is logical that these were the four fabric types examined to determine if and how they are altered overtime. Thus, the fibers chosen for this research were: polyester, nylon, acrylic, and rayon.

1.3.2 Polyester

Polyester was first introduced to the American public in 1951 and today is now the most common manufactured fiber mainly used in the textile industry [8,11]. It can be found in both yarn form, used for crocheting or knitting, as well as in the form of woven and non-woven sheets of fabrics. Polyester is common in the creation of active wear clothing and can also be found in other clothing materials such as dresses, pants, shirts, and skirts. These are popular clothing items that are worn by the general population, and as such have a higher probability of being present at crime scenes.

Polyester a generic term for a fiber, which describes the linkage the connects the monomers that make up the fiber together, for polyester this is an ester linkage. An ester linkage is formed during a reaction between an alcohol and a carboxylic acid [8]. One of the most common types of polyester is Polyethylene terephthalate (PET), which is comprised of a polymer with the repeating unit polyethylene terephthalate, a condensation polymer [12]. Polyester is most often produced using the melt spinning process due to the thermostability of the polymer in high temperature conditions [13]. [13]. The shape of the spinneret determines the cross-section that the fiber may take. Polyester is ordinarily rod-like in appearance with a smooth surface, and due to its common circular cross-section is uniform in diameter [9]. Polyester is a highly resilient, tough, and is not easily prone to breakage [8]. The optical characteristics of polyester

include a parallel refractive index of 1.71 – 1.73 and a perpendicular refractive index of around 1.53 – 1.54. The birefringence is generally around 0.18 and has a positive sign of elongation [9].

1.3.3 Nylon

Nylon fiber was the first synthetic fiber produced in 1939 and was known as the "miracle fiber" because of its strength and elasticity [8]. It is commonly used for carpets, umbrellas, winter coats, kites, ropes, underwear and stockings/hosiery. This fiber type is forensically relevant, not just because of its commonality, but also because transfer of fiber evidence from vehicle carpets have a high likelihood of transfer during sexual assault or kidnapping cases.

Nylon is a fiber composed of the polymer polyamide that is connected through amide linkages that are created through a bondage of an amine and a dicarboxylic acid functional group. The structures that are attached to these functional groups are what determines the type of nylon that is produced [8]. The monomers that are used to produce nylon are variable and thus there are many different types of nylon fibers. For example nylon 6, 6 is composed of 1, 6-diaminohexane and hexane-1,6-dicarboxylic acid, the polymer is formed from a condensation reaction that links the carboxylic acid and amine functional groups together [12]. It is the number of carbon atoms that make up the starting compounds that dictate how the nylon will be named. Therefore, nylon 6,6 is denoted as such because the two compounds that form the monomer are each composed of 6 carbon atoms. Another example would be nylon 12, a form of nylon that is composed of laurolactam monomers which contain 12 carbon atoms.

This synthetic fiber is produced by the melt spinning process and is formed by pushing the heated polyamide though a spinneret [12]. One type of cross-section shape of nylon 6,6 is circular resulting in a rod-like appearance of the fiber. When a non-round cross-section was used

the appearance of the fiber would be irregular due to non-uniform twist and bends and inconsistent diameter along the length of the fiber. Nylon's optical properties may vary on the type of nylon being examined, nylon 6,6 has a parallel refractive index of 1.57 – 1.59 and a perpendicular refractive index of 1.51 – 1.53. Nylon 6,6 generally has a birefringence of around 0.06 and has a positive sign of elongation [9].

1.3.4 Acrylic

Acrylic was first created in 1983 by a French chemist, but due to its instability at high temperatures and insolubility it was unable to be used as a fabric for many years. After being used in the production of rubber for many years, a pair of German scientist developed a process that could spin acrylic material into a fiber [8]. Acrylic is commonly used in the production of fur-like fabric on toys, blankets, carpeting, draperies, and upholstery. Acrylic fibers are commonly used as household textiles due to its high ultraviolet light resistance and its high microorganism resistance [8].

The term acrylic is a shortened term for the word acrylonitrile which is the monomer that is used to produce the fiber. It is formed from petroleum products; the first acrylic fibers were homopolymers composed entirely of acrylonitrile but were difficult to utilize in a textile setting [8]. Over the years copolymers were created and acrylic today is now comprised of at least 85% by weight of the polyacrylonitrile [12]. This fiber is formed using the wet spinning manufacturing process [13]. This process allows for a wide range of cross-sections to be produced. The draw-rate, the speed of in which the fiber solution is pulled through the spinneret, of the acrylic is extremely sensitive for this process, causing the fiber's diameter, cross-sectional shape, and birefringence to vary depending on the production [9]. The most common cross-sectional shape for acrylic fibers is the dog-bone/bean shape, where there is one indentation

down the length of the center of the fiber. The parallel refractive index of acrylic is 1.50 – 1.53 and the perpendicular refractive index is also 1.50 – 1.53. The birefringence of acrylic varies depending on the production but can fall within the range of 0.001 – 0.012. Uniquely, acrylic fibers possess a negative sign of elongation and are thus highly distinguishable from most fiber types [12].

1.3.5 Rayon

Rayon fibers were first produced by a Frenchman in1884 who was attempting to produce "artificial" silk. It was then introduced in the United States in 1910 [8]. Rayon fibers are manufactured fibers and are ever-growing in the textile industry, but they differ from synthetic fibers because they are regenerated cellulose. Rayon is used in textiles due to its elevated luster quality and is commonly used to make shirts, lingerie, scarves, dresses, skirts and other textile accessories that have a glossy appearance [11].

Rayon is a fiber that is formed from regenerated cellulose that is found in wood pulp. To create rayon the cellulose is first broken down into a solution and then reformed by passing it though a spinneret where it is deposited into an acid bath [12]. A rayon fiber is composed of 100% of cellulose. The polymer chains that make up rayon are relatively short compared to cotton, being approximately 400 monomer units long. While cotton's polymer chains are usually comprised of 6,000 – 10,000 units. During formation the polymers that makeup these fibers are not well aligned with the fiber axis. The cross section of this fiber type is commonly crenulated, which means to have a notched external structure, due to the exterior of the fiber polymerizing first as it is placed in the acid bath. Rayon fibers generally have a parallel refractive index of 1.55 and a perpendicular refractive index of 1.52. Like most fibers the sign of elongation is positive and rayon has a birefringence of about 0.02 – 0.05 [9]. One noteworthy characteristic of the fiber

is that there are irregular striations along the length of the fiber from the crenulated cross section. This fiber is being examined due to its cellulosic composition, to see how the degradation rate differs from fibers that are purely synthetic.

1.4 Environmental Conditions

There are many environmental conditions in which fiber evidence may be located including locations where bodies or textile evidence can be buried, concealed, or abandoned. As fiber evidence is exposed to various environmental conditions there is currently little knowledge on if there are morphological or structural changes to the fiber over time. If any alterations to the analytical data of the fiber evidence do occur, then the possibility of erroneous exclusions of fiber evidence is introduced. For example, if questioned fibers are collected from a suspect, but the potential source of the fibers is not discovered until weeks to months later, buried in soil, then the interaction between the possible source fibers and soil may cause issues in properly associating the fibers. When the two fibers are compared, if the microscopic and spectral results have discernable differences then two fibers would be excluded from each other. This brings up the question, were the two fibers excluded from each other because they were from different sources or due to alterations in the analytical data?

1.4.1 Solid Conditions

There are many solid environments that forensic evidence can be concealed in, such as clothing or bodies being buried in mud, soil, sand or compost sites. Therefore, for this research the solid environments investigated were; sand, potting soil, chicken manure, cow manure, and combinations of soil and the two manure types. Sand is granular material that is composed primarily of silicone dioxide in the form of quartz [14]. The other components of sand are dependent on location since sand is formed from the breakdown of location dependent minerals,

due to weathering. The quartz that composes sand is insoluble in water and difficult to breakdown [14]. This environment is primarily found at beaches and lake fronts. Crimes committed in public areas such as these can lead to the perpetrator needing to hide evidence, which may then be concealed or buried in the sand.

Another common solid environmental condition that evidence can be found in is soil. Potting soil was used for this research because, individuals frequently buy it to supplement plant growth in their yards and therefore potting soil is frequently used in people's gardens, increasing the likelihood it may be found at a crime scene. Commercial potting soil is composed of three main ingredients; peat moss, pine bark, and perlite or vermiculite [15]. The peat moss helps the soil to retain moisture but can be extremely acidic on its own. Pine bark also helps to provide moisture and is used to provide air space to the soil, this also helps the soil to not break down too quickly. The presence of moisture promotes the growth of bacteria and microbes, these are also present in soil and may affect how the fibers interact with the soil. Finally, the perlite or vermiculite is volcanic material condensed to a pellet that provides air space so that the potting soil is not too dense [15].

Commonly used in conjunction with potting soil is manure or fertilizers to help facilitate the growth of plants and grass. There are many different types of fertilizers, which can either be plant or animal based. The two types of fertilizer that were used during this experimentation are cow and chicken manure. Cow manure is primarily composed of the elements nitrogen, phosphorous and potassium and has a pH of 4.6 to 7.4 [16]. Due to the heaviness of cow manure it is normally mixed with straw or hay, as well as organic material from plants [16]. Chicken fertilizer is made from the fecal matter of chickens and must first be composted before it can be

used as garden fertilizer. This fertilizer has a slightly higher pH ranging from 6.5 – 8.0 [17]. In some gardens, fertilizer is combined with potting soil to improve garden growth.

1.4.2 Fluid Conditions

Fiber evidence can also be exposed to various types of liquids, for this research the conditions examined were winter road treatments (calcium chloride and sodium chloride pretreatment) and motor oil. There are cases where human remains have been disposed of during the winter and the clothing evidence they were wearing was exposed to the snow. One example of this would be the case of Joanna Yeates from Bristol, England who was reported missing after going out with her friends for a night. Seven days after being reported missing her body was in the snow next to a golf course. During the seven-day period in-between her disappearance and discovery her body and clothing had been exposed to the elements. When her body was discovered, fiber tapings were performed at the scene and in the lab to collect questioned fibers. The fibers collected were able to be linked to a suspect. These fibers were only exposed to the elements for a short period of time, but how would a prolonged exposure to the elements affected the analysis results. The lack of knowledge on how manufactured fibers react with different environments needs to be studied, to ensure that erroneous exclusions will not made during forensic analysis due to environmental interactions.

Roadside snow can be a potential location that evidence may be discarded, for example if a suspect through a piece of clothing out of a car window while driving. During the winter, before a snow storm, the northern roads are prepared with pretreatment samples such as calcium chloride or sodium chloride. After the storm the roads are covered with snow, which then must be cleared to allow for safe driving conditions. Evidence or remains can be hidden on the side of the road which could then be covered in snow/water, as well as any treatments that were applied

to the road. The salt prevents the snow from binding or icing the road making it easier to remove with a snow plow [18]. This methodology is inexpensive, but one concern is the corrosiveness of the salt to the roads. Sodium chloride is corrosive in nature and thus damage the roads over time. Though rock salt is less corrosive than other pretreatments such as calcium chloride which is used in other states [18]. The corrosiveness of both sodium chloride and calcium chloride should be examined in relation to fiber evidence.

Vehicular fluids, such as motor oil, can also be found on forensic textile evidence in cases of a hit and run or in particular crime scene locations. Motor oil is composed of two parts, the base stock and additives. The base stock of regular motor oil is a petroleum base, which is composed of heavy hydrocarbon C_{18} to C_{34}, derived from crude oil. Additives present in the oil can be dispersants, anti-wear additives, antioxidant, and other additives [19]. The interaction of these additives with fibers is important to research to determine if the submergence of fibers in oil for extended periods affects the ability to identify the fibers.

1.5 Microscopy

Fibers are classified/identified based on their physical, optical, chemical, and structural properties. Each laboratory has standard operating procedures that are followed for fiber examinations. The standard operating procedures for fiber analysis from the Trace Evidence Procedures Manual from the Virginia Department of Law Enforcement was used as a guideline for this research, because it follows a generally accepted procedure similar to the FBI fiber analysis protocol [20].

Fibers are first examined macroscopically to identify the presence of any debris, as well as to determine any apparent characteristics such as color. Then fibers are analyzed microscopically, using a stereomicroscope. Stereomicroscopy is the use of a stereomicroscope to

view samples at a relatively low magnification, this is a type of photon microscopy that uses light photons to illuminate and create an image. Stereomicroscopes work using two optical paths for the light to travel though, since the sample is viewed from slightly different angles it is able to be viewed in three dimensions [9]. Stereomicroscopes are used as a preliminary screening technique and can also be used to search for fibers that may be present on articles of evidence There are two main types of stereomicroscopes, the common main objective stereomicroscope and the Greenough design stereomicroscope. The common main objective (CMO) microscope utilizes one objective but contains two separate optical channels that each produce an image from a slightly different angle. While the Greenough designed stereomicroscope uses two separate optical channels with different eyepieces, objectives and intermediate elements [21]. The CMO microscope has convergence of the left and right eyepiece which allows there to be no image tilt when viewing a sample. Though because of the convergence there is a doming effect where the center of the image appears slightly raised. With the Greenough design the separation of the left and right image creates a keystone effect which causes the image on the left side of the right eye and the right side of the left eye to appear smaller. Discriminating between the two types of stereomicroscopes is dependent on the type of sample being analyzed.

Stereomicroscopy is a useful technique because it creates a three-dimensional image for the user giving depth perception to the object. The long working distance for this type of microscope (3-20 cm) allows for micromanipulation of a sample. The long working distance is provided by the relatively small magnification that the stereomicroscope possesses, a mid-range stereomicroscope can have a total magnification range of up to about 300x [9]. One unique magnification feature of the stereomicroscope over other optical microscopes is the ability to change the magnification using zooming feature while other microscopes require a change of

objective to change the magnification. The zoom feature gives the user more control over the magnification of the sample.

After stereomicroscopy examination, the fiber is then further examined microscopically using both bright-field light and polarized light. Brightfield microscopy is another type of photon-based microscopy that uses transmitted light to observe and study the morphology of a microscopic sample. To obtain an image the light is transmitted through the sample and a dark image (the sample) is produced against the lighter background [21]. The contrast within the sample is caused by the varying levels of absorbance of the light within the sample, the more light that is absorbed the less that is transmitted. This area of the sample would appear darker compared to an area on the sample that absorbs less light. Contrast between the sample and the surrounding area depends on the substance the sample is mounted in. To obtain a properly lit image a sample must be illuminated properly this is called KOHLER illumination, this ensures that the sample is being hit with an even amount of light within the field of view [9]. A brightfield microscope may have magnification up to 1000x, which allows for the analysis of fibers at a high magnification.

The properties of fibers that are examined using a brightfield microscope include: the presence of delustering agents, the diameter of the fiber, the apparent cross-section of a fiber and the color of a fiber. Delustering agents are chalks or pigments that are added to the fiber to dull the color [20]. They appear as small black particles and are found mostly in manufactured fibers but may also be found in regenerated fibers depending on their processing. Determining the diameter of a fiber depends on the cross section of the fiber. Fibers that have amorphous cross sections may have different diameters along the length of the fiber, while those with a circular cross section have a uniform diameter along the fiber [9]. Figure 2 shows cross-sections that are

common in various types of fibers [12]. The cross section of the fiber can be determined by using a micrometer to cut a small slice of the fiber and placing it on a slide to examine using a brightfield microscope. This small piece of the fiber is then analyzed under a microscope to determine the cross section. The cross section of the fiber is an important characteristic. This plays a role in determining the physical properties of the fiber, which could then affect the fibers rate of degradation.

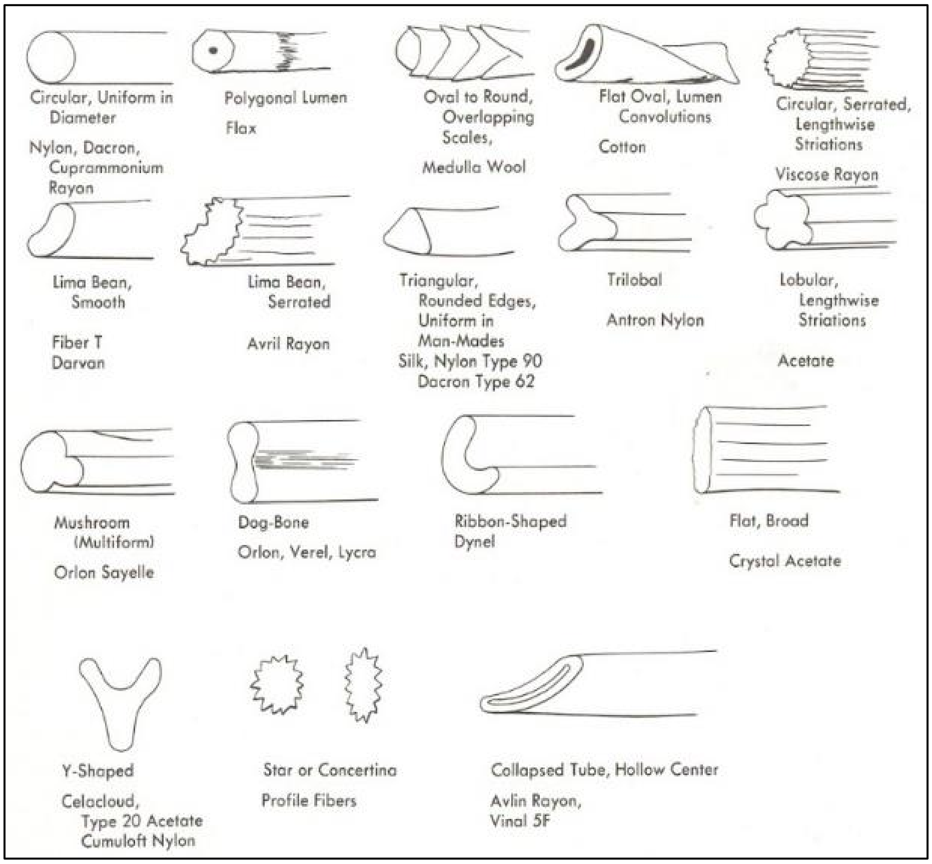

Figure 2: Common Cross-Sections of Fibers

Fibers are then examined using a polarized light microscope to document the optical properties of the fiber. Polarized light microcopy is one of the more versatile techniques for microscopic samples when compared to the stereomicroscopy and the brightfield microscopy. This is also photon microscopy, like the other two types but allows for sample analysis in three types of light; bright field, plane polarized light, and crossed polarized light. Plane polarized

light and crossed polarized light is permitted by the addition of a polarizer and analyzer into the optical pathway of the microscope. The polarizer restricts the light to a single direction, this restriction is called plane polarized light. This hits the sample and the light breaks off into two direction, the extraordinary ray (E-ray) and the ordinary ray (O-ray), with one ray of light traveling slower than the other [9]. If the analyzer, a polarizer that is situated above the specimen, is not engaged this is the light that is viewed through the eye piece. If the analyzer is engaged then the E-ray and O-ray recombine and depending on the interference pattern (formed by one ray moving slower than the other) a retardation color is visualized, this is the birefringence of the sample and it occurs when a sample has two refractive indexes [9].

Polarized light microscopy allows for both qualitative and quantitative analysis of samples. Qualitative analysis includes the morphological analysis of samples and their characteristics, while quantitative analysis includes the determination of the refractive index of a sample, which is done in plane polarized light, and the birefringence of a sample, which is done in crossed polarized light.

When both the polarizer and analyzer are engaged the sample is being viewed under crossed polarized light. If a sample is anisotropic, contains two refractive indices, the viewable

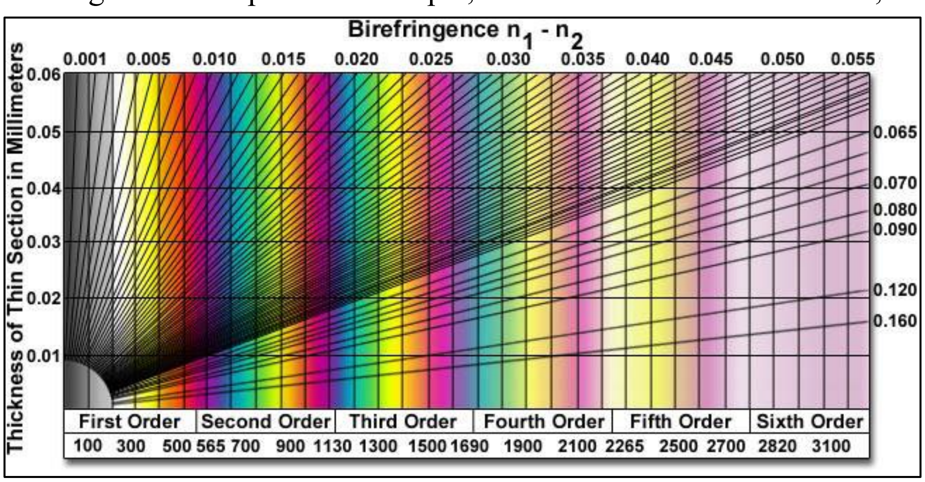

Figure 3:Michel – Levy Birefringence Chart

optical properties change dependent on the orientation of the sample with in relation to the incident light [9]. When a fiber is in the same orientation as the polarizer or analyzer the fiber every 90 degrees, in general, will go into extinction. Extinction of fibers is when the wave components of the fiber are in the same plane as the polarizer or analyzer and the sample appears dark though the eyepiece [9]. When the sample fiber is at a 45-degree angle from the compensator the sample will take on interference colors based on the optical properties of the fiber. The colors can be found on the Michel- Levy Chart, shown in Figure 3 [22], which provides information on the thickness, birefringence, or color order of the sample. The sign of elongation of the fiber can be determined using the changes of color of the fiber that occur under crossed polarized light after a compensator is applied [9].

To manually calculate birefringence, the refractive index of n-parallel and n-perpendicular must be determined. This is usually done by immersing the fiber at a 90-degree angle in immersion oils that have higher and lower refractive indices of the fiber and look for the presence of a Becke Line. The Becke Line is a line indicates when there are differences between the refractive indices of two mediums [9]. Once the Becke Line is almost unobservable, when horizontally orientated, the refractive index of the oil used indicates the n-parallel refractive index. The method is repeated to determine the n-perpendicular refractive index by orienting the fiber vertically and using immersion oils.

The sign of elongation is another characteristic determined using PLM that can assist in fiber classification. To determine if a fiber has a positive or negative sign of elongation, a full wave plate is placed in the compensator [9]. The fiber is oriented at a 45-degree angle and then the compensator is engaged. The color after the compensator is added is compared to the original birefringence of the fiber, if the color of the fiber is a higher order when the compensator is

added, then the fiber has a positive sign of elongation. If a color of a lower order is observed, then the fiber has a negative sign of elongation [9].

1.6 Fourier Transform Infrared Spectroscopy

Attenuated Total Reflectance Fourier-Transform Infrared Spectroscopy (ATR-FTIR) is a non-destructive identification technique that determines the chemical structure of the material of interest. This technique is mainly used on manufactured fibers to identify the polymers present in the fiber [23]. This allows for determination of a fibers classification and possibly subclassification. The FTIR is not a common technique for the detection of dyes on the fiber because they make up such a small percentage of the composition that they cannot be detected by the instrument [24]. IR spectroscopy can be successfully used to determine the classification of a fiber's coating. When combined with the ATR, information about a fiber's coatings and treatments can be analyzed [25]. When fibers are exposed to different substances the coating may prevent alterations to the fiber from occurring while the coating degrades.

The ATR–FTIR instrument is composed of a few key pieces; a source, an interferometer which contains a stationary mirror, a moving mirror, and a beam splitter, then the sample, the detector, and finally the recorder [26]. A schematic of an ATR-FTIR is shown below in figure 4 [27]. The source produces light at the wavelengths of interest that is then sent through the rest of the instrument, into the interferometer.

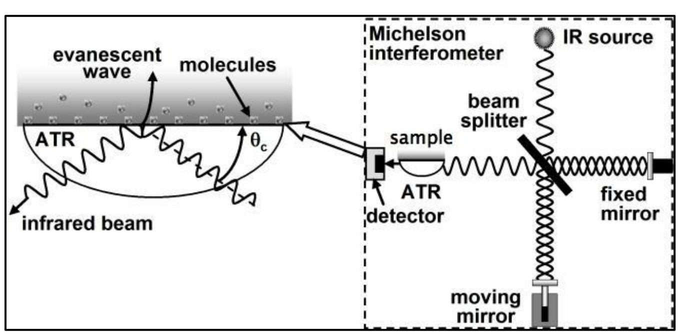

Figure 4: Components of an ATR-IR

The interferometer allows for all frequencies of radiation to be measured at the same time. As the light enters into the interferometer it is broken into two paths by the beam splitter. One of the light paths is sent to the stationary mirror where it is then reflected back to the beam splitter. The other light path is directed to the moving mirrors and then back to the beam splitter. As the mirror moves, the path length of the light changes and thus when the light is recombined at the beam splitter the waves of light can either have constructive or destructive interference. This is called an interferogram [26]. This beam of light is then sent though the sample which absorbs light based on its composition. The light that is absorbed is removed from the interferogram and the remaining light hits the detector. The laser is present to measure the location of the movable mirror as a function of time to allow for an accurate measure the level of interference [21]. The computer takes this information and uses a mathematical function, Fourier transform, to transform the interferogram from an intensity vs. time spectrum to an intensity vs. frequency spectrum [26].

Preparation of the sample is one of the most important steps to obtaining a good and reproducible spectrum of the sample. The sample preparation must allow for there to be no air in the path of the IR beam. The optical window (i.g. KBr) must not absorb IR radiation near the IR range of interest and moisture of any type should be avoided when preparing samples (preparation materials should be kept in the desiccator) [21]. ATR attachments are used to analyze the surface of materials and, compared to transmission spectroscopy, requires significantly less sample preparation. ATR is used to characterize materials that are too thick or too strong to be analyzed by transmission spectroscopy, include aqueous solutions that are absorbent. Radiation from the interferometer hits the diamond and is reflected through the diamond slightly penetrating the sample at each reflection through the diamond [21].

Characteristic information about the sample is obtained and the IR radiation then heads to the detector.

The spectra are compared by overlaying the questioned and the known spectra and looking for any discernable differences between peaks [28]. For two peaks to be considered the same they must fall within ± 3 cm^{-1} of each other. If a sample falls outside of this ranged then this leads to exclusion of the questioned fiber from the source [20]. To ensure the reproducibility of the experiment several spectra should be taken along the length of the fiber.

1.7 Raman Spectroscopy

Another popular spectroscopic technique used to analyze fibers is Raman spectroscopy. This technique is used as a complementary technique to IR spectroscopy to determine structural information about a sample of interest. Raman spectroscopy differs from other spectroscopic methods because it measures the inelastic scattering of light to determine the structure information of molecules [29]. This technique is becoming more common in forensic laboratories due to its sensitivity and non-destructive nature.

A beam of light or photons are aimed at a small portion of the sample, causing the light either be absorbed into the sample or scattered. The frequency of light that is measured is only a small portion of the light that interacts with the sample, most light passes though the sample while a small portion is scattered, this is the Raman Effect. The frequency of the light scattered is related to the molecular vibrations of the sample, these molecular vibrations cause the light to oscillate in a unique pattern [30]. The scattered light that is measured by the spectrometer has the same frequency as the source light, this is known as Rayleigh scattering and is caused by elastic impacts of the light with the sample. The light that is measured by the detector is called Raman

scatter or Raman light, and is light that is inelastically scattered when it interacts with the sample [29].

The Raman spectrometer consists of a laser light source of one or more wavelength, lenses, filters, diffraction grating or prism, a sensitive detector, and the computer. As the light is emitted from the source, it passes through the diffraction grating to split the light into its constituent frequencies. The light from the laser is then sent though the instrument where the lenses focus the light. After the light interacts with the sample the filters collect the scattered light. After the light interacts with the sample it passes though the filters which allows only the Raman light to reach the detector [29]. Due to the weakness of the scattered light that is produced, the detector is extremely sensitive in order to collect all of the light. This can be an issue if parts of the sample fluoresce during the light interaction, since that could cause the light to overwhelm the detector. The fluorescence intensity depends on the type of sample being examined and the wavelength of the laser that it is being examined with and must be taken into consideration during methodology development.

While the Raman is commonly used to measure fabric dyes, research by Miller and Bartick demonstrated the utility of the Raman spectrometer for the classification of non-dyed fibers and may provide relevant information to this study [31]. Raman spectra of non-dyed fibers contain few peaks due to their polymer make up. The results are obtained by detecting for the asymmetric shifts of the molecules when the light hits the samples.

1.8 Fluorescence Spectroscopy

Another method for fiber examination is to examine the evidence with a ultraviolet – visible (UV-Vis) microspectrophotometer (MSP) [20]. This is a versatile non-destructive

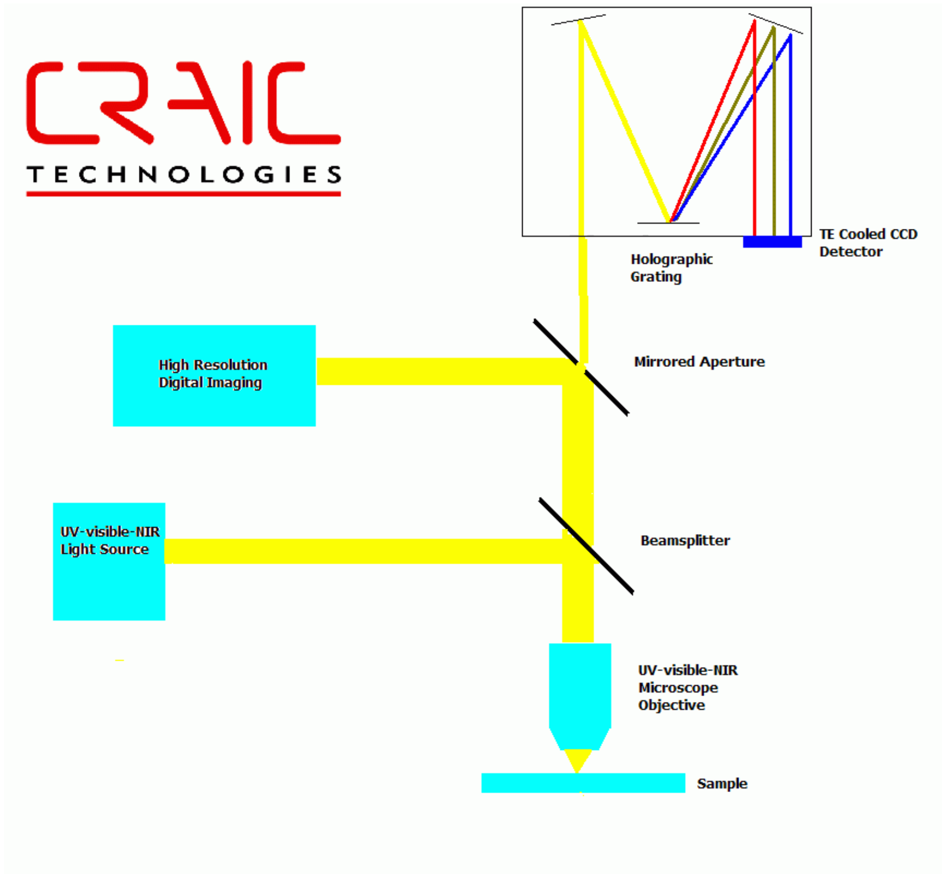

Figure 5: General Diagram of a Reflectance Microspectrometer

technique that is able to detect absorbance, reflectance, and fluorescence. This instrument is a combination of a microscope and a highly sensitive spectrometer. The microscope allows for the analysis of dyes without chemical extraction and the spectrometer uses electromagnetic energy within the UV-Vis region to identify any electronic transition in a sample to produce a spectrum [32]. The MSP is a versatile instrument because it allows for multiple types of illumination, which permits different measurements. The analysis of non-dyed fibers cannot be done using absorbance analysis since there are no dyes present in the samples, therefore fluorescence

measurements can be used to analyze the samples. The general schematic of a reflectance microspetrometer, which is used to excite the sample, is shown in Figure 5 [33].

Fluorescence occurs when a photon is emitted from a sample after first being excited. When a material is excited, an electron will jump up to what is called the excited state [21]. As the electron relaxes it will fall back down to the ground state, it is during this relaxation process that a photon may be emitted. It does not always occur, but when it does this is considered fluorescence [21]. This relaxation process transpires vary rapidly and the occurrence can be caused and altered by many different factors, some of which are difficult to identify. For fluorescence analysis the spectrometer measures for the emission of photons as an electron is drops to a ground state from an excited state, after being stimulated by a laser.

This method of analysis is to determine if there were any changes in the fluorescence over the course of the experimentation, due to environmental contaminants that the fiber may interact with. Comparisons of known and questioned spectra are done in laboratories by overlaying the two spectra [28]. If there are any unexplainable and discernable differences, then there is cause for an exclusion. Based on the "Forensic Fiber Examination Guidelines," the position of the max wavelength peak, the peak width, and the intensity of the peak must be compared between spectra. To be considered a positive association between spectra all values must be consistent. If the spectra are different from one another or present peaks are inconsistent with the known source then the sample is excluded [20].

1.9 Summary

In forensic case work, often times the evidence received for analysis has been left in non-ideal conditions for various periods of time. These environments can interact with the textile evidence which may cause degradationand affect the ability to identify the sample of interest. As

stated in the literature review, most research thus far has focused on how natural fibers are affected by various environments, with only little research focusing on the degradation of manufactured fibers. Therefore, this research focused on how various environmental conditions impact the forensic analysis of the manufactured fibers nylon, acrylic, rayon, and polyester.

CHAPTER II

2.1 Materials and Sample Preparation

2.1.1 Fabrics

For this research, the manufactured fabrics used were 100% white acrylic from Big Duck Canvas Warehouse, 100% white nylon from Joann, 100% polyester from Joann, and 100% rayon from Stylish Fabrics. These fabric types were chosen due to their prevalence in the world. To limit the number of variables being examined the fabrics analyzed were non-colored, non-coated and non-blended. For labeling purposes, the fabrics were assigned a letter A-D to distinguish each fabric type; nylon = A, acrylic = B, rayon = C, and polyester = D. Each of the four fabric types were cut into eleven 6.35 cm by 6.35 cm squares. One square from each fabric type was placed into ten different environmental conditions (described below) and one square was kept as the control. The control fibers were analyzed using ATR-FTIR and a library search was performed to determine the chemical composition of the original fabrics. All of the fibers were determined to be consistent the advertised fabric type.

2.1.2 Environmental Conditions

The four fabric types were exposed to ten environmental conditions to determine if the analytical data of the fabrics would be altered over the course of six months. The fabrics were exposed to the following conditions:

1. Hermit Beach Sand composed of natural sand, calcium carbonate, coconut fiber, sea salt mix, and probiotics

2. Miracle Grow potting soil composed of a blend of sphagnum peat moss, aged bark fines, perlite, plant food, and a wetting agent

3. Chicken manure obtained from a farm

4. Cow manure obtained from a farm

5. Chicken manure and potting soil (1:2 ratio)

6. Cow manure and potting soil (1:2 ratio)

7. Bare Ground Bolt calcium chloride winter pretreatment

8. Bare Ground Bolt calcium chloride winter pretreatment and water (1:2 ratio)

9. Scotwood Industries sodium chloride winter pretreatment and water (1:2 ratio)

10. Mobil Super Premium motor oil

Each condition was placed in its own 22 oz kinetic glasswork storage container. These containers had a ventilated lid to prevent the growth of mold in the solid conditions. Each container held one each of the nylon, acrylic, rayon, and polyester fabric squares. For the six solid conditions the fabric squares were buried to ensure that all of the sample was exposed to the environmental conditions; likewise, in the four liquid conditions the fabrics were completely submerged in the liquids for total exposure. During the six-month period, most of the containers were stored in a dark and dry cabinet. The temperature of the laboratory ranged from 70 – 72 degrees Fahrenheit and the humidity ranged from 16% – 22% during the six months of exposure. The exceptions were the containers that held cow and chicken manure; these containers were stored in the fume hood in a secured preparation lab. These samples were stored in the fume hood because the smell they produced was malodorous and required the samples to be stored separately. The environmental condition containers were only removed from these locations every two weeks, when fibers were being pulled for sampling.

2.1.3 Control Fabrics

Controls for this experimentation were fibers that were not exposed to any environmental conditions. The control fibers were stored in a druggist fold to prevent exposure to any outside factors. The fibers from each fabric type (acrylic, nylon, polyester, and rayon) were analyzed with the same methodology that was used on the exposed fibers. The control fibers were then placed back in the druggist fold for later testing. The control fibers were analyzed periodically throughout the sample testing period. This was done to guarantee that there was no change to the controls over the course of the six months.

2.2 Sample Collection

Fiber Sampling

Over the course of six months, three threads from each test sample were pulled for analysis every two weeks. Since there were four different fabric types in ten different environmental conditions, 40 samples were generated every two weeks. Each sample was assigned a unique label, following the format "X. YZ" (X = condition number, Y = week, and Z = fabric type). For example, a sample labeled 1.2A would be from the environmental condition sand, pulled in week 2, and the fiber type would be nylon.

To remove fiber samples from the environmental conditions, the fabric squares were extracted from the container and tweezers were used to remove three threads from the square for nylon, acrylic and rayon. Threads were pulled from multiple locations on the fabric square. For polyester, it was more difficult to remove individual threads/fiber from the fabric square due to the fabrics construction, so a small section of the fabric was cut from the square. Any notable observations of the fabrics (degradation, changes in color, texture, and size) in each environment

were made as fibers were removed. 70% reagent alcohol was used to clean the tweezers and scissors in-between pulling out samples to ensure that there was no contamination.

As the fibers were removed from each condition, they were placed on a labeled paper towel so that the fibers could be cleaned and then left to dry. The fibers from each

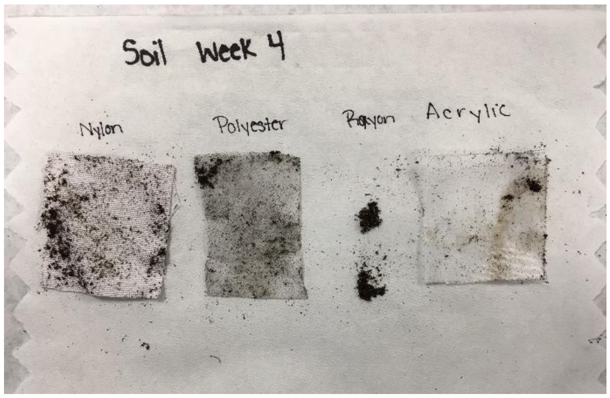

Figure 6: Image of fabric swatches pulled from soil on week four before thread removal

environmental condition were placed on their own paper towel to avoid contamination between conditions. The fibers were then rinsed with deionized water to remove any remnants of the environmental condition in which they were stored. Another paper towel was then used to cover the fibers while they dried. Once dried the fibers were placed in separate druggist folds until they were analyzed, period between sampling and analysis varied due to laboratory access and time restrictions.

2.3 Fiber Analysis

The fibers from each condition were then analyzed using bright-field and polarized light microscopy, Fourier-Transform Infrared spectroscopy, Raman spectroscopy, and fluorescence spectroscopy using an ultraviolet-visible microspectrophotometer.

2.3.1 Bright-Field and Polarized Light Microscope

Fibers were first examined using bright-field and polarized light microscopy (PLM) to determine if there were any changes to the physical and optical characteristics of the fibers. For this examination, three fibers from each sample (one from each thread that was pulled from the sample) were mounted on a quartz slides with deionized water as the mounting medium. The fibers were covered with a quartz coverslip and were then examined. A Lecia DM EP PLM microscope was used for microscopic analysis. When measuring the diameter of the fibers the measurements were made using ocular scale divisions (OSD) and was then converted to micrometers. It was calculated that at 100x 1 OSD = 20 µm, at 200x 1 OSD = 10 µm, at 400x 1 OSD = 5 µm, and at 630x 1 OSD = 4 µm. Fibers were analyzed at 200x throughout this portion of the experimentation.

The protocols that were followed for the examination of fibers were modeled closely on the standard operating practices of a forensic laboratory. Form 222-F106 Fiber Worksheet from the Virginia Department of Forensic Science was used to document the physical and optical characteristics of the fibers (Appendix A) [28]. Each of the fibers were first examined in bright-field lighting to observe and document the fibers' physical characteristics, including the fiber's diameter, its color (including if the color is consistent or variable along the shaft of the fiber as time progresses), the presence of delustering particles, the optical cross-sectional shape of the fiber, and the fibers' surface characteristics including manufacturing striations and damage.

After the fibers' physical characteristics were examined, the optical characteristics of the fibers were documented by examining the fiber in polarized light. Optical properties of the fiber that were documented were the fibers' birefringence, point of extinction, and sign of elongation.

In total approximately 1,440 fibers were examined microscopically to determine if, after exposure to various environmental conditions, the fibers would or would not be able to be related back to a known source. Based on the microscopic examination a preliminary association decision was noted, i.e. whether the fiber had a positive, negative, or inconclusive association back to the fiber's known source.

2.3.2 Fourier Transform Infrared Spectroscopy

FT-IR spectroscopy was used to analyze the polymer structure present in fibers and determine if the chemical structure was altered over time. The fibers were examined using a benchtop Thermo Scientific™ Nicolet iS10 Fourier-Transform Infrared Spectrometer with an Attenuated Total Reflection attachment (FTIR-ATR). Spectra were collected in percent transmittance mode. Collection parameters included: 32 scans, a resolution of 4, and no sampling corrections. Bench parameters included: a DTGS KBr detector, a KBr Beamsplitter, a diamond window, a medium resolution aperture, a 0.4747 optical velocity, and a range of 4000 – 600 nm. The program used for data collection and post-processing analysis was Thermo Fisher Scientific OMINC 9 software.

Each day, before analysis of experimental samples the quality of the instrument was tested with a certified polystyrene standard. A background scan was run approximately every hour. For each sample the threads were used for analysis instead of the individual fibers, because the ATR attachment was utilized and required a slightly larger sample size. The ATR benchtop was used due to its fast analysis speed, so that all samples were able to be analyzed in the allotted time frame. To account for any variability within and between the sample each of the three threads were analyzed at three points along the threads, totaling nine scans per sample. With every sample producing nine spectra, with a total of 480 samples, this produced approximately

4,320 spectra overall. To analyze the FTIR data the nine spectra per sample were averaged, resulting in approximately 480 spectra.

The purpose of FTIR analysis was to determine if the chemical structure of the fiber was altered by the various environmental conditions over the course of six months. For each of the averaged spectra the peak finding tool in the OMINC software was used to document the prominent peaks. For each fabric type the most prominent peaks from the control fibers were documented. Then the peaks from each of the samples over the six months were analyzed and placed in a table. For the peaks to be considered consistent with the known sources, which were the control samples, the peaks needed to be within plus or minus three wavenumbers from the control. If they were outside of this range only one time during the six months of samples, it was considered an anomaly. But if the peaks were consistently outside of this range then it was considered an alteration in the chemical structure of the fabric's non-symmetrical bonds due to the environmental condition it was exposed.

2.3.3 Raman Spectroscopy

As a complement to FTIR spectroscopy, Raman spectroscopy was used to determine if there were any changes to the symmetrical bonds within the fabrics' chemical structure. The samples were examined with a Thermo Fisher Scientific DXR™ Raman Microscope with a MPlan 10x/0.25 BD objective with a 780 nm laser. To prepare the samples for analysis they were removed from their druggist fold and three of the fibers from the sample, one from each thread pulled, were taped down at the ends onto a quartz slide using low adhesive tape. Once secured onto the quartz slide the fibers were then placed on the microscope stage within the Raman sample chamber. The objective was then focused on one point along the fibers, and the aperture box was placed at the center of the fiber. To ensure consistency between measurements all fibers

were measure at a horizontal orientation. Spectra were taken from one point from each of the three fibers per sample, resulting in three spectra per sample.

Parameters for analysis varied by fabric type to produce spectra with the lowest signal to noise ratio. The variations in parameters were adopted to reduce the interference that was created due to the inherent fluorescence of the different fabrics. Photobleaching was also used to reduce the noise due to fluorescence. Some parameters were uniform across all four fabric types, including: aperture- 50 µm pinhole, number of sample/background exposures- 32 scans, sampling range- 200 cm^{-1} – 2400 cm^{-1}, the spectra's final format- cm^{-1}, and the correction- fluorescence.

Methodology development was done to determine the amount of photobleaching, the laser power, and length of sample exposure that was ideal for each fabric type. The instrument parameters that were developed for each fabric type are shown in the table below.

Sampling Condition	**Nylon**	**Acrylic**	**Rayon**	**Polyester**
Laser Power (mW)	22	15	20	20
Sample Exposure Time (seconds)	3	4	4	3
Photobleaching (minutes)	0.5	1	1	0.5

Table 1: Instrument parameters for Raman analysis of samples

In Raman spectral analysis, a peak is considered qualitatively applicable only if the peak is larger than three standard deviations of the noise [30]. Various instrument parameter combinations were tried for each fabric type, including testing long 30-minute photobleaching for the highly fluorescent fabric types, acrylic and rayon. Despite the numerous trials the signal-to-noise ratio for acrylic and rayon were still significantly high, and the peaks were not larger than three standard deviations of the noise level. Thus, data analysis for acrylic and rayon was not able to be performed due to their poor signal-to-noise ratio.

For nylon and polyester fibers, the data analysis process for Raman was similar to the FTIR data analysis. For each sample three spectra were taken to account for variability within each of the samples. An average of the three spectra were then taken and the averaged spectrum was used for data analysis. The Thermo Scientific OMINC 9 software was used to identify peaks in the control samples and the averaged spectra. The prominent peaks were selected for each fabric type using the data from the control samples. The average spectrum from each sample over the six-month time period was analyzed to determine if there were alterations to the fiber's chemical structure post-exposure. For the peaks to be considered consistent with the control samples the peaks needed to be within plus or minus three wavenumbers from the control. As with the FTIR data, if there was an inconsistency in only one week, then this was an anomaly. But if the differences with a peak's wavenumber persisted, then this was considered an alteration in the fabrics structure after exposure the environmental conditions.

2.3.4 UV/Vis Microspectrophotometer

The UV-Vis microspectrophotometer (MSP) was used in fluorescence mode to determine if, after exposure to the environmental conditions, there was any significant changes to the fluorescence of the samples. The instrument used was a CRAIC FLEX™

Microspectrophotometer and the software used for analysis was the CRAIC MINERVA^{TM} microspectroscopy program with CRAIC ImageUV^{TM} UV-vis-NIR imaging software. The samples were analyzed in fluorescence mode, with an excitation wavelength of 365nm. The other instrumentation parameters for the MSP were: sampling ranges- 200 nm – 700 nm, number of scans- 50, and the integration time ranged between 700 – 900 ms throughout the analysis process. Before each of the days the samples were run, CRAIC-provided standards were run to ensure the functionality of the instrument.

For each sample three fibers, one from each thread, were placed onto a quartz slide and mounted in glycerol. To reproduce the most consistent results the fibers were placed and then analyzed at a horizontal orientation. To account for variability between and within each sample, three fluorescence spectra were taken along the length of all three fibers, resulting in a total of nine spectra per sample. A background scan was run in between each sample analysis, or every 3 scans. Each of the four fabric types (nylon, acrylic, rayon and polyester), fluoresced at various intensities with rayon appearing to have the highest fluorescence and acrylic having the lowest fluorescence. Images were taken with the imaging software to document the apparent differences in fluorescence. To obtain images and spectra with the highest possible fluorescence results, all spectra were collected in a dark room. After collection of all of the fluorescence spectra, the first derivative of every scan was taken. This was done to correct for baseline shift during the sampling process. The results were then exported into Excel tables for analysis, each of which contained the wavelength-specific fluorescence counts

The nine spectral derivatives for each sample were averaged. The averaged results were placed into a cohesive table; individual tables were made for each fabric type and environmental conditions. The following data analysis process was done for every fabric type for each of the ten conditions. The cohesive table produced contained all six months' worth of averaged spectral data. From the averaged derivatives, the highest peak was chosen and the values at that wavelength for each week were isolated and graphed. To determine if the differences in fluorescence were significant an ANOVA- single factor statistical analysis was performed.

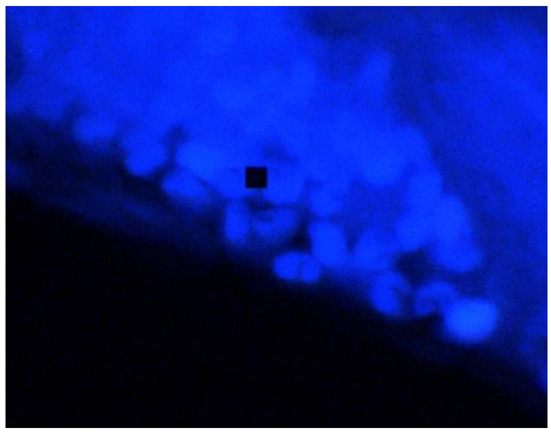

Figure 7: Image of Acrylic Cross-Section

To determine if the changes in the fiber's fluorescence was occurring throughout the fiber or just on the edges of the sample, the fibers were microtomed and then imaged using the MSP. The fibers were microtomed using a hand-fiber microtome. For each sample, the fibers were sandwiched in-between yarn of a contrasting color and was then microtomed with a razorblade. The cross sections were placed on a quartz slide, mounted in glycerol and imaged using the CRAIC software. Images of the cross-sections were only taken from the samples every other collection period, which was once a month, while the fluorescence spectra were taken every two weeks.

CHAPTER III

3.1 Results

3.1.1 Microscopy

Nylon

All nylon fibers for each condition possessed similar physical and optical properties at week 0. The nylon fibers were white in color, contained delustering agents, appeared to have a circular/round cross-section, and had a diameter range of 21-25 µm. Optically, the nylon fibers had a birefringence of approximately 0.050 – 0.060, went into extinction at 90° and 180° and possessed a positive sign of elongation. Over the course of the six-month exposure the nylon fabric did not degraded, though in the motor oil condition the fabric swatches became almost translucent by week 10. This affect in motor oil did not affect the microscopic properties of nylon which remained consistent during the experimentation.

Acrylic

All acrylic fibers possessed similar physical and optical properties at week 0. The acrylic fibers were white in color, did not possess delustering agents, appeared to have a dog-bone cross-section and had a diameter range of 11-20 µm. Optically, the acrylic fibers had a birefringence of approximately 0.014 – 0.021, went into extinction at 90° and 180° and possessed a negative sign of elongation. Over the course of the exposure period the acrylic fibers did not show signs of degradation, and their physical and optical properties remained constant over time.

Rayon

The physical and optical characteristics of all rayon fibers were consistent at week 0. All of the rayon fibers were white in color, did not possess any delustering agents and had a diameter

range of 10- 21 µm. The striations along the length of the fiber was indicative of rayon having a crenulated cross-section. Optically the rayon fibers had a birefringence of 0.023 – 0.026, went into extinction at 90° and 180° and had a positive sign of elongation. During the six months of exposure to the various environments, rayon was the most affected fiber type.

In week two rayon had already begun to show apparent signs of degradation in soil (Figure 8), holes appeared in the fabric swatch and the areas around the hole were turning green in color. At week four, rayon had completely broken down in the environmental condition soil. After searching the containers for any remaining fibers, there appeared to be no trace left behind in the container. By week six rayon had completely degraded in the following conditions; soil and cow manure mix, soil and chicken manure mix, and pure cow manure. Once again there was no visible fibers were left behind after degradation.

Figure 8: Rayon fabric swatch from soil week 2

In the remaining conditions (sand, chicken manure, motor oil, sodium chloride pretreatment and water, calcium chloride pretreatment and calcium chloride pretreatment and water) the rayon fibers did not degrade but did seem to be physically affected by some of the environments. In sand the fibers retained more moisture than any of the other fiber types, causing sand to cling to it and thus required a secondary wash with deionized water. In motor oil the fibers appeared almost translucent by week 10 and remained that way the rest of the experiment. And by week 8 of the experimentation the rayon fibers in the calcium chloride pretreatment

became more brittle, the fabric swatch tore easily when trying to remove fibers for sampling. These changes did not measurably affect the fibers physical and optical properties.

Polyester

The physical and optical properties of all polyester fibers were similar at week 0. Physically the polyester fibers were white in color, contained delustering agents, appeared to have a circular/ round cross-section and had a diameter range of 10–14 µm. Of the four fabric types being examined polyester had the most consistent diameter along the length of the fiber. Optically polyester had a birefringence of 0.070 – 0.080, went into extinction at 90° and 180°, and had a positive sign of elongation. During the six months of exposure the polyester fibers did not show signs of degradation in any environmental condition, and the microscopic characteristics of the fibers remained constant.

3.1.2 Infrared Spectroscopy

Nylon

The structure of the nylon fibers remained mostly constant over the course of the experimentation, there were very few changes to the IR spectra of nylon across all of the conditions. The changes that did occur in the IR spectra involved some peak shifting over time. None of the peaks disappeared as a result of exposure to the various environments. Some of the averaged IR spectra are shown in Appendix B and the tables of IR data for each condition are shown in Appendix C. Wavenumbers highlighted in green fall within ± 3 cm^{-1} and those wavenumbers not in green fall outside of the accepted range.

A peak shift at 1540 cm^{-1} occurred, this is a peak indicative of NH bending. This shift occurred in the four liquid conditions. For calcium chloride pretreatment with water the shift

from 1540 cm^{-1} to 1544 cm^{-1} occurred at week six of experimentation. For motor oil, sodium chloride pretreatment with water and calcium chloride pretreatment this shift did not occur until week 20. At 2929 cm^{-1} and 2859 cm^{-1}, peaks consistent with CH stretching, there was a peak shift in two of the environmental conditions, motor oil and sodium chloride pretreatment and water. These peak shifts began at week two for both conditions. One notable observation for the condition motor oil was that, the 2929 cm^{-1} and 2859 cm^{-1} peaks showed an increase in intensity in all fiber types every week. This may have occurred due to C-H stacking in the IR spectra, which is known to cause an increased peak signal. Though there were shifts to some peaks in the IR spectra there were no changes to the peaks relative intensities.

Acrylic

Acrylic fibers, like nylon did not have many changes in structure over the course of this research. All changes that occurred in the IR spectra of acrylic fibers were in peaks associated with C-H stretching and bending. Like with nylon, there were no overall losses in any of the peaks, just shifts over time. Averaged IR spectra for acrylic are shown in Appendix D and tables that show how the peaks in the IR spectra changed over time are shown in Appendix E.

At 2923 cm^{-1} there was a peak shift in the following conditions: sand, soil and cow manure, sodium chloride pretreatment and water, and calcium chloride pretreatment and water. The 2923 cm^{-1} peak relates to CH stretching. These changes occurred periodically throughout the experimentation starting from week two for the sodium chloride pretreatment/water and the calcium chloride pretreatment/water conditions. In the conditions sand and soil/cow manure conditions there was not a shift in the 2923 cm^{-1} peak until week eight. The peaks 1366 cm^{-1} and 1451 cm^{-1} are both consistent with CH bending. Shifts in both of these peaks occurred in motor oil. While a shift in only the 1366 cm^{-1} peak was observed in the environmental condition

chicken manure. Though there were shifts to some peaks in the IR spectra there were no changes to the peaks relative intensities.

Rayon

Of all the fiber types examined, rayon fibers had the most measurable changes to their chemical structure over time. Some of the averaged IR spectra for rayon for the six months of exposure are shown in Appendix F and the tables of changes to specific peaks for rayon are shown in Appendix G. Besides when the fibers degraded completely, there was no outright loss of any peaks but there was a shift in the peaks over time.

In all conditions except calcium chloride pretreatment and water there were changes to the 3331 cm^{-1} peak, which is indicative of an OH stretching vibration. Due to the broad nature of the OH peak, the peak would sometimes shift down to around 3200 cm^{-1}. Another peak shift that occurred to changes in an OH group was the 1645 cm^{-1} peak. This peak designates the presence of OH bending due to an absorption of water. In almost all conditions, except sand and calcium chloride pretreatment and water, there was a shift in the 2891 cm^{-1} peak, consistent with CH symmetric stretching. And in all of the environmental condition there was a shift in the 1366 cm^{-1} peak, which is indicative of an alteration in CH bending vibration.

Finally, one change in only the conditions where the fibers degraded was a shift at the 1018 cm^{-1} peak. This peak represents the CO, COH, OH ring vibration that would occur due to ring structure of viscose rayon. Shifts in this peak occurred in the following environmental conditions: soil, soil with chicken manure, and soil with cow manure. In all of the other environmental conditions where rayon did not degrade there were no changes to this peak over time. Though there were shifts to some peaks in the IR spectra there were no changes to the peaks relative intensities.

Polyester

The polyester fibers were the most resilient of the four fabric types and did not show any significant changes to the IR data over the six months. There was a change, in some conditions, to the 1470 cm^{-1} peak. This peak is at the higher end of the range for CH_2 bending vibrations. In sand, cow manure and motor oil these peaks shifted down to the 1460 cm^{-1} range, which still falls within the CH_2 bending vibration range. Therefore, even though there was some peak shifting it does not indicate that there were any changes to polyester's chemical structure. Like the rest of the other fabric types there was an intensity increase at peaks approximately 2920 cm^{-1} and 2850 cm^{-1} in motor oil. Data tables of polyester in the ten environmental conditions are in Appendix I and the some of the averaged IR spectra are shown in Appendix H. Though there were shifts to some peaks in the IR spectra there were no changes to the peaks relative intensities.

3.1.3 Raman Spectroscopy

Nylon

Only two of the four fiber types were able to be analyzed with Raman Spectroscopy, and of the two nylon was the only one that had any measurable changes in its data. In all of the liquid conditions the Raman peaks remained consistent, but in the solid conditions were there changes to the spectra over time. In sand and soil with cow manure there was a shift in the 1122 cm^{-1} peak. This peak is indicative of CN stretching within the structure of nylon. The shift in the 1122 cm^{-1} peak only occurred a few times in each condition: weeks 18, 20, and 22 for sand and week 14,16, and 18 for soil with cow manure. While this shift only occurred three times for each condition, it was a consecutive occurrence and therefore was noted as significant.

The main changes to Raman data of nylon that occurred happened in the conditions chicken manure and cow manure. The spectra from these conditions were difficult to analyze do to what appeared to be fluorescence interference in these two conditions. The detection of peaks was difficult and at week 18, in both conditions, there was a drop off in signal for all of the peaks. The spectra became almost a flat line for nylon in chicken manure and cow manure week 18 and onwards (see Figures 152 and 154). From that point the spectra were unable to be analyzed and the fiber unable to be identified, with Raman analysis. Averaged Raman spectra for nylon are in Appendix J and tables of the analytical data are in Appendix K.

Rayon and Acrylic

Unfortunately, both acrylic and rayon fibers were unable to be analyzed due to a low signal-to-noise ratio. This means that the peaks of interest were not higher than 3 standard deviations of the noise. For acrylic there was a large amount of fluorescence interference, despite photobleaching, which made the analysis of acrylic Raman spectra impossible. For the rayon fibers, it was a combination of a large noise level as well as the presence of fluorescence interference that made the analysis impossible.

Polyester

Polyester was the most stable fiber over the course of the experimentation, there were no measurable changes to the Raman spectroscopic data over the course of the time study. Averaged Raman spectra from periodic periods of this research are shown in Appendix P and data tables of the Raman data for polyester are in Appendix Q.

3.1.4 Fluorescence Spectroscopy

Nylon and Acrylic

Determining any analytical changes to the fluorescence of nylon and acrylic was not able to be done because the outside of the fibers did not fluoresce, which is where the measurements

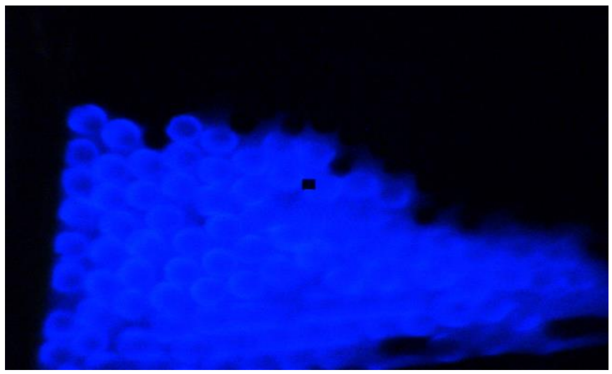

Figure 10: Nylon fiber cross section at 365 nm excitation

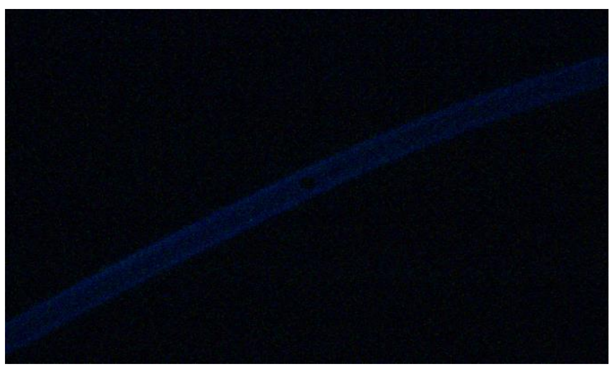

Figure 9: Nylon fiber at 365 nm excitation

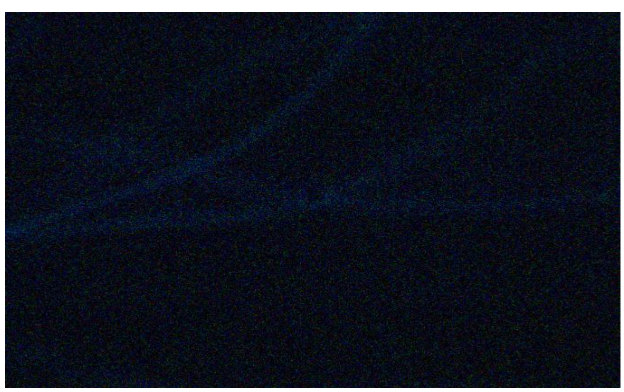

Figure 11: Acrylic fiber at 365 nm excitation

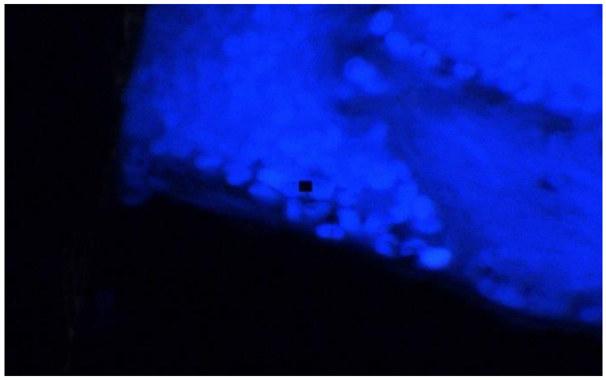

Figure 12: Acrylic fiber cross-section at 365 nm excitation

took place. When the fibers were cross-sectioned, the internal structure of the fiber did appear to fluoresce more than the external structure of the fiber. Photomicrographs of the external and internal fluorescence of nylon are shown in Figure 9 and 10. Photomicrographs of the external and internal fluorescence of acrylic are shown in Figure 11 and 12. Due to the lack of fluorescence of the external structures of nylon and acrylic the resulting spectra were a flat line, and thus no post data collection analysis was performed.

Rayon and Polyester

Both rayon and polyester experience fluorescence at 365 nm excitation. Over the period of analysis there were significant changes to the fluorescence of rayon and polyester in almost every condition. To analyze how the fluorescence changed 9 spectra were collected from each sample and analyzed. The raw data experienced a baseline shift, a phenomenon where the baseline would rise each time a sample was run. This made it impossible to make comparisons between spectra on the intensity of the fluorescence peaks. To correct for this the first derivative of the averaged spectra were taken and those results were compared.

The fluorescence for rayon and polyester did change over time, but those changes were not always regressive. In some conditions, there would be a drop of fluorescence signal between

two weeks, but the following weeks sample would show an increase in fluorescence. This occurred in both conditions. Graphs of the changes in fluorescence for rayon and polyester are shown in Appendix R and Appendix S respectively. From the data collected an ANOVA (single factor test of significance) was performed to determine if the changes in fluorescence were significant. The results of this analysis are shown in Table 2, the highlighted cell shows where the changes to fluorescence were not significant. Only rayon in the condition soil with cow manure was calculated to not be significant. These results are purely analytical data and it is currently unknown why the fluorescence of these fibers was altered over time

P-Value: Determining Significant Changes to Fluorescence Over Time		
	Rayon	**Polyester**
Sand	4.8683E-41	6.52342E-49
Soil	8.79321E-09	4.91701E-41
Soil and Chicken Manure	0.009149531	1.97154E-40
Chicken Manure	1.27046E-31	1.97366E-47
Soil and Cow Manure	0.997841435	2.32151E-37
Cow Manure	0.018348482	4.93752E-56
Motor Oil	1.88858E-44	1.38679E-46
Water and Salt Pretreatment	5.4056E-51	5.85735E-49
Calcium Chloride and Water	1.7187E-49	5.24348E-70
Calcium Chloride Pretreatment	3.19513E-34	3.35657E-59

Table 2: Table of P-Values - Determine if Significant Changes to Fluorescence Occurred Over Time

After determining there was a significant change to the fluorescence overtime, the fibers were cross-sectioned to determine if these changes were happening uniformly throughout the fiber or just on the outer edges. It was determined that the changes were occurring uniformly throughout the fiber. The cross-sectioned rayon and polyester fibers showed uniform changes in fluorescence over time.

CHAPTER IV

4.1 Discussion

4.1.1 Nylon

As a synthetic fiber, it was not surprising that nylon did not experience a large amount of measurable changes that affected the ability to relate it back to the control. Microscopically nylon was unchanged in both its physical and optical properties. This shows that a properly trained microscopist would be able to classify a nylon fiber after long-term exposure to the environments that were research.

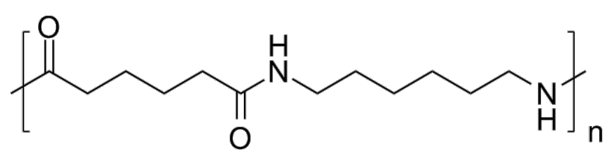

Figure 13: Structure of Nylon 6,6

When analyzing nylon using IR spectroscopy the results indicated that there were some changes in the bond's vibration after exposure to some of the conditions. Figure 12 shows the structure of nylon. The 1540 cm^{-1} peak shift that occurred in all the liquid conditions is indicative of a change to the NH bond vibrations. The nitrogen areas of this fiber appear to be the points that are most prone to being affected by the various environments. This is further proven with the Raman data where the only peak shift that occurred was at the 1122 cm^{-1} peak. In Raman this peak is consistent with a change to the CN stretching. Due to the strength of the nylon fiber these slight changes indicated by the stretching and bending vibrations were not enough to cause a breakage of the polymer structure. Thus, the nylon fibers did not degrade in any of the conditions.

The difficulty in analyzing the fibers that were in chicken manure and cow manure using the Raman spectrometer was an unexpected result. The eventual flatlining of the spectra show

that something present within the manure was causing interference with the Raman. Since the fibers in these conditions remained intact there was likely not a breakdown of the fiber's structure in the cow and chicken manure. The implication that there was interference from these conditions indicates that either the fibers were not cleaned enough after removal from the conditions, or perhaps that the fibers became coated with something from these conditions. More in-depth analysis of these conditions would be necessary to determine why they caused such difficulty in Raman analysis of nylon. This indicates that a more thorough cleaning methods of fibers need to be tested, in an attempt to determine if the decrease in signal is caused by the coating on the fiber or by the fiber's interaction of the manure with the fiber itself.

Due to the lack of external fluorescence of nylon, changes in the fibers fluorescence was not able to be measured. The difference between the internal and external fluorescence of nylon is interesting and more work needs to be done to determine what in the fibers are causing the fluorescence. As a white fiber there are no apparent chromophores that would cause fluorescence. Therefore, before value can be placed on the fluorescence results more research to truly understand the mechanism behind what is occurring.

Despite the few measurable changes that occurred to the nylon in each of the conditions, using some or all of the analytical techniques, nylon was able to be related back to its known source. These results indicate that forensic fiber comparisons are able to be performed with a high degree of confidence on fibers that are exposed to various environments.

4.1.2 Acrylic

The acrylic fibers also showed few measurable changes throughout the six months of exposure to the various environments. Microscopically the physical and optical properties

remained constant. Acrylic is unique in the fact that it has a negative sign of elongation, which is a property that is commonly used to identify acrylic using PLM. The consistency of this characteristic, as well as all the other properties examined show that, despite exposure to different environments, acrylic was still able to be microscopically classified.

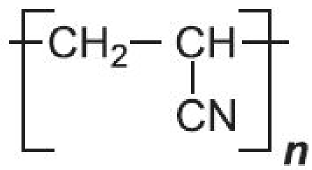

Figure 14: Structure of Acrylic

The structure of acrylic is a fairly stable polymer that is not prone to breakage. This is shown in the IR results where the only peaks shift that occurred were due to slight changes in the CH bending and stretching vibrations. There were no vibrational changes to and CC bonds or the CN nitrile bond. This shows why there was no degradation of acrylic in any of the conditions.

Acrylic was unable to be analyzed using either Raman spectroscopy because it exhibited a high fluorescence when excited at 780 nm. To perform Raman analysis on acrylic fibers it appears that a laser of a different wavelength is required, because at 780 nm neither qualitative nor quantitative analysis can be performed. Acrylic was also not able to be analyzed using fluorescence analysis, at a 365 nm excitation the acrylic fiber did not exhibit a significant amount of fluorescence. Like nylon, once the fiber was cross-sectioned the internal segment of the fiber exhibited florescence. Thus, more research is necessary to determine the differences between the internal and external properties of acrylic and how that affect its fluorescence.

Overall, acrylic was one of the more difficult fibers to analyze, because it could only be analyzed using two of the four techniques. It is important to understand how different wavelengths of light interact with the fibers of interest, because not all analysis techniques are suitable for all types of fiber. Though, with just using microcopy microscopy and FT-IR

spectroscopy, the acrylic fibers exposed to the different environments were able to be connected back to their known source, the control fibers.

4.1.3 Rayon

Viscose rayon was the only regenerated fiber type analyzed during this research. As expected, this was the fabric type that was most prone to degradation, it completely broke down in the environmental conditions soil, soil with chicken manure, soil with cow manure and cow manure. Though, before the complete degradation of the rayon the samples that were pulled were able to be classified as rayon fibers. Microscopically, the fiber's physical and optical properties were not altered over time.

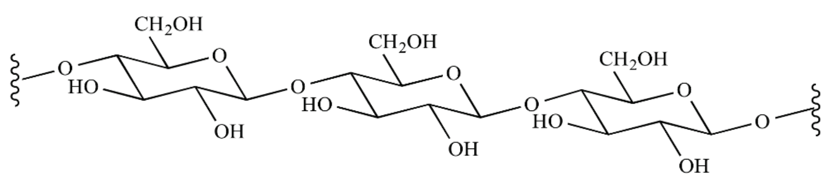

Figure 15: Structure of Viscose Rayon

The structural component responsible for rayon's stability is the cellulose ring, thus when alterations ring's vibration occurred, the fiber was more prone to degradation in those conditions. The IR data showed changes to the 1018 cm^{-1} peak, responsible for the ring vibration, in the conditions where rayon broke down. This indicates that there may have been breakage in the ring which caused the degradation to occur. In the conditions where there were no changes in the 1018 cm^{-1} peak the fiber did not degrade. Though up until the point of complete degradation, the IR spectra of rayon was able to be identified as rayon. Raman analysis of rayon fibers was not able to be performed because at 780 nm excitation the fibers exhibited a significant amount of fluorescence interference and a low signal-to-noise ratio.

While there were significant changes to the fluorescence of rayon over time, currently it is unknown why the fibers fluoresced, and therefore why the fluorescence changed over time. More analysis needs to be done to determine why these fluctuations in fluorescence occurred before any statement can be made.

Overall, the rayon fibers were able to be correlated back to their known source using at least one analytical technique. Microscopy appeared to be the most useful technique in identifying rayon, since the physical and optical properties were not altered. While spectroscopically there were some significant changes to the IR results, the alterations do relate to the degradation of rayon. From these results it is possible for forensic analysis of rayon to be performed, but consideration must be taken depending on how long the fiber has been in various environments. With prolonged exposure, the structural analysis of rayon becomes more difficult to perform.

4.1.4 Polyester

Of the four fiber types examined polyester was the most resilient, experiencing few to no measurable changes in all analytical techniques used for analysis. Microscopically polyester remained consistent after six months of exposure to various environments. There were no changes to physical or optical characteristics of polyester.

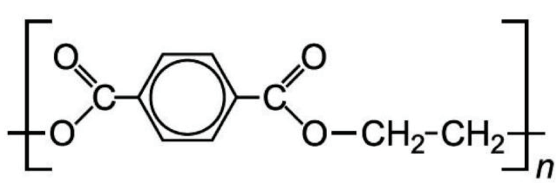

Figure 16: Structure of Polyester

Polyester was unchanged in both IR and Raman spectral analysis. There were no significant peak shifts in either form of analysis, which is consistent with the lack of degradation

of polyester. Due to the presence of the benzene ring, which is an extremely stable chemical molecule, it is unsurprising that there were no structural changes to polyester over time. The fluorescence of polyester was significantly different over time in all of the environmental conditions. But, as with rayon, more research needs to be performed to determine why these changes occurred.

These results indicate that polyester is a very stable fiber in many environmental conditions. The lack of structural changes after six months of exposure show that when polyester is examined there is little chance it will be misidentified, because of environmental effects.

4.2 Conclusions

The main goal of forensic fiber comparison analysis is being able to relate a questioned fiber back to its known source. In general, there had been little research on how manufactured fibers are affected by various environmental conditions. And, if there were any changes, would this inhibit an analyst's ability to link a questioned fiber back to its known source? Based on the analysis of nylon, acrylic, rayon and polyester it was shown that, microscopically and spectroscopically all four fiber types were able to be related back to their known source after exposure to various environmental conditions. The only exception to this is when the fibers completely degraded. This occurred in the situations of rayon in the conditions soil, soil/cow manure, soil/chicken manure, and cow manure.

Microscopically all four of the fiber types remained constant during the time study up to the point of complete degradation, with neither the physical nor optical characteristics of the fibers being measurably altered over time. Spectroscopically, even though there were some measurable peak shifts, the four fabric types were able to be related back to their known source, the control fibers. The only times spectroscopy was not able to be used to link a fiber back to its

known source was Raman spectroscopy of acrylic and rayon, due to a low signal-to-noise ratio. Also, Raman spectroscopy was not able to be used to relate nylon back to its known source in the conditions of chicken manure and cow manure after week 18.

Fluorescence analysis proved to exhibit the most significant and least probative changes observed throughout this research. Nylon and acrylic fibers were not able to be analyzed using fluorescence analysis because they did not fluoresce at the analyzed wavelength. Rayon and polyester did fluoresce and both fibers experienced significant changes to fluorescence over time in all conditions, except rayon in soil with cow manure. And while the change to rayon and polyesters fluorescence was uniform throughout the entire fiber, the changes were not always regressive. Unfortunately, this is currently pure empirical data and the cause of the changes to fluorescence needs to be investigated before conclusive statements can be made.

Overall, of the non-dyed fibers analyzed, the viscose rayon fibers were most prone to degradation. This was expected because it was a regenerated fiber. The rapid speed in which the fiber degraded in certain conditions was unexpected, in some conditions degrading within one month. This rapid degradation seems to correlate to a breakage in the cellulose ring that make up rayon. Unsurprisingly, the synthetic fibers were more structurally resilient and did not degrade in any of the environmental conditions. The polyester fibers were the most stable and experienced few measurable changes to the analytical data. Despite any slight changes to the fibers over time, except when the fibers completely degraded, they were always able to be related back to their known source. Indicating that even when manufactured fabrics are exposed to environmental conditions for an extended period of time, forensic comparative fiber analysis can be performed.

4.3 Future Work

This research focused on the alterations to the microscopic and structural properties of four man-made fabrics in ten environmental conditions over the course of six months. While this researched covered a wide range of variables, there is still more that needs to be explored that were outside the scope of this research project. One point of interest for this research will be to determine if there were physical alterations to the surface of the exposed fibers at a nanoscopic level. This determination will be done using a scanning electron microscope so that the surface of the fibers is able to be analyzed. Another research focus for the collected samples will be to determine the cause of the changes to the fibers' fluorescence over time. This includes determine what in the fibers is fluorescing and determining why it is changing over time.

There are many properties of manufactured fibers that need to be researched in order to obtain a full scope of how manufactured fibers are affected by various environments. One goal would be a continued investigation on the changes to analytical data of manufactured fibers in different environments than the ones that were examined. Researching conditions such as sunlight, heat and humidity would be beneficial to determine how manufactured fibers are affected in real world situations. Another environmental condition to be considered is the effect of contaminated water on manufactured fibers. This should be done to simulate the effect of bodies or evidence disposed of in watery environments.

One important environmental condition that needs to be studied is the effect of decomposition fluid on different fabric types. Many homicide victims remain undiscovered for extended periods of time wearing the clothing they were murdered in. Therefore, it is important to know how decomposition fluid will affect the analytical data of manufactured fibers to ensure that comparative fiber analysis can be properly performed

Finally, another research goal will be determining if there are changes to the data of dyed fibers in various environmental conditions. One characteristic of fibers that are compared between questioned and known fibers is the color of the fibers. If the colors of the fibers are changed due to assorted environments, then this would affect the comparative analysis of the fiber.

APPENDIX A: MICROSCOPY FIBER TEMPLATE WORKSHEET

FIBER WORKSHEET **FS #:**________________

DATE:____________ **ITEM #:**____________ **EXAMINER:**______________________

VERIFICATION: (Initials and Date) ______________________

ITEM DESCRIPTION: ____

____

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MICROSCOPE USED: Olympus BX-40 PLM _____ Olympus SZ-11/SZ-40 Stereomicroscope _______
Olympus BX-40 Comparison PLM _____ Nikon SMZ-1 Stereomicroscope _____
Leitz Laborlux D ______ Leica CFM 2 ______ Other ________________________

Mounted In: H_2O Xylene Substitute Permount ProTexx Norland

MAGNIFICATION (x):

ITEM #				
COLOR				
DELUSTERED				
DIAMETER				
EXTINCTION				
BIREFRINGENCE				
SIGN OF ELONGATION				
OPTICAL CROSS-SECTION				
Optional: Refractive Index nm:				
Other				

Cross-section technique: Norland Super Glue PLB Joliff plate Norland/Pipette

Cross-sectional shape				

Trace Evidence Fiber Worksheet
Issued by Chemistry Program Manager
Issue Date: 19-March-2009

DFS Document 222-F106
Revision 1
Page 1 of 1

APPENDIX B: IR SPECTRA OF NYLON

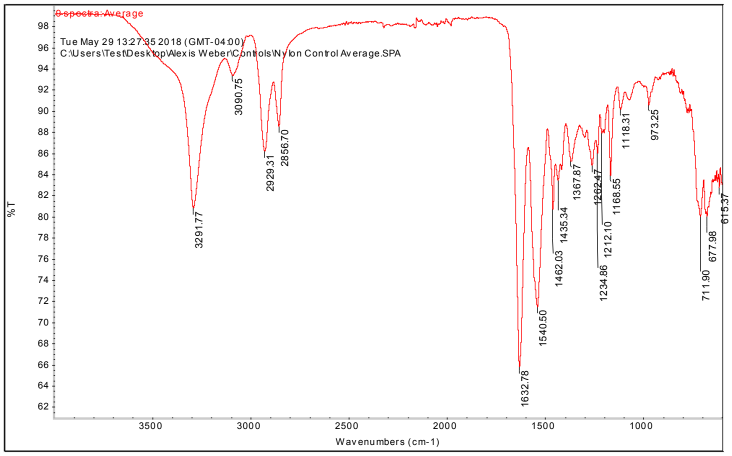

Figure 17: IR Average Spectrum of Control Nylon

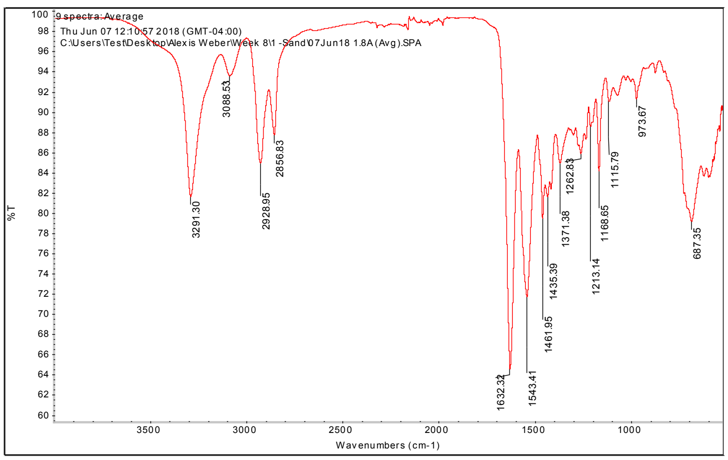

Figure 18: IR Averaged Spectrum of Nylon - Week 8 in Sand

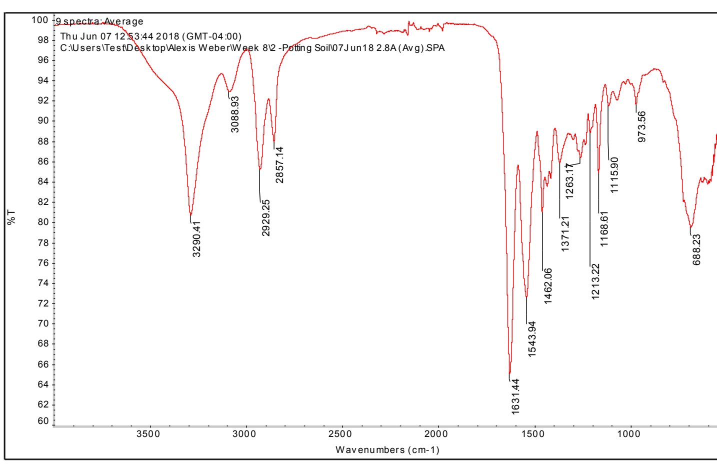

Figure 19: IR Average Spectrum of Nylon - Week 8 in Soil

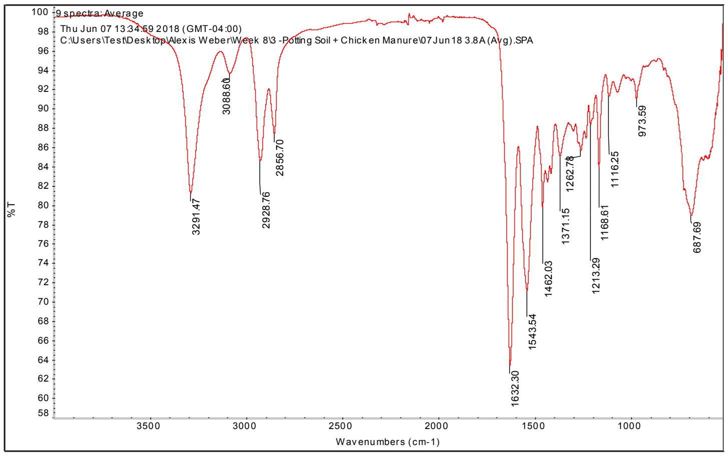

Figure 20: IR Average Spectrum of Nylon - Week 8 in Soil and Chicken Manure

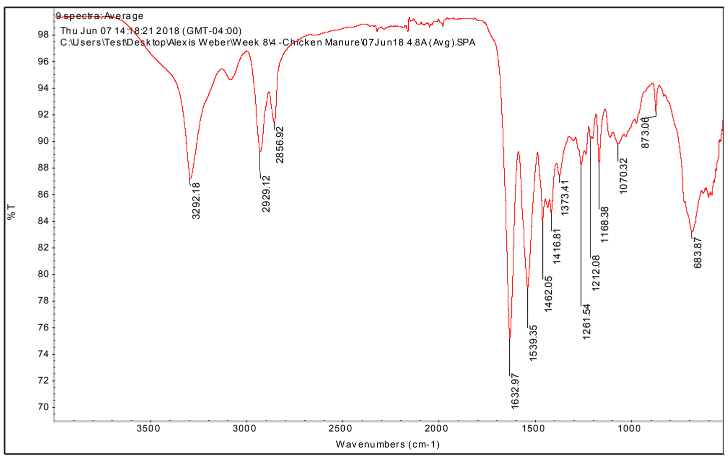

Figure 21: IR Average Spectrum of Nylon - Week 8 in Chicken Manure

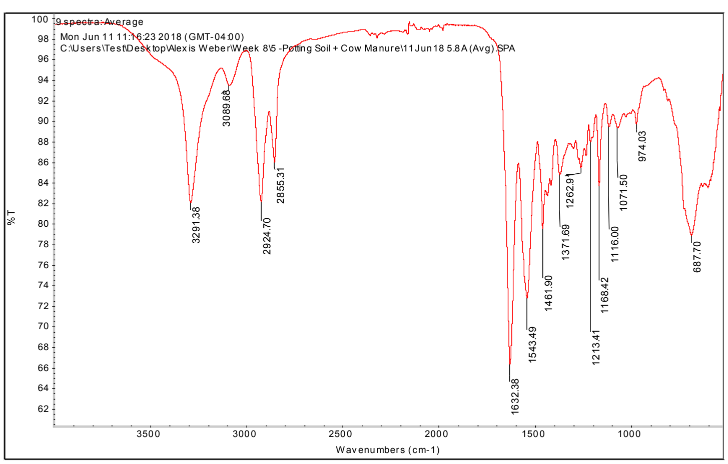

Figure 22: IR Average Spectrum of Nylon - Week 8 in Soil and Cow Manure

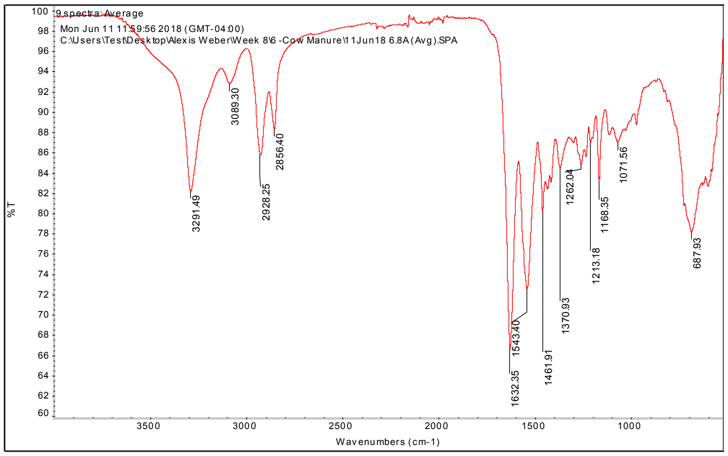

Figure 23: IR Average Spectrum of Nylon - Week 8 in Cow Manure

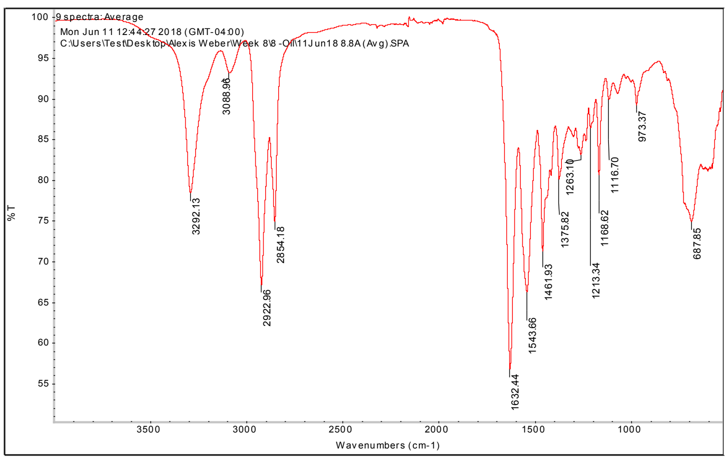

Figure 24: IR Average Spectrum of Nylon - Week 8 in Oil

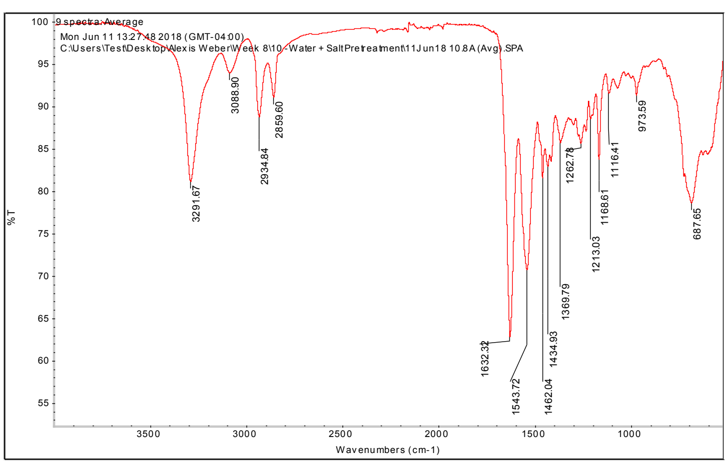

Figure 25: IR Average Spectrum of Nylon - Week 8 in Salt Pretreatment and Water

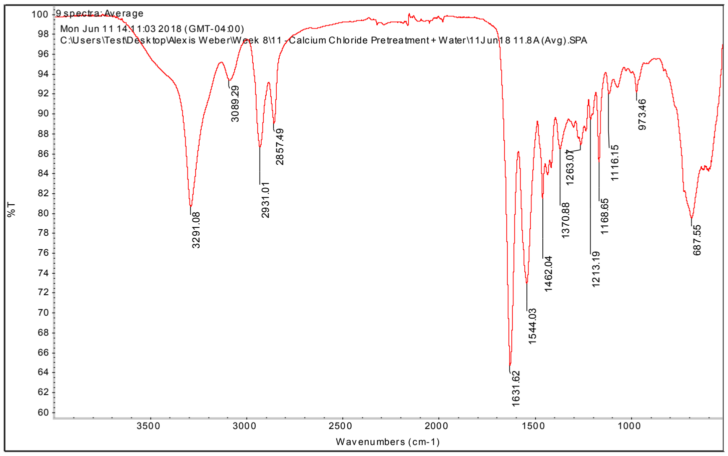

Figure 26: IR Average Spectrum of Nylon - Week 8 in Calcium Chloride Pretreatment and Water

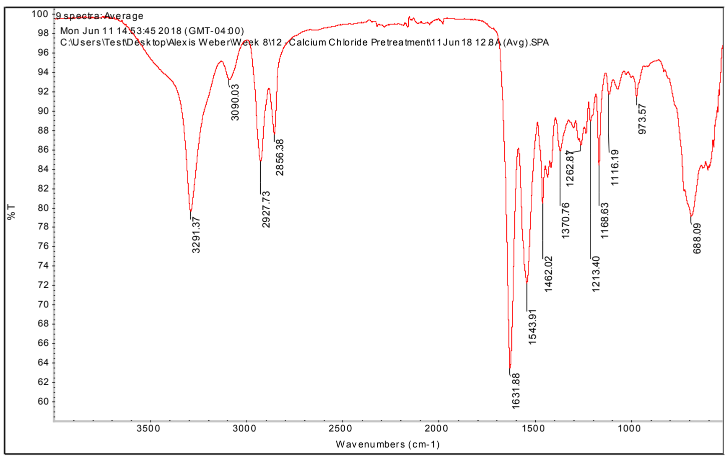

Figure 27: IR Average Spectrum of Nylon - Week 8 in Calcium Chloride Pretreatment

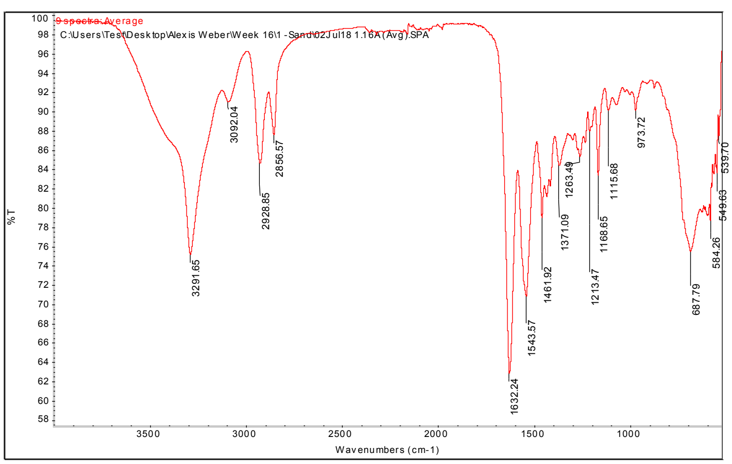

Figure 28: IR Average Spectrum of Nylon - Week 16 in Sand

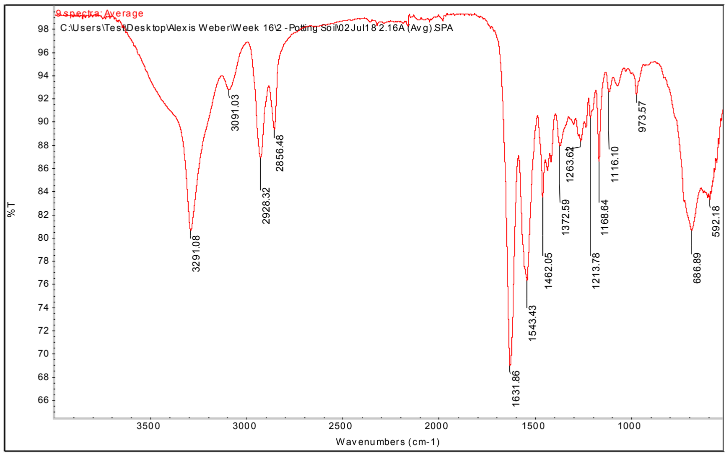

Figure 29: IR Average Spectrum of Nylon - Week 16 in Soil

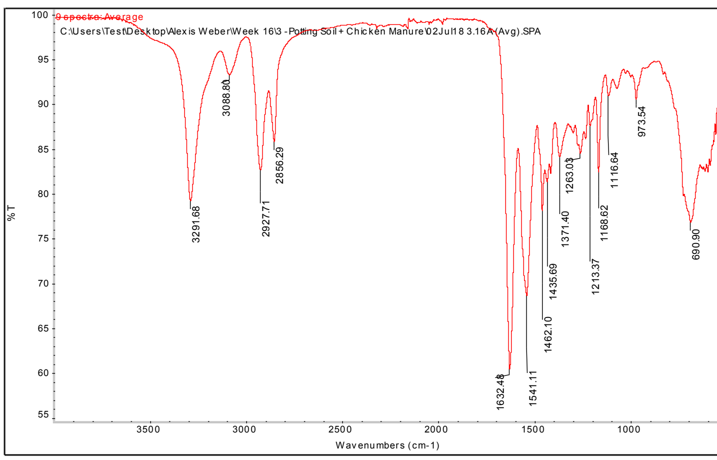

Figure 30: IR Average Spectrum of Nylon - Week 16 in Soil and Chicken Manure

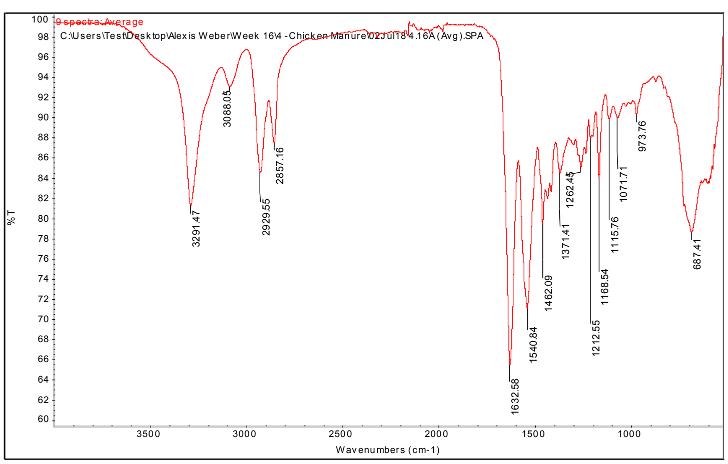

Figure 31: IR Average Spectrum of Nylon - Week 16 in Chicken Manure

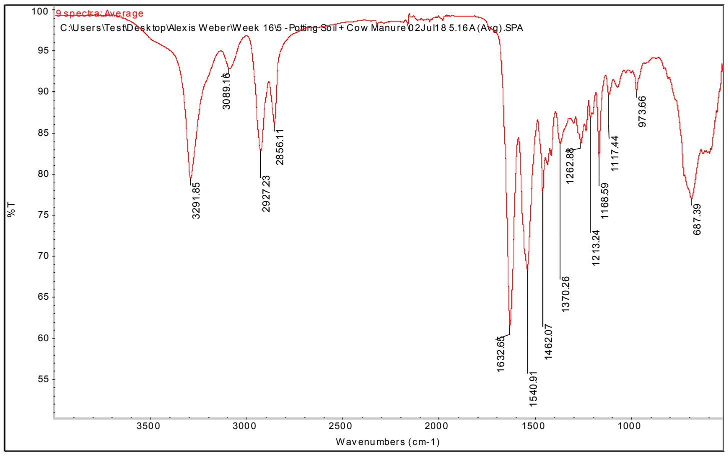

Figure 32: IR Average Spectrum of Nylon - Week 16 in Soil and Cow Manure

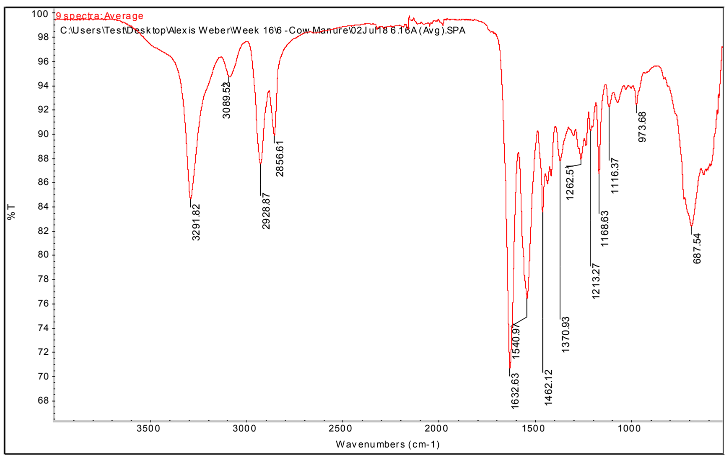

Figure 33: IR Average Spectrum of Nylon - Week 16 in Cow Manure

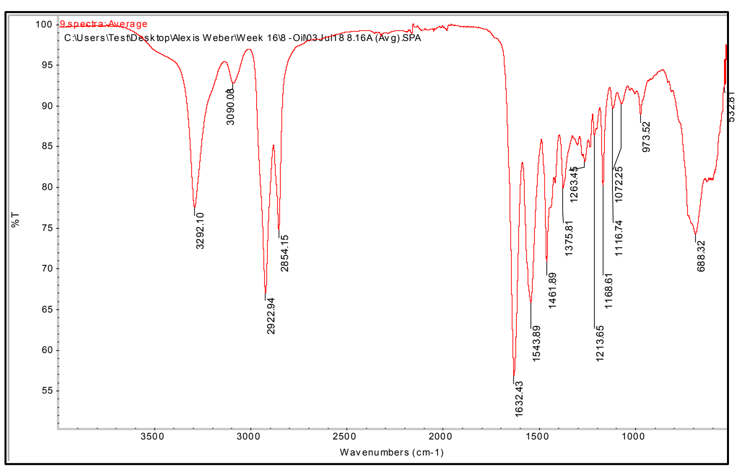

Figure 34: IR Average Spectrum of Nylon - Week 16 in Oil

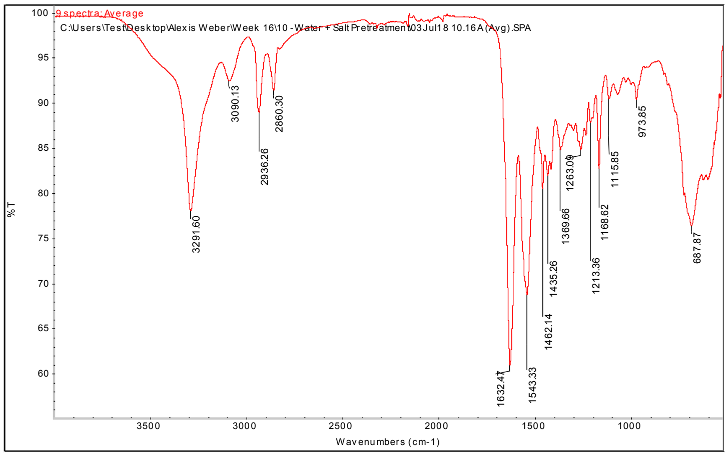

Figure 35: IR Average Spectrum of Nylon - Week 16 in Salt Pretreatment and Water

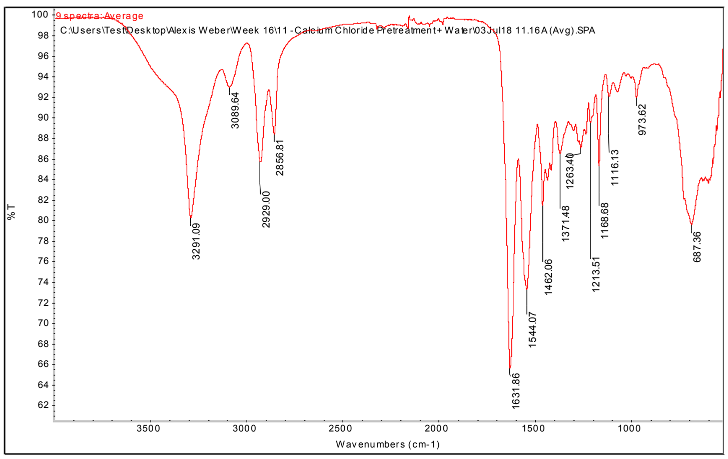

Figure 36: IR Average Spectrum of Nylon - Week 16 in Calcium Chloride Pretreatment and ater

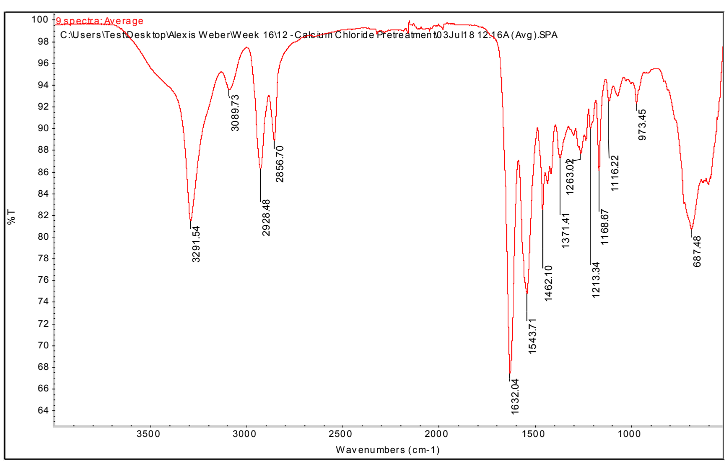

Figure 37: IR Average Spectrum of Nylon - Week 16 in Calcium Chloride Pretreatment

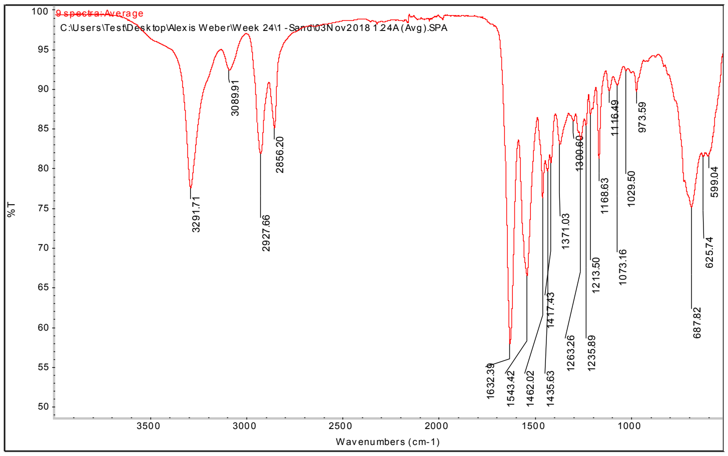

Figure 38: IR Average Spectrum of Nylon - Week 24 in Sand

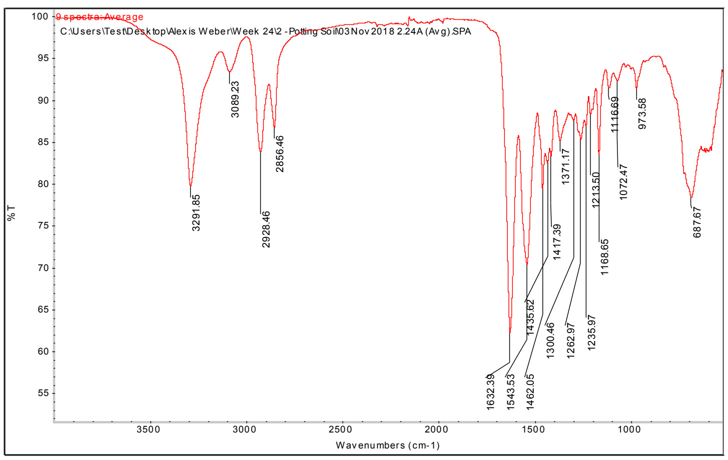

Figure 39: IR Average Spectrum of Nylon - Week 24 in Soil

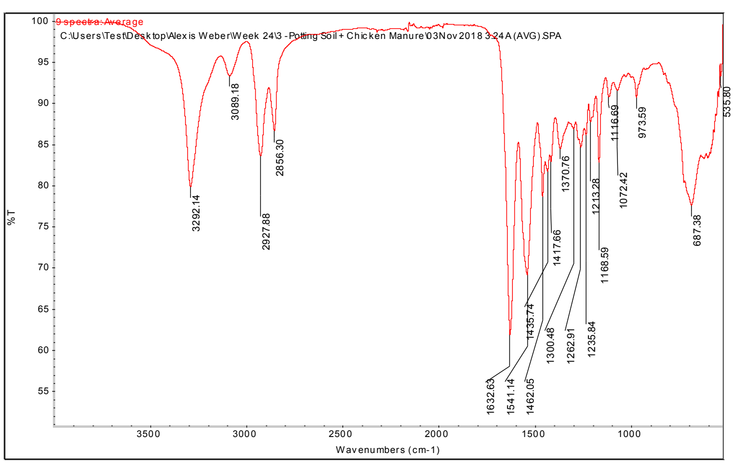

Figure 40: IR Average Spectrum of Nylon - Week 24 in Soil and Chicken Manure

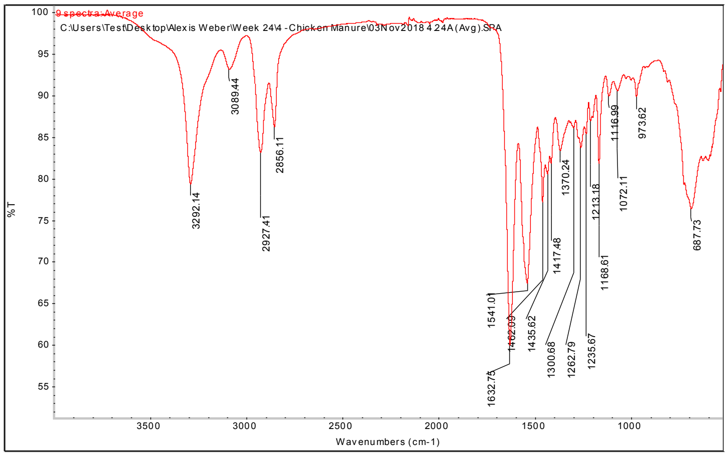

Figure 41: IR Average Spectrum of Nylon - Week 24 in Chicken Manure

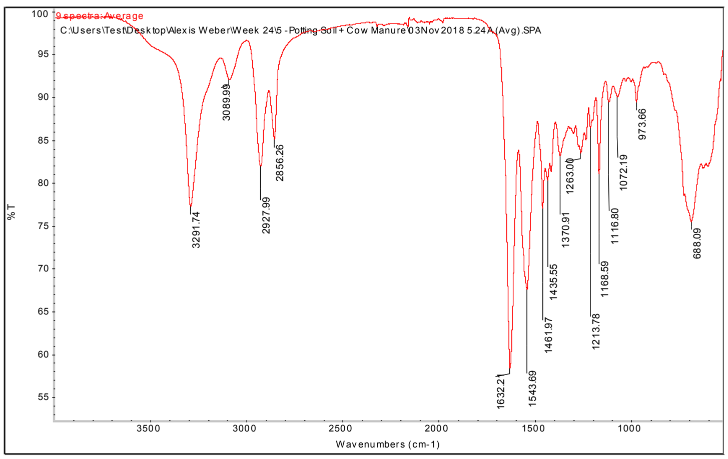

Figure 42: IR Average Spectrum of Nylon - Week 24 in Soil and Cow Manure

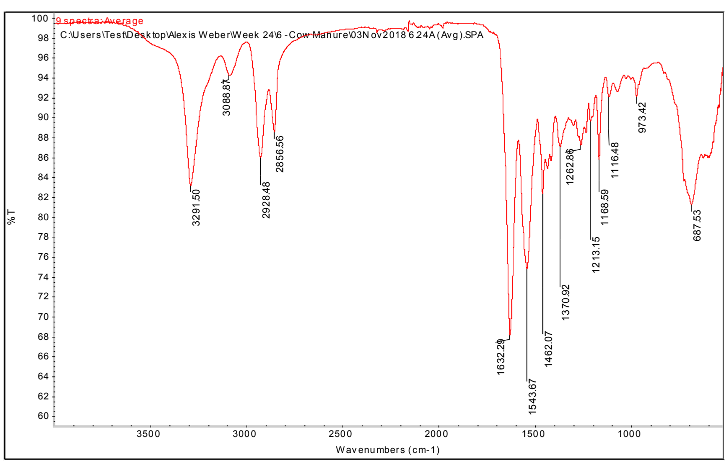

Figure 43: IR Average Spectrum of Nylon - Week 24 in Cow Manure

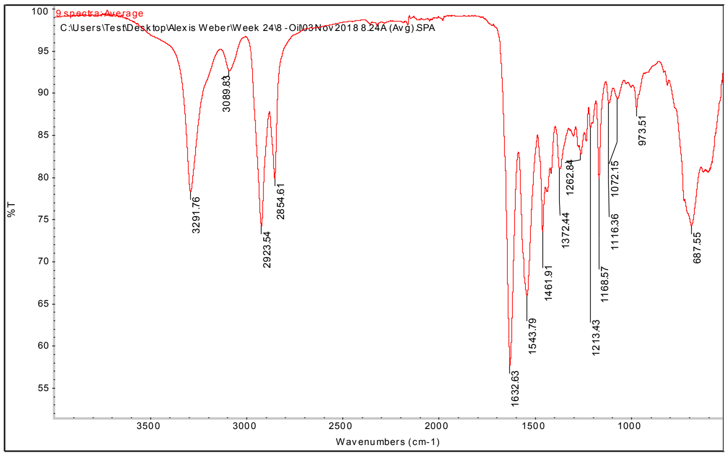

Figure 44: IR Average Spectrum of Nylon - Week 24 in Oil

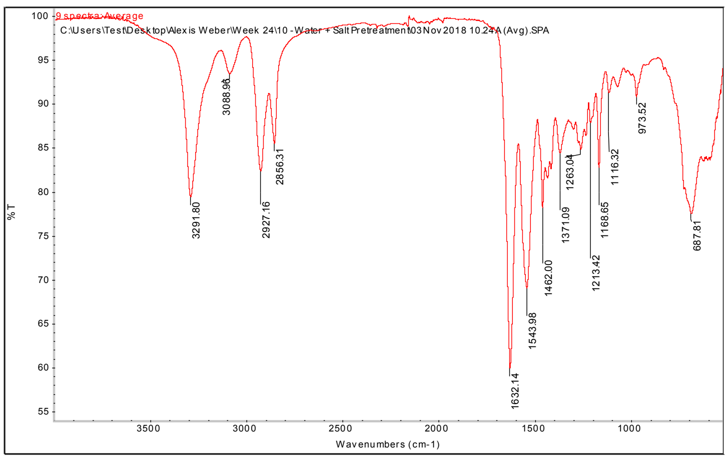

Figure 45: IR Average Spectrum of Nylon - Week 24 in Salt Pretreatment and Water

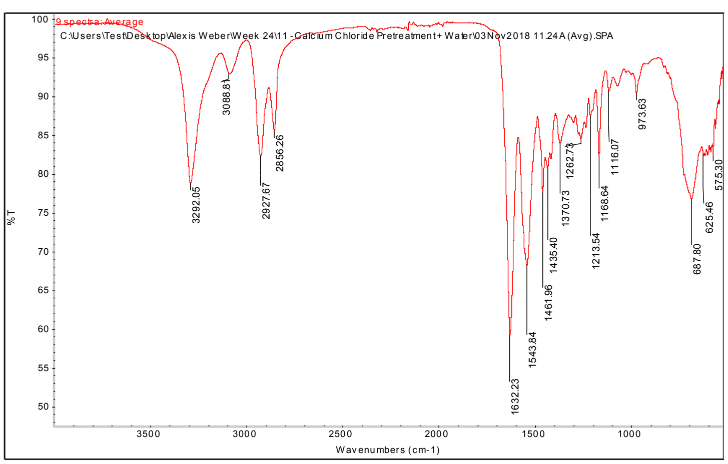

Figure 46: IR Average Spectrum of Nylon - Week 24 in Calcium Chloride Pretreatment and Water

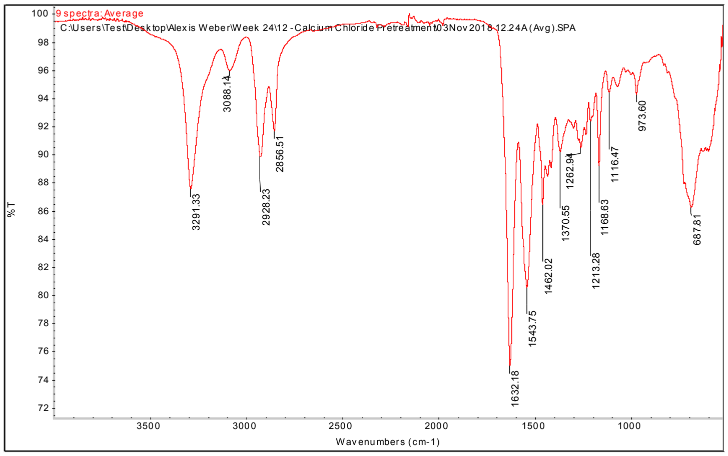

Figure 47: IR Average Spectrum of Nylon - Week 24 in Calcium Chloride Pretreatment

APPENDIX C: TABLES OF IR DATA OF NYLON

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
3291.77	3291.34	3291.08	3291.69	3291.3	3291.37	3291.9	3291.96	3291.65	3291.7	3292.81	3291.35	3291.71
3090.75	3088.99	3088.05	3088.71	3088.53	3088.67	3089.3	3089.1	3092.04	3089.95	3089.11	3089.69	3089.91
2929.31	2928.41	2929.41	2928.49	2928.95	2929.98	2929.64	2928.52	2928.85	2928.71	2927.99	2929.1	2927.66
2856.7	2856.42	2857.23	2856.58	2856.83	2856.92	2857.03	2856.6	2856.57	2856.52	2856.36	2856.67	2856.2
1632.78	1632.57	1632.57	1632.34	1632.32	1632.32	1632.54	1632.36	1632.24	1632.73	1632.8	1632.33	1632.39
1540.5	1541.12	1540.94	1543.6	1543.41	1543.5	1541.18	1543.5	1543.5	1541.05	1541.03	1543.97	1543.42
1462.03	1462.04	1462	1462	1461.95	1462.03	1462.1	1462.05	1461.92	1462.06	1462.2	1462.05	1462.02
1168.55	1168.84	1168.63	1168.15	1168.95	1168.66	1168.7	1168.67	1168.65	1168.68	1168.8	1168.7	1168.63

Table 3: IR Data of Nylon in Sand

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
3291.77	3291	3291.29	3291.34	3290.41	3291.52	3290.74	3291.51	3291.08	3291.5	3292.38	3292.08	3291.85
3090.75	3088	3088.6	3088.67	3088.93	3088.48	3091.26	3089.1	3091.03	3089.59	3090.11	3089.45	3089.23
2929.31	2928	2929.17	2928.28	2929.25	2928.7	2928.38	2929.05	2928.32	2928.42	2928.11	2928.37	2928.46
2856.7	2856	2857.03	2856.74	2857.14	2856.75	2856.63	2856.83	2856.48	2856.43	2856.23	2856.4	2856.46
1632.78	1632	1632.47	1632.22	1631.44	1632.32	1631.5	1632.39	1631.86	1632.41	1632.68	1632.66	1632.39
1540.5	1541	1541.04	1543.63	1543.94	1543.28	1543.76	1543.39	1543.43	1543.48	1541.1	1541.02	1543.5
1462.03	1462	1462.14	1462.06	1462.06	1462.07	1462.76	1462.09	1462.05	1462.06	1462.09	1462.09	1462.05
1168.55	1168	1168.66	1168.6	1168.61	1168.63	1168.62	1168.62	1168.63	1168.61	1168.62	1168.62	1168.65

Table 4: IR Data of Nylon in Soil

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
3291.77	3291	3291.46	3291.33	3291.47	3291.23	3291.23	3291.49	3291.68	3291.47	3291.78	3290.92	3292.14
3090.75	3088	3088.4	3088.25	3088.6	3088.84	3089.19	3089.08	3088.8	3089.02	3089.61	3088.93	3089.18
2929.31	2929	2928.92	2928.93	2928.73	2928.64	2922.6	2929.42	2927.71	2928.95	2928.6	2928.85	2927.86
2856.7	2857	2856.82	2856.85	2856.7	2856.88	2853.02	2856.89	2856.29	2856.74	2856.55	2857.16	2856.3
1632.78	1633	1632.31	1632.31	1632.3	1632.34	1632.61	1632.45	1632.48	1632.35	1632.49	1632.53	1632.63
1540.5	1539	1543.44	1541.38	1543.5	1543.1	1543.32	1543.45	1541.11	1543.71	1543.47	1541.01	1541.14
1462.03	1462	1462.05	1462.08	1462.03	1461.97	1462.3	1462.11	1462.1	1462.11	1462.1	1462.18	1462.05
1168.55	1168	1168.63	1168.65	1168.61	1168.57	1168.58	1168.65	1168.62	1168.61	1168.66	1168.66	1168.58

Table 5: IR Data of Nylon in Soil and Chicken Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
3291.77	3291.55	3291.39	3292.09	3292.18	3291.6	3291.46	3291.04	3291.48	3292.15	3292.15	3291.6	3292.14
3090.75	3089.08	3088.23	3088.1	3088.1	3088.25	3089.16	3089.29	3088.05	3089.04	3089.37	3089.33	3089.44
2929.31	2924.16	2928.7	2928.8	2929.12	2925.94	2928.6	2929.18	2929.55	2927.93	2928.65	2929.17	2927.41
2856.7	2854	2856.7	2856.62	2856.92	2855.77	2856.79	2856.9	2857.16	2856.27	2856.53	2856.77	2856.11
1632.78	1632	1632.48	1632.96	1632.97	1632.43	1632.51	1632.46	1632.58	1632.82	1632.7	1632.76	1632.75
1540.5	1540	1540.92	1540.18	1539.35	1538.26	1540.7	1543.15	1540.84	1540.6	1540.86	1541.02	1541
1462.03	1462	1462.04	1462.05	1462.05	1461.9	1461.94	1462.11	1462.09	1462.06	1462.1	1462.15	1462.09
1168.55	1168	1168.52	1168.35	1168.38	1168.01	1168.31	1168.57	1168.54	1168.55	1168.59	1168.6	1168.61

Table 6: IR Data of Nylon in Chicken Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
3291.77	3291	3291.24	3291.51	3291.38	3291.38	3291.58	3291.82	3291.85	3291.49	3291.99	3291.77	3291.74
3090.75	3088	3088.61	3088.73	3089.68	3088.64	3089.52	3089.67	3089.16	3089.2	3090.14	3088.87	3089.99
2929.31	2928	2928.45	2928.38	2924.7	2928.48	2928.46	2924.64	2927.23	2929.34	2926.84	2928.77	2927.99
2856.7	2856	2856.65	2856.63	2855.31	2856.67	2856.52	2855.29	2856.11	2856.9	2855.9	2856.64	2856.26
1632.78	1632	1632.42	1632.32	1632.38	1632.23	1632.34	1632.52	1632.65	1632.27	1632.51	1632.41	1632.32
1540.5	1543	1543.39	1543.39	1543.49	1543.5	1543.29	1543.35	1540.91	1543.77	1543.5	1543.33	1543.69
1462.03	1462	1462.08	1462.01	1461.9	1462.03	1462.07	1461.94	1462.07	1462.1	1462.06	1462.07	1461.97
1168.55	1168	1168.61	1168.57	1168.42	1168.56	1168.64	1168.47	1168.69	1168.58	1168.61	1168.6	1168.58

Table 7: IR Data of Nylon in Soil and Cow Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
3291.77	3291.72	3291.41	3291.02	3291.49	3291.26	3291.47	3291.2	3291.82	3291.99	3292.39	3291.69	3291.5
3090.75	3088.39	3088.87	3088.84	3089.3	3088.78	3088.36	3089.14	3089.52	3089.24	3088.76	3089.16	3088.87
2929.31	2929.13	2928.99	2928.25	2928.25	2927.82	2929.21	2930.1	2928.87	2928.01	2927.98	2929.26	2928.48
2856.7	2856.94	2856.8	2856.62	2856.4	2856.44	2856.9	2857.21	2856.61	2856.36	2856.38	2856.78	2856.56
1632.78	1632.84	1632.5	1632.26	1632.35	1632.26	1632.4	1632.65	1632.62	1632.86	1632.56	1632.63	1632.29
1540.5	1540.26	1541.23	1541.43	1543.4	1541.45	1541.49	1540.95	1540.97	1540.85	1541.16	1543.56	1543.67
1462.03	1462.12	1461.23	1462.05	1461.91	1461.92	1462.13	1462.13	1462.12	1462.04	1462.13	1462.21	1462.07
1168.55	1168.5	1168.52	1168.42	1168.35	1168.34	1168.66	1168.52	1168.63	1168.52	1168.71	1168.68	1168.59

Table 8: IR Data of Nylon in Cow Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
3291.77	3292.6	3291.86	3291.37	3292.13	3291.89	3291.73	3291.96	3292.1	3291.64	3292.07	3292.18	3291.76
3090.75	3088.59	3089.34	3089.2	3088.96	3089.15	3089.19	3088.66	3090.08	3089.77	3089.5	3089.83	3089.83
2929.31	2923.11	2922.72	2923.25	2922.96	2922.93	2922.85	2923.72	2922.94	2923.43	2923.78	2923.19	2923.54
2856.7	2854.2	2853.87	2854.29	2854.18	2854.01	2854.02	2854.77	2854.15	2854.54	2854.78	2854.23	2854.61
1632.78	1633.43	1632.45	1632.35	1632.44	1632.5	1632.36	1632.41	1632.43	1632.46	1632.49	1632.62	1632.63
1540.7	1538.84	1543.48	1543.5	1543.66	1541.32	1543.62	1543.69	1543.89	1543.44	1543.83	1543.75	1543.79
1462.03	1462.1	1461.9	1461.82	1461.93	1461.92	1461.91	1462.01	1461.89	1461.88	1461.88	1461.78	1461.91
1168.55	1168.59	1168.61	1168.56	1168.62	1168.6	1168.64	1168.64	1168.61	1168.62	1168.61	1168.46	1168.57

Table 9: IR Data of Nylon in Oil

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
3291.77	3291.88	3291.68	3291.75	3291.67	3291.93	3291.88	3291.65	3291.6	3292.05	3291.02	3292.23	3291.8
3090.75	3089.4	3089.56	3089.18	3088.9	3089.3	3089.49	3089.19	3090.13	3089.68	3088.93	3090.06	3088.96
2929.31	2935.71	2932.65	2939.59	2934.84	2939.57	2938.9	2927.84	2936.26	2938.5	2935.36	2936.34	2927.16
2856.7	2860.26	2857.28	2862.2	2859.6	2862.62	2862.26	2856.45	2860.3	2861.85	2859.63	2859.84	2856.31
1632.78	1632.86	1632.36	1632.25	1632.32	1632.37	1632.43	1632.47	1632.47	1632.59	1632.4	1632.56	1632.14
1540.5	1540.78	1543.45	1543.5	1543.72	1543.41	1543.5	1543.47	1543.33	1541.42	1543.71	1543.73	1543.98
1462.03	1462	1462	1462.03	1462.04	1463.41	1462.09	1462.11	1462.14	1462.13	1462.08	1462.03	1462
1168.55	1168.51	1168.48	1168.69	1168.61	1168.65	1168.63	1168.14	1168.62	1168.56	1168.67	1168.98	1168.65

Table 10: IR Data of Nylon in Salt Pretreatment and Water

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
3291.77	3291.62	3291.72	3291.32	3291.08	3291.6	3291.14	3291.39	3291.09	3291.86	3291.65	3291.51	3292.05
3090.75	3088.1	3088.78	3088.64	3089.29	3088.61	3089.62	3089.22	3089.64	3089.54	3088.95	3089.6	3088.81
2929.31	2929.84	2928.46	2931.31	2931.01	2930.99	2929.78	2929.28	2929	2928.7	2929.17	2929.81	2927.67
2856.7	2857.24	2856.51	2857.5	2857.49	2857.44	2856.99	2856.93	2856.81	2856.61	2856.81	2856.92	2856.26
1632.78	1632.52	1632.42	1632.15	1631.62	1632.11	1631.57	1632.2	1631.86	1632.28	1632.28	1632.23	1632.23
1540.5	1540.52	1543.37	1543.83	1544.03	1544.68	1544.15	1543.83	1544.07	1543.92	1543.61	1543.79	1543.84
1462.03	1462.15	1462.07	1462.02	1462.04	1462.09	1461.99	1462.13	1462.06	1462.1	1462.02	1462.11	1461.96
1168.55	1168.66	1168.68	1168.67	1168.65	1168.69	1168.64	1168.08	1168.68	1168.72	1168.67	1168.75	1168.64

Table 11: IR Data of Nylon in Calcium Chloride Pretreatment and Water

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
3291.77	3291.43	3291.51	3291.76	3291.37	3291.51	3291.56	3291.79	3291.54	3291.93	3291.97	3291.89	3291.33
3090.75	3088.62	3088.8	3088.23	3090.03	3089.46	3090.29	3089.3	3089.73	3088.95	3089.35	3088.83	3088.14
2929.31	2926.94	2928.61	2929.13	2927.72	2930.01	2928.24	2928.3	2928.48	2929.33	2928.99	2928.96	2928.23
2856.7	2856.28	2856.51	2856.85	2856.38	2856.87	2856.43	2856.5	2856.7	2856.78	2856.74	2856.73	2856.51
1632.78	1632.78	1632.15	1632.3	1631.88	1632.35	1631.94	1632.3	1632.04	1632.55	1632.27	1632.38	1632.18
1540.7	1540.24	1544.05	1543.5	1543.51	1541.3	1543.7	1543.77	1543.7	1541.37	1543.9	1543.71	1543.75
1462.03	1462.06	1461.99	1462.08	1462.02	1462.06	1461.94	1462.09	1462.1	1462.17	1462.1	1462.09	1462.02
1168.55	1168.57	1168.65	1168.68	1168.63	1168.66	1168.62	1168.66	1168.67	1168.77	1168.66	1168.67	1168.63

Table 12: IR Data of Nylon in Calcium Chloride Pretreatment

APPENDIX D: IR SPECTRA OF ACRYLIC

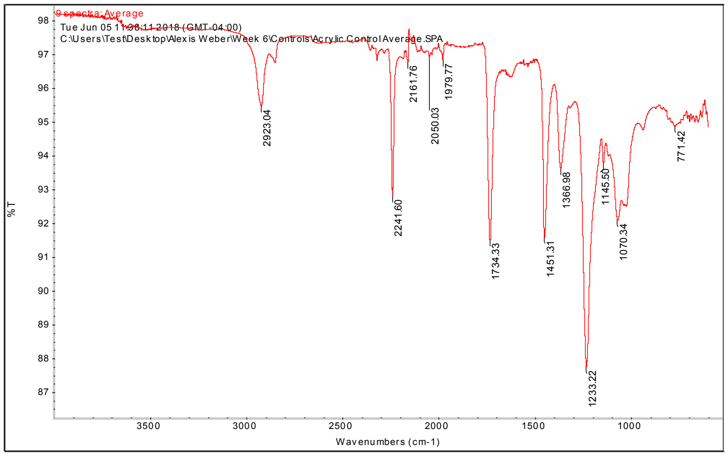

Figure 48: IR Average Spectrum of Control Acrylic

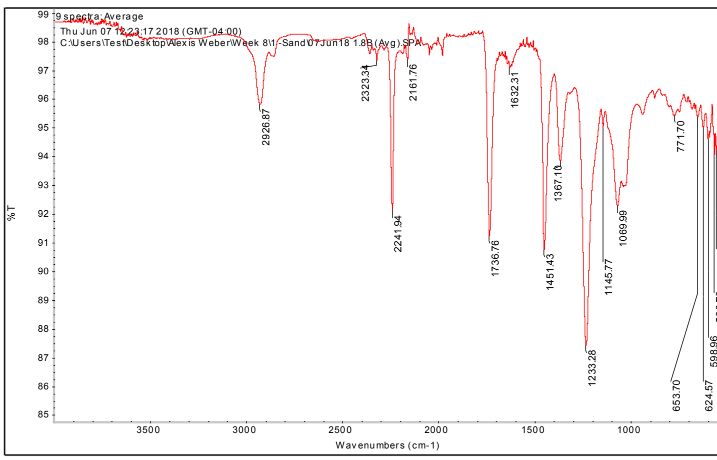

Figure 49: IR Average Spectrum of Acrylic - Week 8 in Sand

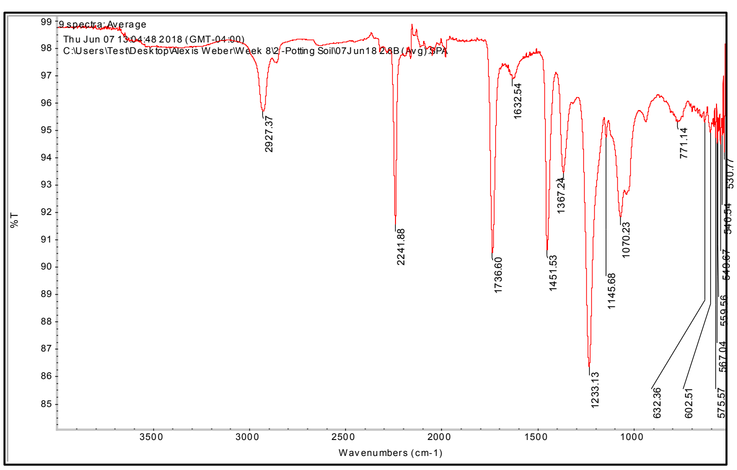

Figure 50: IR Average Spectrum of Acrylic - Week 8 in Soil

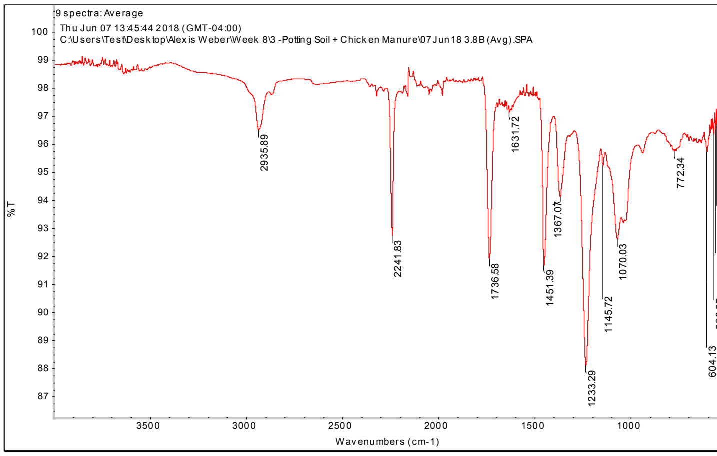

Figure 51: IR Average Spectrum of Acrylic - Week 8 in Soil and Chicken Manure

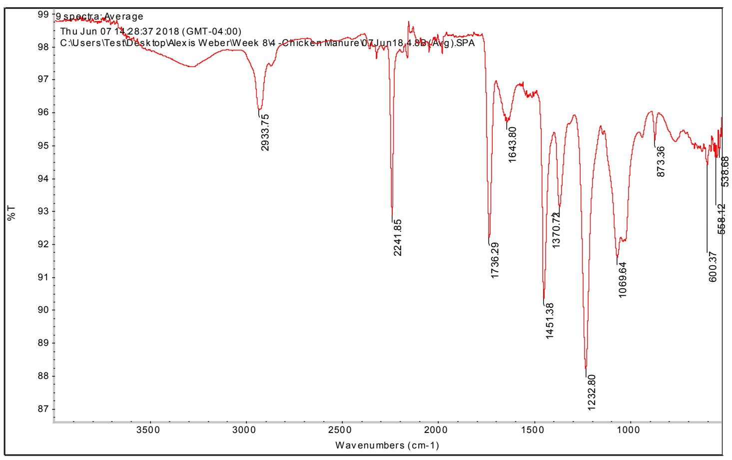

Figure 52: IR Average Spectrum of Acrylic - Week 8 in Chicken Manure

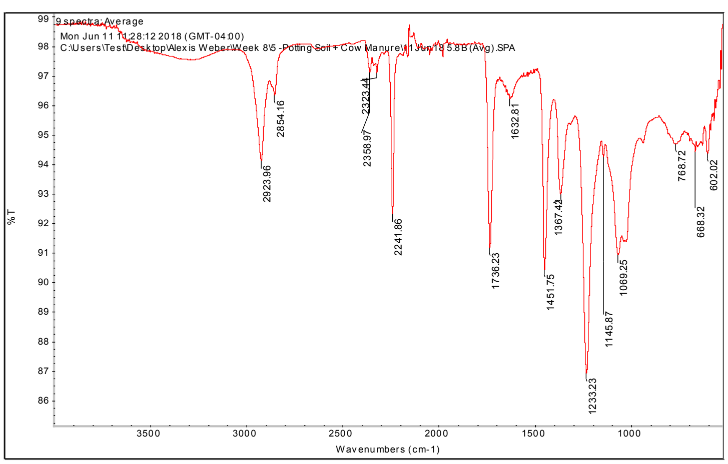

Figure 53: IR Average Spectrum of Acrylic - Week 8 in Soil and Cow Manure

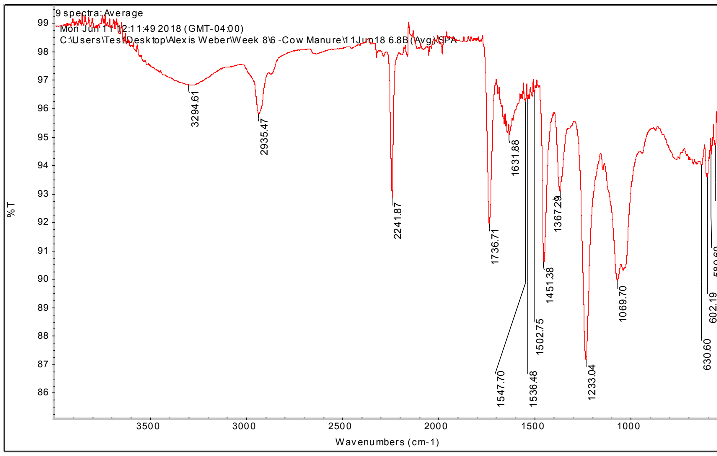

Figure 54: IR Average Spectrum of Acrylic - Week 8 in Cow Manure

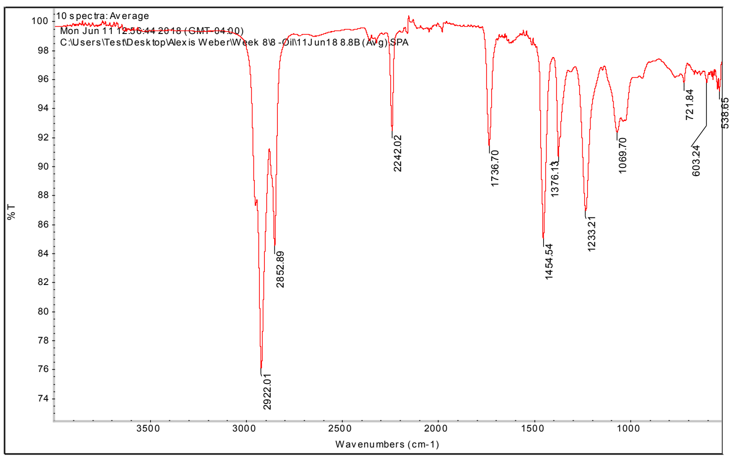

Figure 55: IR Average Spectrum of Acrylic - Week 8 in Oil

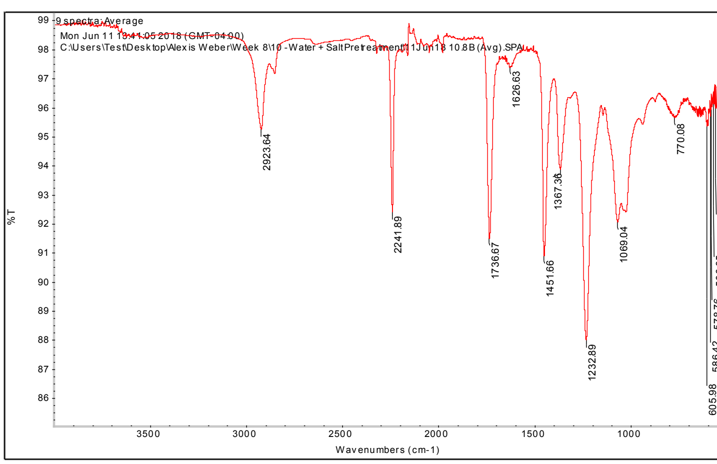

Figure 56: IR Average Spectrum of Acrylic - Week 8 in Salt Pretreatment and Water

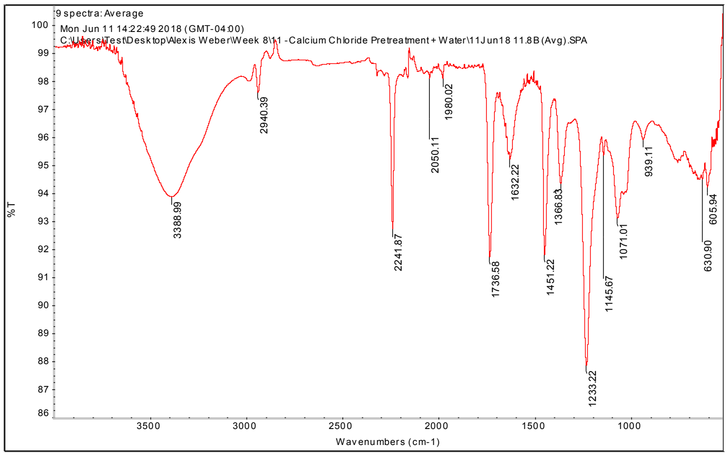

Figure 57: IR Average Spectrum of Acrylic - Week 8 in Calcium Chloride Pretreatment and Water

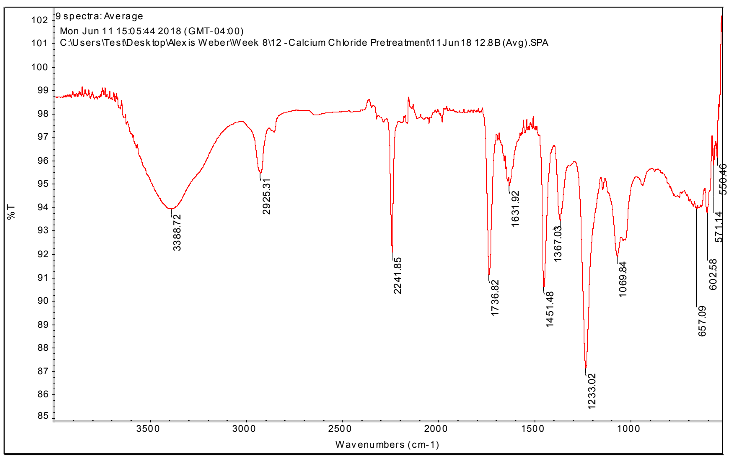

Figure 58: IR Average Spectrum of Acrylic - Week 8 in Calcium Chloride Pretreatment

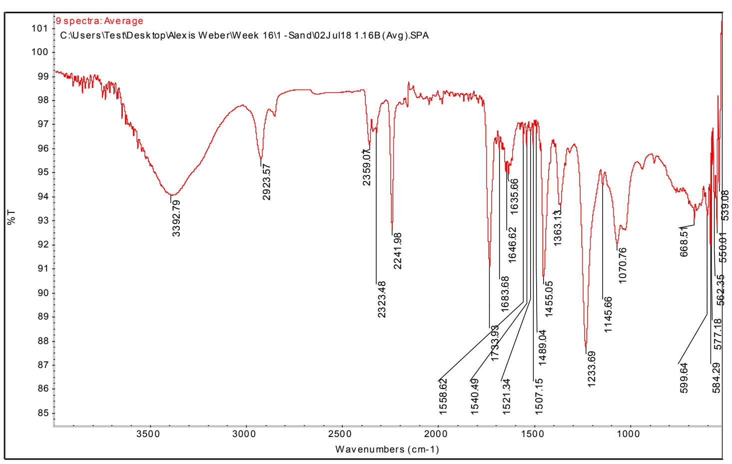

Figure 59: IR Average Spectrum of Acrylic - Week 16 in Sand

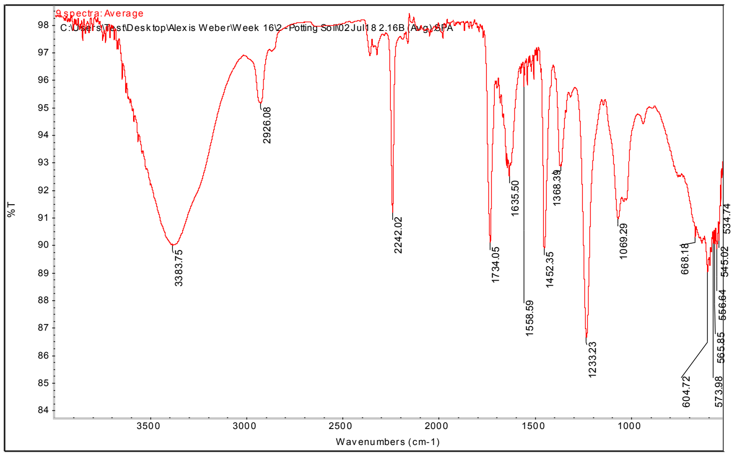

Figure 60: IR Average Spectrum of Acrylic - Week 16 in Soil

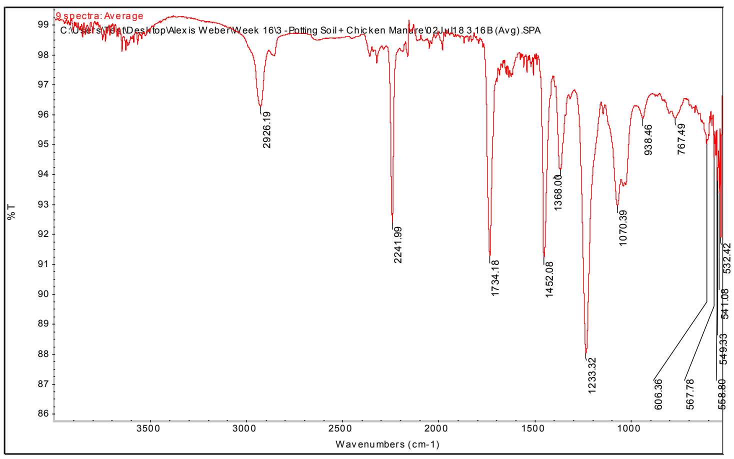

Figure 61: IR Average Spectrum of Acrylic - Week 16 in Soil and Chicken Manure

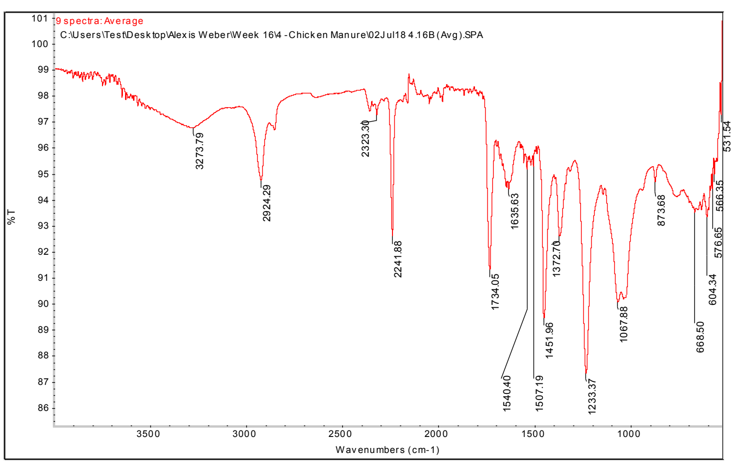

Figure 62: IR Average Spectrum of Acrylic - Week 16 in Chicken Manure

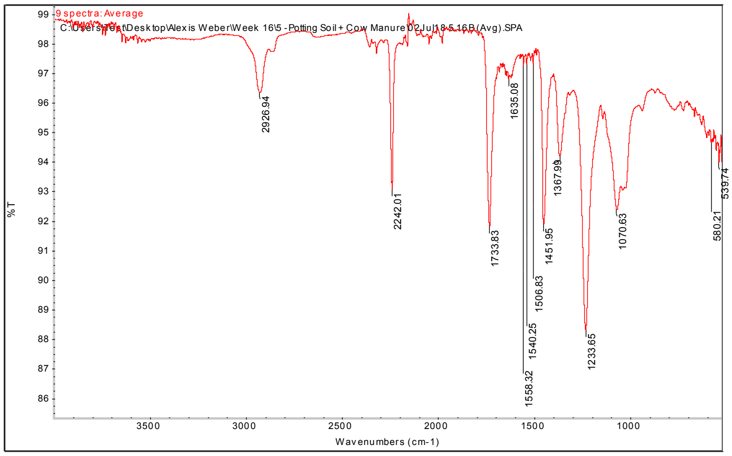

Figure 63: IR Average Spectrum of Acrylic - Week 16 in Soil and Cow Manure

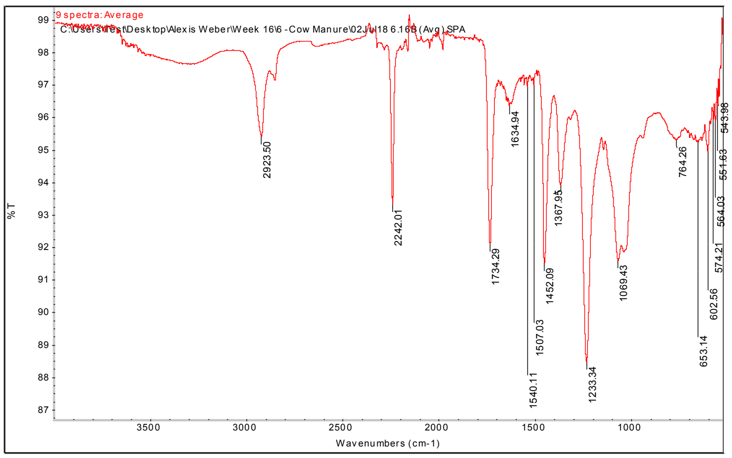

Figure 64: IR Average Spectrum of Acrylic - Week 16 in Cow Manure

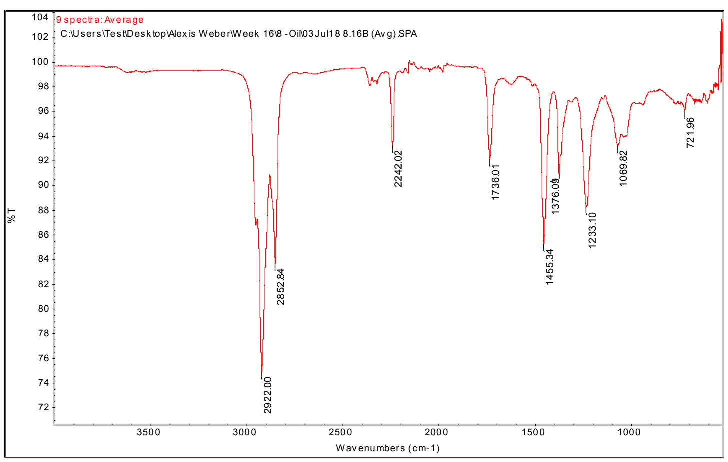

Figure 65: IR Average Spectrum of Acrylic - Week 16 in Oil

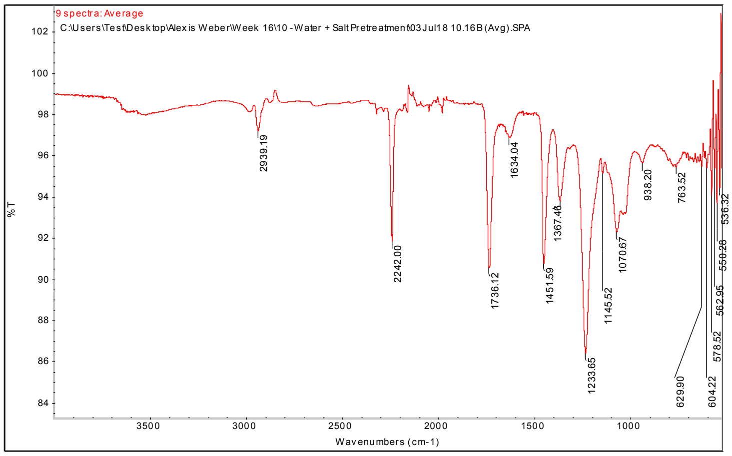

Figure 66: IR Average Spectrum of Acrylic - Week 16 in Salt Pretreatment and Water

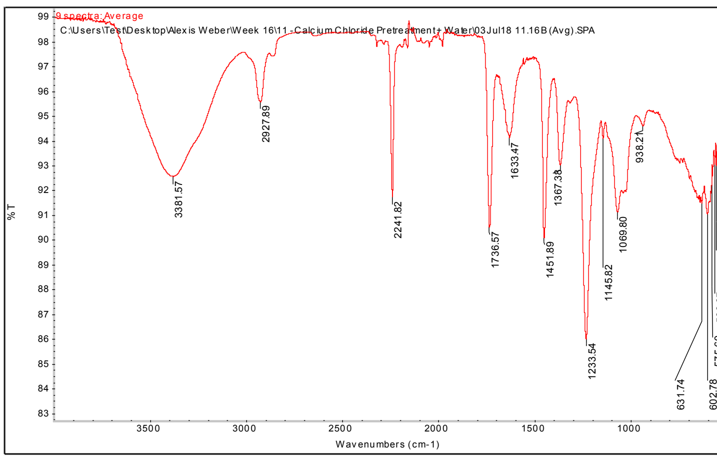

Figure 67: IR Average Spectrum of Acrylic - Week 16 in Calcium Chloride Pretreatment and Water

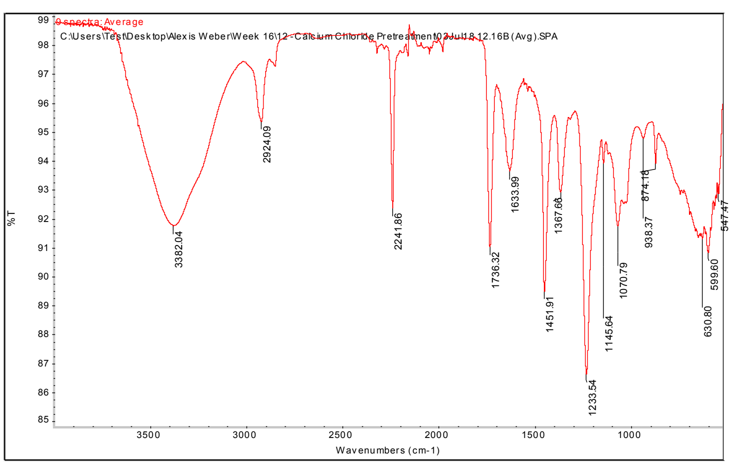

Figure 68: IR Average Spectrum of Acrylic - Week 16 in Calcium Chloride Pretreatment

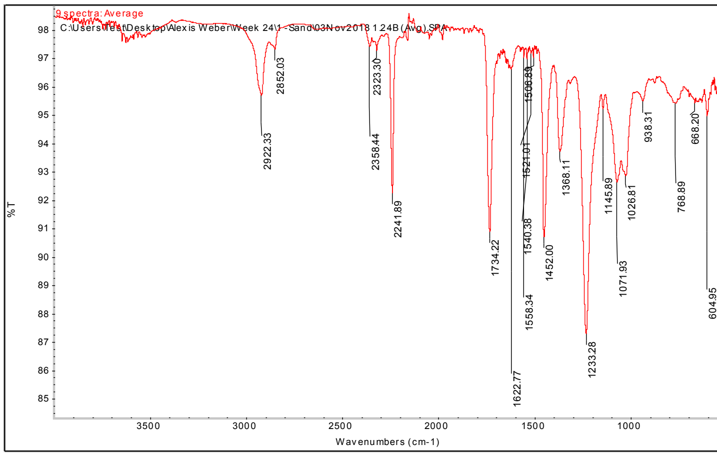

Figure 69: IR Average Spectrum of Acrylic - Week 24 in Sand

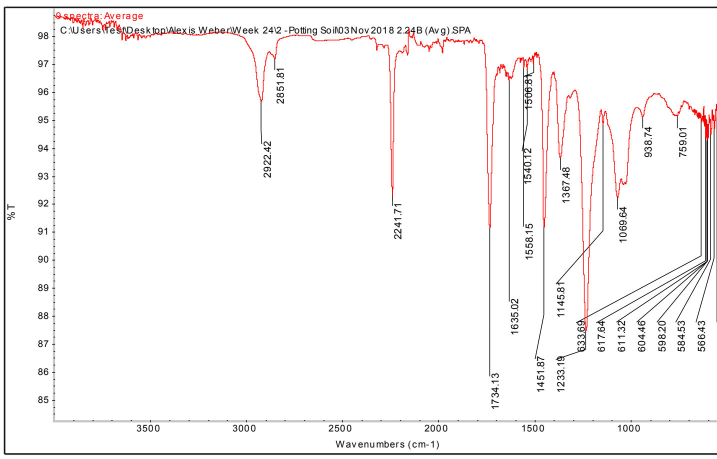

Figure 70: IR Average Spectrum of Acrylic - Week 24 in Soil

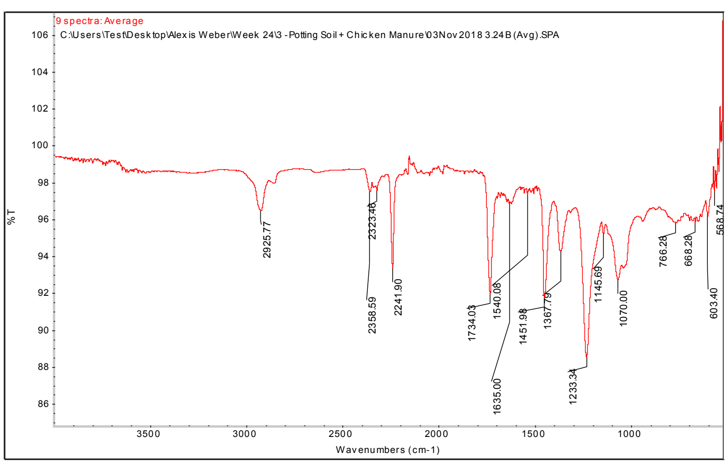

Figure 71: IR Average Spectrum of Acrylic - Week 24 in Soil and Chicken Manure

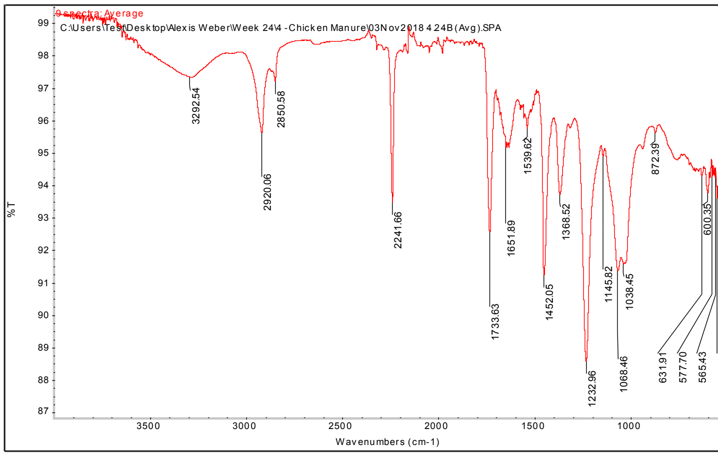

Figure 72: IR Average Spectrum of Acrylic - Week 24 in Chicken Manure

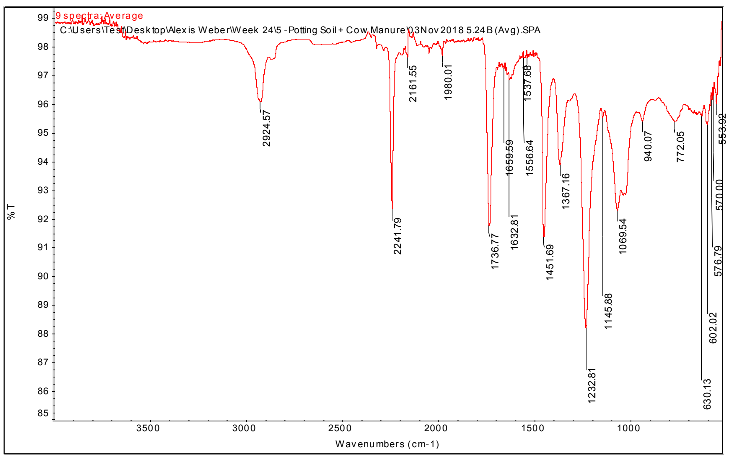

Figure 73: IR Average Spectrum of Acrylic - Week 24 in Soil and Cow Manure

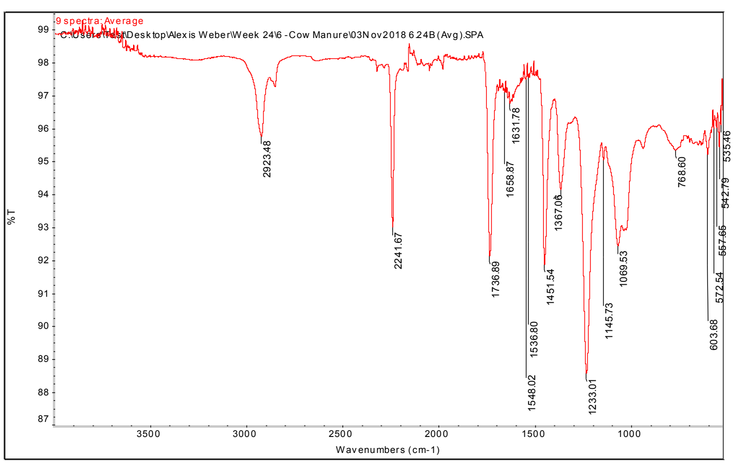

Figure 74: IR Average Spectrum of Acrylic - Week 24 in Cow Manure

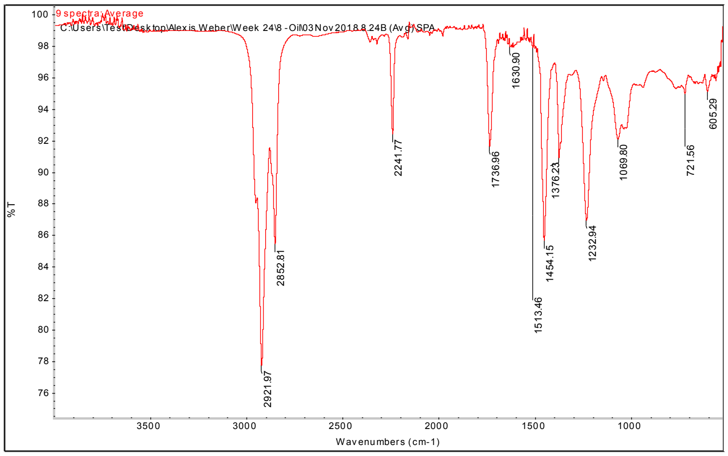

Figure 75: IR Average Spectrum of Acrylic - Week 24 in Oil

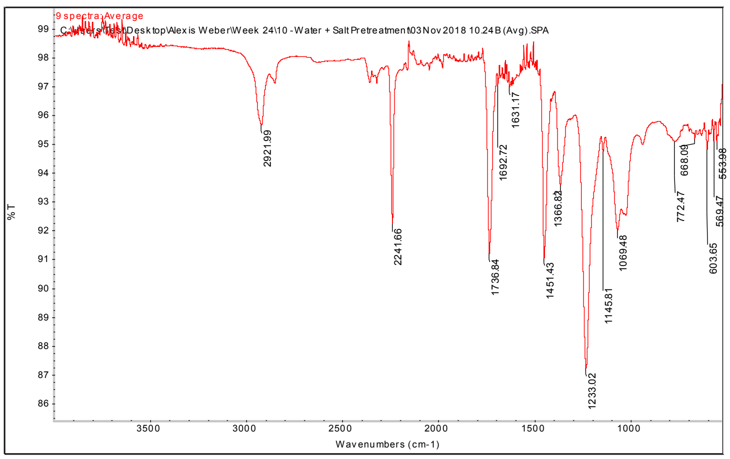

Figure 76: IR Average Spectrum of Acrylic - Week 24 in Salt Pretreatment and Water

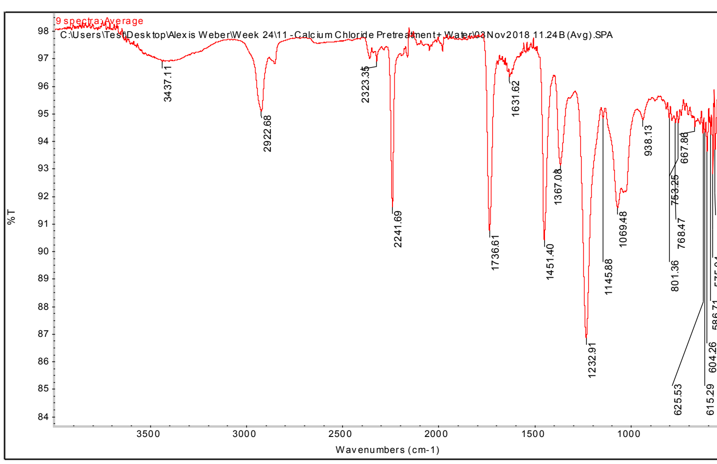

Figure 77: IR Average Spectrum of Acrylic - Week 24 in Calcium Chloride Pretreatment and Water

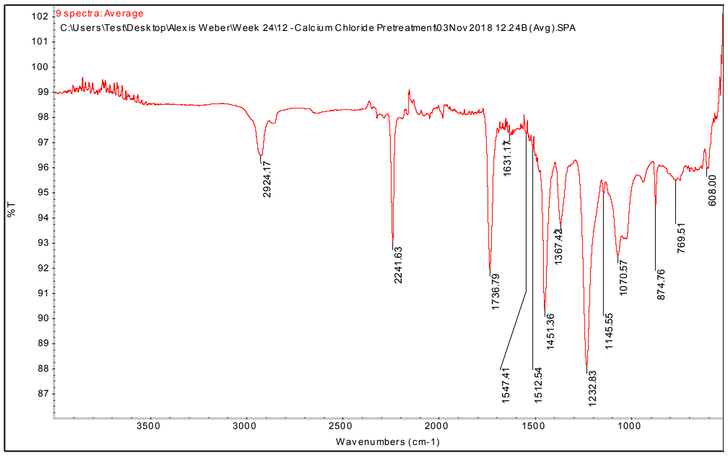

Figure 78: IR Average Spectrum of Acrylic - Week 24 in Calcium Chloride Pretreatment

APPENDIX E: TABLES OF IR DATA OF ACRYLIC

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2923.04	2924.8	2924.39	2924.11	2926.87	2927.19	2936.74	2922.41	2923.57	2923.23	2923.75	2924.43	2922.33
2241.6	2242	2241.86	2241.83	2241.94	2241.82	2241.84	2241.91	2241.98	2241.82	2241.92	2241.91	2241.89
1734.33	1736.39	1734.44	1736.75	1736.76	1736.17	1734.59	1734.12	1733.93	1733.84	1734.17	1734.24	1734.22
1451.31	1451	1451.71	1451.3	1451.43	1451.64	1451.68	1451.96	1455.05	1455.92	1452.03	1451.83	1452
1366.98	1367	1367.64	1366.86	1367.1	1367.73	1367.83	1367.51	1363.13	1362.82	1368.13	1367.66	1368.11
1233.22	1233	1233.13	1233.02	1233.28	1233.32	1233.04	1233.99	1233.69	1233.2	1233.69	1233.55	1233.28
1070.34	1070	1070.24	1070.1	1069.99	1070.2	1070.02	1070.61	1070.76	1069.77	1070.22	1069.98	1071.93

Table 13: IR Data of Acrylic in Sand

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2923.04	2924	2925.53	2927.48	2927.37	2925.73	2923	2927.43	2926.08	2925.25	2925.57	2926.79	2922.42
2241.6	2241	2242.05	2241.95	2241.88	2241.81	2241.88	2241.83	2242.02	2241.87	2241.88	2241.93	2241.71
1734.33	1736	1736.23	1736.34	1736.6	1736.65	1734.41	1734.08	1734.05	1735.13	1734.38	1734.27	1734.13
1451.31	1451	1451.66	1451.47	1451.53	1451.59	1451.83	1451.98	1452.35	1452.08	1451.92	1451.98	1451.87
1366.98	1367	1367.17	1367.24	1367.24	1367.26	1367.57	1367.73	1368.39	1367.64	1367.68	1367.76	1367.48
1233.22	1233	1233.22	1233.34	1233.13	1233.16	1233.38	1233.47	1233.23	1233.55	1233.6	1233.73	1233.19
1070.34	1070	1070.24	1070.15	1070.23	1026.72	1069.95	1070.05	1069.29	1069.75	1070.37	1070.31	1069.64

Table 14: IR Data of Acrylic in Soil

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2923.04	2925	2925.93	2924.78	2935.89	2924.39	2921.42	2934.89	2926.19	2930.29	2925.37	2931.41	2925.77
2241.6	2241	2241.83	2241.98	2241.83	2241.86	2241.88	2241.97	2241.99	2241.96	2241.87	2242.04	2241.9
1734.33	1736	1736.83	1734.52	1736.58	1736.73	1736.51	1734.01	1734.18	1734.44	1734.34	1734.19	1734.03
1451.31	1451	1451.7	1451.72	1451.31	1451.46	1452.31	1451.83	1452.08	1451.8	1451.8	1451.86	1451.98
1366.98	1367	1367.7	1367.84	1367.07	1367.39	1367.66	1367.87	1368	1367.67	1367.76	1367.89	1367.79
1233.22	1233	1233.04	1233.27	1233.29	1233.36	1233.43	1233.27	1233.32	1233.63	1233.4	1233.43	1233.34
1070.34	1069	1070.05	1070.74	1070.03	1069.48	1068.22	1070.27	1070.39	1069.67	1070.1	1069.26	1070

Table 15: IR Data of Acrylic in Soil and Chicken Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2923.04	2924	2923.01	2924.76	2933.75	2925.77	2934.82	2925.92	2924.29	2925.1	2923.92	2923.42	2920.06
2241.6	2241	2241.82	2241.78	2241.85	2241.81	2241.89	2241.86	2241.88	2241.96	2241.84	2241.87	2241.66
1734.33	1736	1736.48	1734.04	1736.29	1736.59	1736.15	1733.59	1734.05	1734.21	1736.53	1736.58	1733.63
1451.31	1451	1451.69	1451.7	1451.38	1451.27	1451.05	1451.38	1451.69	1451.69	1451.88	1451.86	1452.05
1366.98	1367	1368.47	1372.25	1370.2	1371.01	1370.6	1373.64	1372.7	1367.92	1368.11	1367.94	1368.52
1233.22	1233	1233.49	1232.74	1232.8	1232.82	1233.35	1233.65	1233.37	1233.18	1233.05	1233.25	1232.96
1070.34	1069	1069	1069.35	1069.64	1068.6	1027.99	1026.95	1067.88	1068.95	1067.78	1069.2	1068.46

Table 16: IR Data of Acrylic in Chicken Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2923.04	2925	2924.05	2924	2923.96	2926.55	2926.09	2923.77	2926.94	2928.79	2925.57	2924.82	2924.57
2241.6	2241	2241.81	2241.85	2241.86	2241.83	2241.93	2241.89	2241.01	2242	2241.77	2241.91	2241.71
1734.33	1736	1735.59	1736.84	1736.23	1736.1	1734.41	1734	1733.83	1735.35	1736.53	1736.57	1736.77
1451.31	1451	1451.68	1451.65	1451.75	1451.53	1451.72	1452.23	1451.95	1451.35	1451.71	1451.77	1452.69
1366.98	1367	1367.17	1367.21	1367.42	1367.42	1367.52	1367.78	1367.99	1367.72	1367.34	1367.43	1367.16
1233.22	1233	1232.97	1233.16	1233.23	1233.14	1233.34	1233.35	1233.65	1233.56	1233.31	1233.46	1232.81
1070.34	1069	1069.85	1069.9	1069.25	1069.89	1069.91	1069.51	1070.63	1069.47	1069.44	1069.51	1069.54

Table 17: IR Data of Acrylic in Soil and Cow Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2923.04	2924.22	2924.92	2926.88	2935.47	2924.79	2924.94	2923.11	2923.5	2925.74	2926.25	2923.33	2923.48
2241.6	2241.91	2241.93	2241.81	2241.87	2241.74	2241.77	2241.69	2242.01	2241.9	2241.83	2241.92	2241.67
1734.33	1736.15	1734.3	1736.52	1736.71	1734	1736.26	1733.49	1734.29	1733.95	1734.27	1734.54	1736.89
1451.31	1451.62	1451.68	1451.54	1451.38	1451.67	1451.66	1451.97	1452.09	1452.07	1451.87	1452.26	1451.54
1366.98	1367.56	1368.25	1367.43	1367.29	1367.94	1368	1372.63	1367.95	1367.97	1367.82	1367.81	1367.06
1233.22	1233.07	1233.09	1233	1233.04	1232.81	1233.06	1232.63	1233.34	1233.47	1232.94	1233.48	1233.01
1070.34	1070.01	1069.56	1069.5	1069.7	1068.75	1068.65	1038.3	1069.43	1069.23	1068.94	1069.59	1069.53

Table 18: IR Data of Acrylic in Cow Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2923.04	2921.98	2921.98	2922.05	2922.01	2921.96	2921.85	2921.94	2922	2921.9	2922.2	2921.96	2921.97
2241.6	2241.95	2241.95	2241.94	2242.02	2241.99	2241.97	2241.91	2242.02	2242.02	2241.91	2241.97	2241.77
1734.33	1736.47	1736.11	1735.43	1736.7	1734.41	1735.77	1736	1736.01	1734.41	1736.33	1734.91	1736.96
1451.31	1455.03	1455.09	1455.13	1454.54	1455.8	1455.34	1455.16	1455.34	1455.68	1455.03	1455.51	1454.15
1366.98	1376.19	1376.12	1375.98	1376.13	1375.83	1376.13	1376.04	1376.09	1375.85	1375.82	1376.07	1376.23
1233.22	1233.41	1233.44	1233.34	1233.21	1233.27	1233.34	1233.39	1233.1	1233.62	1233.38	1233.17	1232.94
1070.34	1070.08	1070.99	1070.42	1069.7	1070.2	1070.24	1069.11	1069.82	1069.87	1070.81	1069.56	1069.8

Table 19: IR Data of Acrylic in Oil

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2923.04	2938.37	2926.83	2923.64	2923.64	2939.73	2939.75	2922.32	2939.19	2940.26			2921.99
2241.6	2241.96	2241.87	2241.82	2241.89	2241.87	2241.88	2241.89	2242	2241.93		2241.9	2241.66
1734.33	1736.38	1735.97	1735	1736.67	1736.23	1736.45	1733.99	1736.12	1734.93		1736.48	1736.84
1451.31	1451.48	1451.66	1451.79	1451.66	1451.51	1451.29	1452.12	1451.59	1451.63		1451.41	1451.43
1366.98	1367.33	1367.68	1367.45	1367.36	1367.56	1367.07	1367.88	1367.46	1367.79		1367.63	1366.82
1233.22	1233.41	1233.2	1233.25	1232.89	1232.86	1233.44	1233.45	1233.65	1233.5		1233.31	1233.02
1070.34	1070.39	1070.05	1070.1	1069.04	1069.82	1070.31	1069.57	1070.67	1069.88		1069.97	1069.48

Table 20: IR Data of Acrylic in Salt Pretreatment and Water

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2923.04	2937	2933.87	2939.43	3388.99	2939.64	3394.2	2929.02	2927.89	2927.16	2924.72	2937.13	2922.68
2241.6	2241.91	2241.9	2241.91	2241.87	2241.93	2241.85	2241.98	2241.82	2241.95	2241.96	2241.83	2241.69
1734.33	1736.32	1734.54	1735.2	1736.58	1734.61	1736.47	1736.45	1736.57	1735.37	1734.15	1734.28	1736.61
1451.31	1451.54	1452.02	1451.62	1451.22	1451.57	1451.52	1451.69	1451.89	1451.89	1451.89	1452.02	1451.4
1366.98	1367.46	1367.48	1367.6	1366.83	1367.91	1367.17	1367.56	1367.38	1367.41	1367.77	1367.57	1367.08
1233.22	1233.27	1233.19	1232.95	1233.22	1233.53	1233.33	1233.16	1233.54	1233.43	1233.68	1233.45	1232.91
1070.34	1070.81	1073.33	1070.34	1071.01	1071.62	1069.74	1069.44	1069.8	1070.63	1070.75	1070.35	1069.48

Table 21: IR Data of Acrylic in Calcium Chloride Pretreatment and Water

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2923.04	2923.92	2925.15	2924.75	2925.31	2924.1	2926.7	2925.82	2924.09	2925.03	2929.33	2927.75	2924.17
2241.6	2241.93	2241.82	2241.87	2241.85	2241.93	2241.91	2241.89	2241.86	2241.92	2241.95	2241.85	2241.63
1734.33	1736.19	1736.58	1736.79	1736.82	1734.44	1736.44	1736.79	1736.32	1735.68	1735.68	1736.75	1736.79
1451.31	1451.75	1451.55	1451.56	1451.48	1451.8	1451.73	1451.52	1451.91	1451.91	1452	1451.95	1451.36
1366.98	1367.26	1362.04	1367.31	1367.92	1367.61	1367.45	1367.12	1367.66	1367.8	1367.93	1368.41	1367.42
1233.22	1233.26	1233.24	1233.23	1233.02	1233.41	1233.36	1232.95	1233.54	1233.49	1233.61	1233.31	1232.83
1070.34	1070.12	1070.2	1069.94	1069.84	1070.27	1070.38	1070.11	1070.79	1070.35	1070.34	1071.34	1070.57

Table 22: IR Data of Acrylic in Calcium Chloride Pretreatment

APPENDIX F: IR SPECTRA OF RAYON

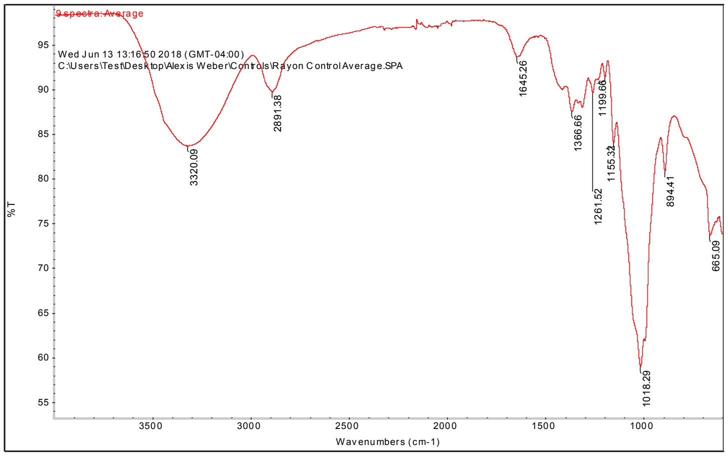

Figure 79: IR Average Spectrum of Control Rayon

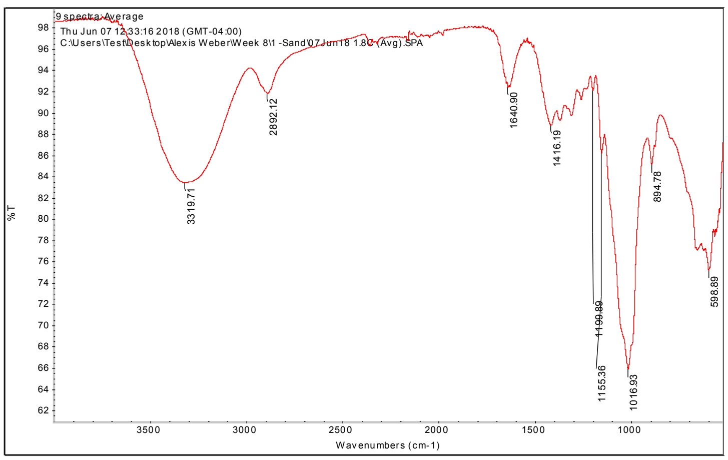

Figure 80: IR Average Spectrum of Rayon - Week 8 in Sand

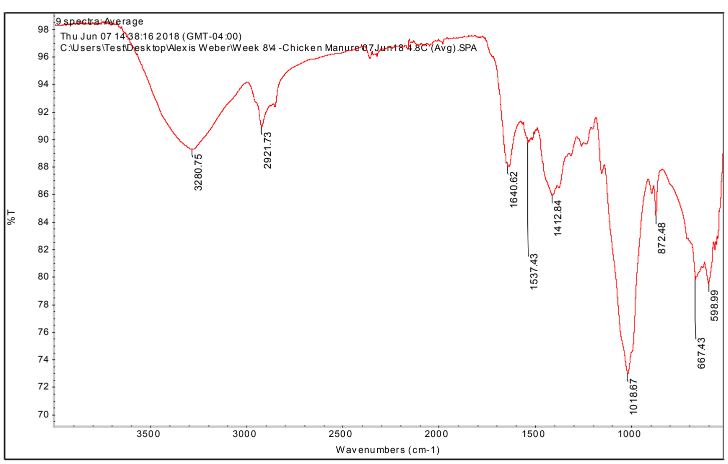

Figure 81: IR Average Spectrum of Rayon - Week 8 in Chicken Manure

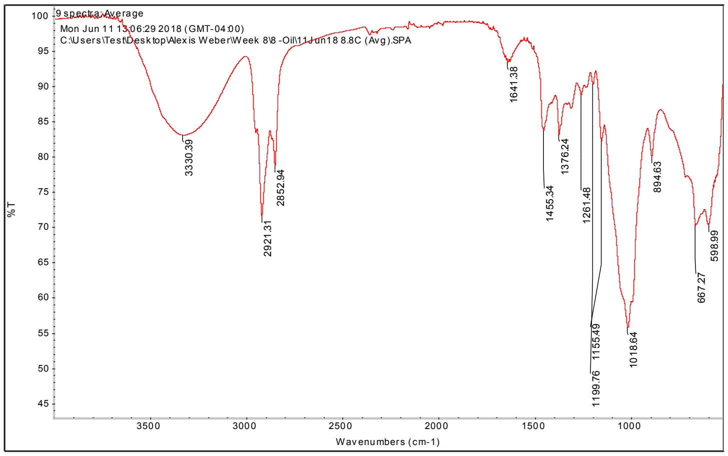

Figure 82: IR Average Spectrum of Rayon - Week 8 in Oil

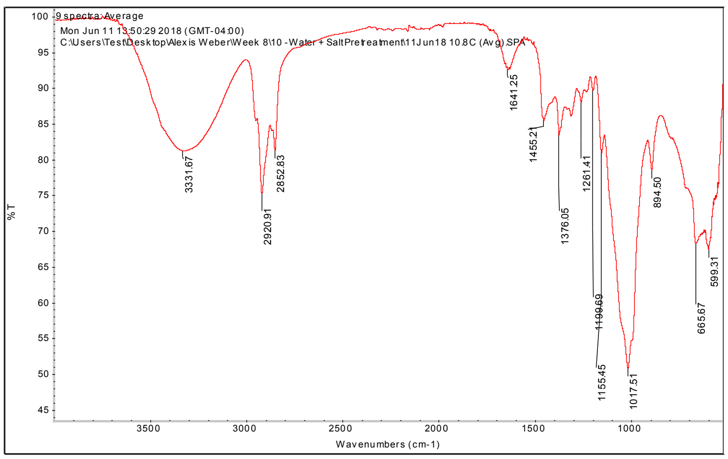

Figure 83: IR Average Spectrum of Rayon - Week 8 in Salt Pretreatment and Water

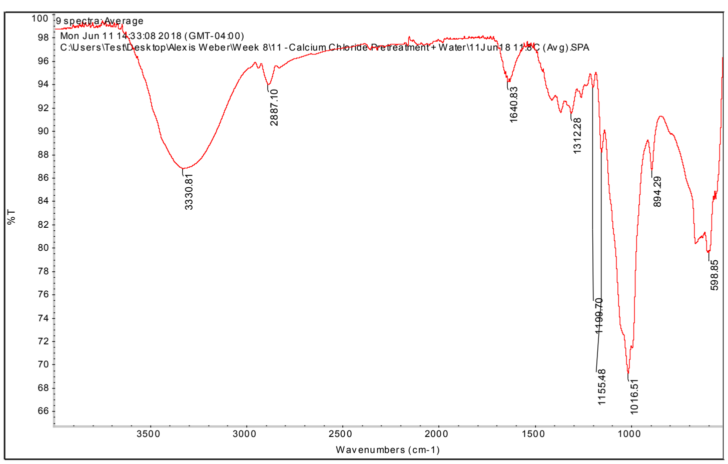

Figure 84: IR Average Spectrum of Rayon - Week 8 in Calcium Chloride Pretreatment and Water

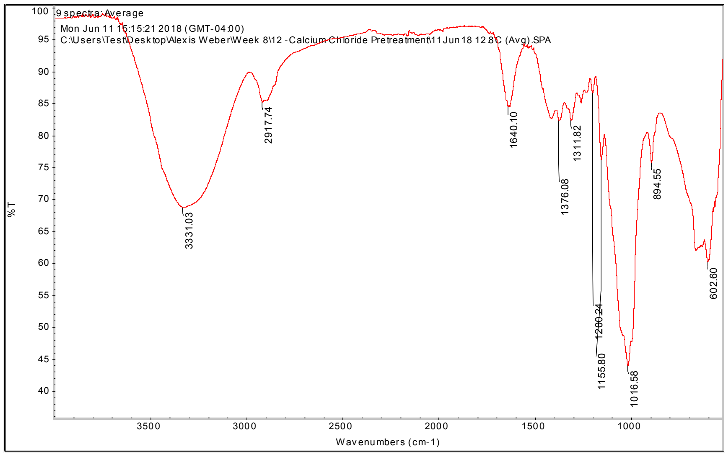

Figure 85: IR Average Spectrum of Rayon - Week 8 in Calcium Chloride Pretreatment

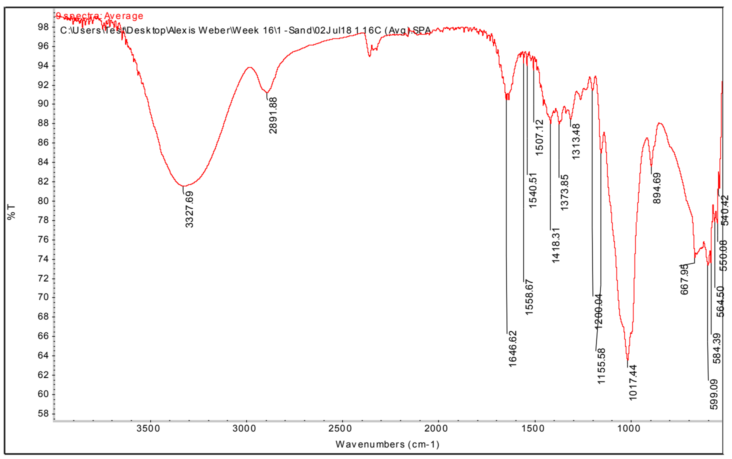

Figure 86: IR Average Spectrum of Rayon - Week 16 in Sand

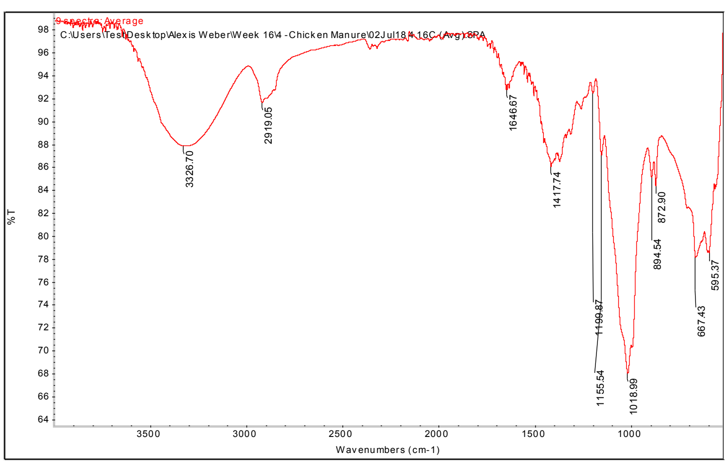

Figure 87: IR Average Spectrum of Rayon - Week 16 in Chicken Manure

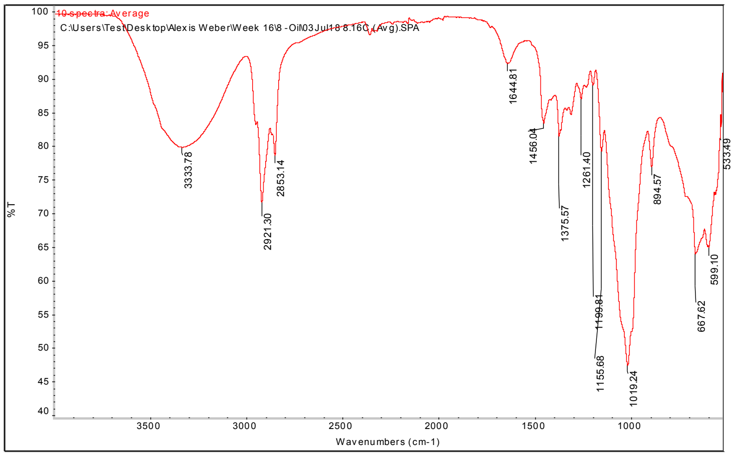

Figure 88: IR Average Spectrum of Rayon - Week 16 in Oil

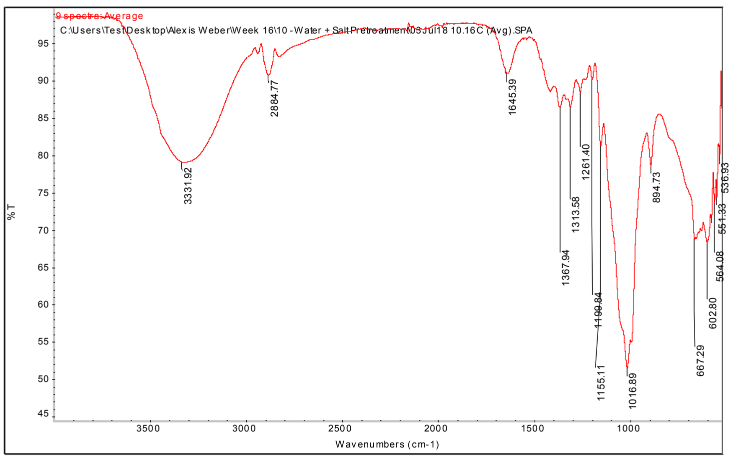

Figure 89: IR Average Spectrum of Rayon - Week 16 in Salt Pretreatment and Water

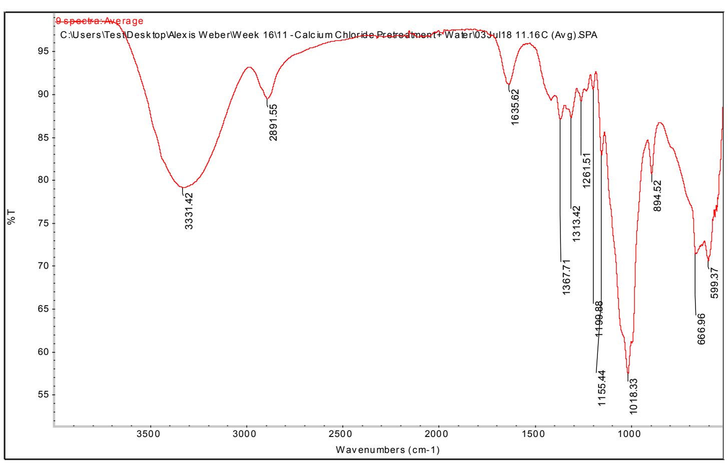

Figure 90: IR Average Spectrum of Rayon - Week 16 in Calcium Chloride Pretreatment and Water

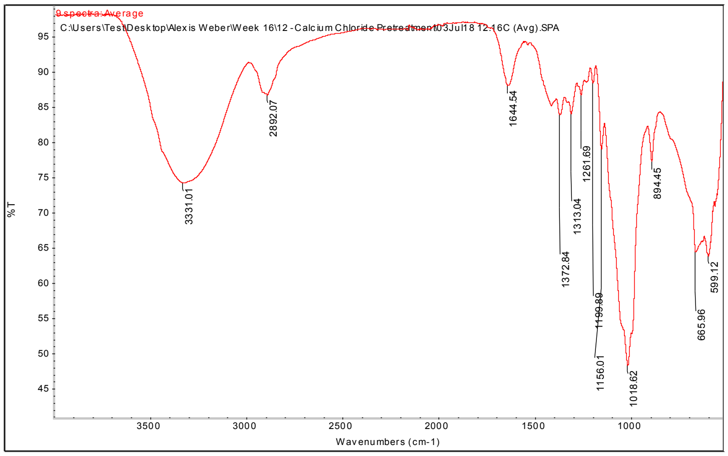

Figure 91: IR Average Spectrum of Rayon - Week 16 in Calcium Chloride Pretreatment

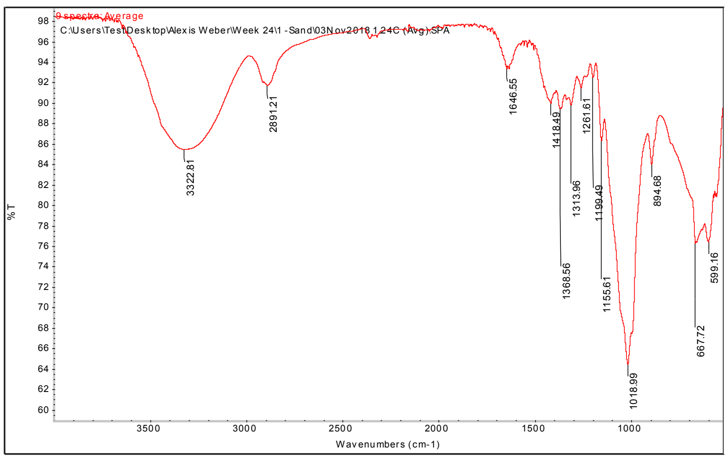

Figure 92: IR Average Spectrum of Rayon - Week 24 in Sand

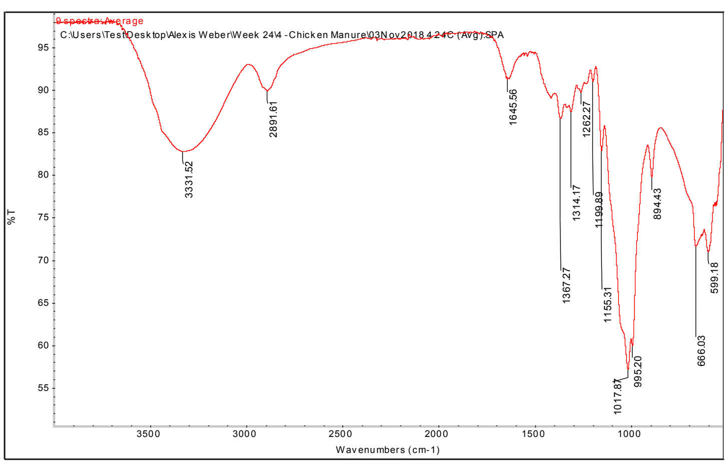

Figure 93: IR Average Spectrum of Rayon - Week 24 in Chicken Manure

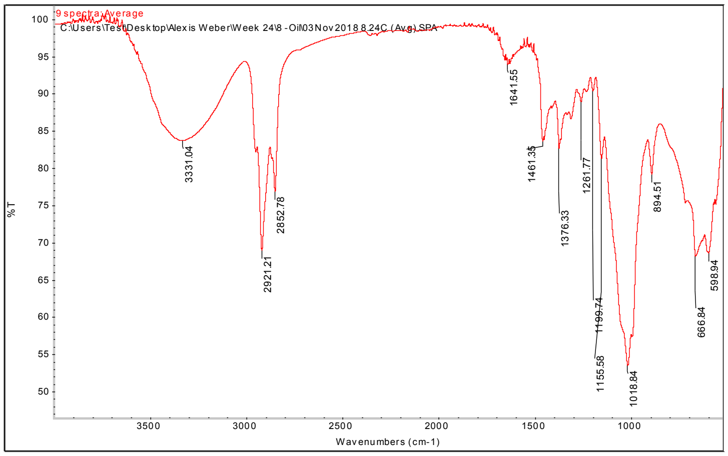

Figure 94: IR Average Spectrum of Rayon - Week 24 in Oil

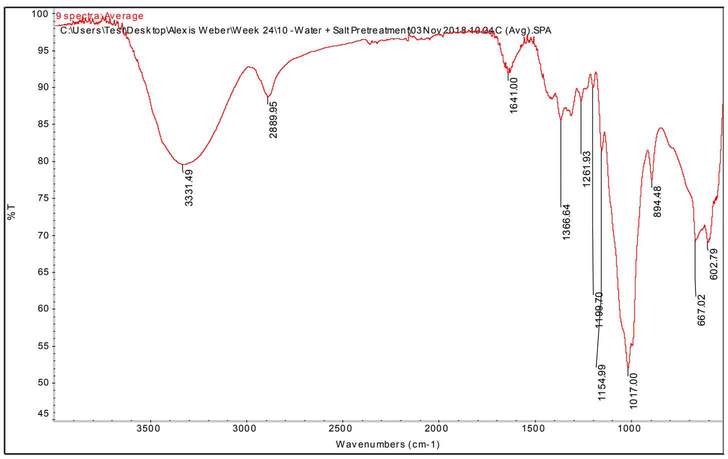

Figure 95: IR Average Spectrum of Rayon - Week 24 in Salt Pretreatment and Water

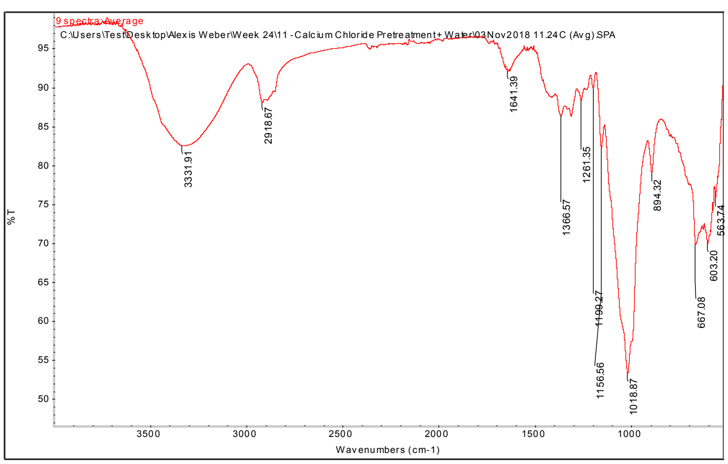

Figure 96: IR Average Spectrum of Rayon - Week 24 in Calcium Chloride Pretreatment and Water

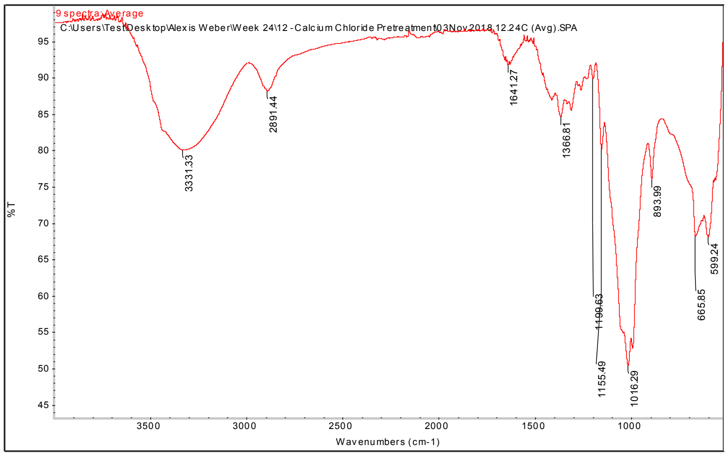

Figure 97: IR Average Spectrum of Rayon - Week 24 in Calcium Chloride Pretreatment

APPENDIX G: TABLES OF IR DATA OF RAYON

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
3331	3331	3330.91	3330.77	3319.71	3323.31	3320.44	3328.22	3327.69	3320.46	3334.38	3332.74	3322.81
2891.38	2891	2892.15	2891.34	2892.12	2919.41	2891.62	2891.12	2891.88	2891.93	2891.27	2891.24	2891.21
1645.26	1643	1635.71		1640.9	1645.99	1635.78	1635.31	1646.62	1644.86	1646.12	1635.79	1646.55
1366.66	1366	1367.24	1366.46		1367.93	1372.5	1367.25		1367.27	1368.29	1368.33	1368.56
1018.29	1018	1019.01	1018.6	1016.93	1018.47	1017.85	1019.29	1017.44	1019.37	1018.48	1019.42	1018.99
894.41	894	894.67	894.39	894.78	894.63	894.78	895.16	894.69	894.84	894.62	894.85	894.66

Table 23: IR Data of Rayon in Sand

Control Wave Numbers	Week 2	Week 4
3331	3319	3295.25
2891.38	2892	2921.45
1645.26	1643	1635.26
1366.66	1366	1373.63
1018.29	1019	1022.4
894.41	894	894.42

Table 24: IR Data of Rayon in Soil

Control Wave Numbers	Week 2	Week 4	Week 6
3331	3331	3288.28	3281.15
2891.38	2892	2921.81	2922.23
1645.26	1643	1645.05	1635.12
1366.66	1366	1373.26	1374.01
1018.29	1018	1023.05	1022.4
894.41	894	895.07	894.17

Table 25: IR Data of Rayon in Soil and Chicken Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
3320.09	3328	3320.23	3288.73	3280.75	3298.37	3327.99	3297.93	3326.7	3331.69	3332.58	3331.81	3331.52
2891.38	2891	2891.42	2917.78	2921.73	2919.01	2891.14	2893.95	2919.05	2891.97	2891.88	2891.27	2891.61
1645.26	1643	1645.34	1646.11	1640.62	1643.11	1641.47	1636.06	1646.67	1635.58	1646.14	1635.62	1645.56
1366.66	1366	1367.46	1373.01			1367.57	1374.1		1367.57	1372.92	1367.15	1367.26
1018.29	1018	1018.19	1018.54	1018.67	1018.63	1017.74	1018.99	1018.99	1019.25	1019.28	1018.97	1017.87
894.41	894	894.37	894.33	872.48	894.71	894.48	894.9	894.45	894.81	894.53	894.54	894.43

Table 26: IR Data of Rayon in Chicken Manure

Control Wave Numbers	Week 2	Week 4
3320.09	3331	3291.5
2891.38	2891	2922.41
1645.26	1644	1635.56
1366.66	1366	1373.4
1018.29	1018	1020.19
894.41	894	894.57

Table 27: IR Data of Rayon in Soil and Cow Manure

Control Wave Numbers	Week 2	Week 4
3331	3329.14	3297.09
2891.38	2891.8	2919.35
1645.26	1643.55	1635.61
1366.66	1366.54	1368.96
1018.29	1018.85	1018.63
894.41	894.68	894.27

Table 28: IR Data of Rayon in Cow Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
3331	3331.72	3333.41	3333.29	3330.39	3334.57	3332.26	3333.65	3333.76	3334.83	3332.26	3335.01	3331.04
2891.38	2853.11	2852.9	2921.4	2921.31	2921.18	2921.29	2921.26	2921.3	2852.91	2853.29	2852.82	2852.78
1645.26	1712.76	1640.52		1641.38	1652.72			1644.81	1635.66	1644.96	1646.53	1641.55
1366.66	1375.92	1376.1	1375.51	1376.2	1375.53	1375.86	1375.79	1375.57	1375.01	1375.48	1376.05	1376.33
1018.29	1017.47	1018.71	1019.17	1018.64	1019.09	1019	1019.46	1019.24	1019.34	1019.06	1019.47	1018.84
894.41	894.8	894.81	894.82	894.63	894.56	894.64	894.77	894.57	894.68	894.78	894.59	894.51

Table 29: IR Data of Rayon in Oil

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
3331	3331.47	3328.31	3332.62	3331.67	3331.43	3327.69	3334.67	3331.92	3334.15	3331.51	3331.6	3331.49
2891.38	2883.26	2892.02	2920.88	2920.91	2852.84	2883.85	2918.64	2884.77	2882.49	2282.17	2881.66	2889.95
1645.26	1640.37	1635.87	1635.51	1641.25	1635.95	1639.73	1646.61	1645.39	1635.11	1635.04	1635.93	1641
1366.66	1366.96	1367.37	1373.76	1376.05	1375	1367.48	1363.16	1367.94	1367.39	1367.21	1363.24	1366.64
1018.29	1018.09	1018.47	1018.27	1017.51	1019.05	1016.51	1018.43	1016.89	1018.91	1018.73	1018.46	1017
894.41	894.6	894.82	894.55	894.5	894.68	894.62	894.88	894.73	894.56	894.65	894.68	894.48

Table 30: IR Data of Rayon in Salt Pretreatment and Water

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
3331	3332.52	3332.23	3331.44	3330.81	3333.8	3331.44	3332.07	3331.42	3319.96	3332.41	3332.26	3331.91
2891.38	2890.42	2890.56	2886.66	2887.1	2853.01	2891.93	2891.49	2841.55	2891.69	2891.36	2891.32	
1645.26	1640.15	1634.97		1640.83	1646.39	1642.02	1641.04	1635.62	1635.97	1635.48	1645.87	1641.39
1366.66	1367.02	1366.91	1366.82		1375.3	1367.04	1366.86	1367.71	1367.26	1367.32	1366.99	1366.57
1018.29	1018.78	1018.06	1018.25	1016.51	1019.23	1018.41	1018.48	1018.33	1019.05	1018.36	1018.96	1018.87
894.41	894.79	894.4	894.54	894.29	894.61	894.55	894.49	894.32	894.44	894.43	894.56	894.32

Table 31: IR Data of Rayon in Calcium Chloride Pretreatment and Water

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
3331	3272.83	3316.01	3320	3331.03	3299.68	3327.87	3331.26	3331.01	3328.72	3331.44	3332.18	3331.33
2891.38	2891.86	2891.56	2891.45	2917.74	2891.83	2892.07	2891.94	2892.02	2891.51	2891.69	2892.26	2891.44
1645.26	1651.73	1641.2	1642.47	1640.1	1645.51	1640.35	1641.33	1644.54	1635.67	1645.26	1645.38	1641.27
1366.66	1372.1	1370.82	1367.17	1376.08	1367.97	1371.41	1366.76	1372.84	1369.55	1367.36	1367.53	1366.81
1018.29	1017.39	1016.93	1018.93	1016.58	1018.68	1016.4	1019.29	1018.62	1018.8	1019.42	1018.88	1016.29
894.41	894.64	894.38	894.3	894.55	894.41	894.23	894.37	894.45	894.38	894.46	894.41	893.99

Table 32: IR Data of Rayon in Calcium Chloride Pretreatment

APPENDIX H: IR SPECTRA OF POLYESTER

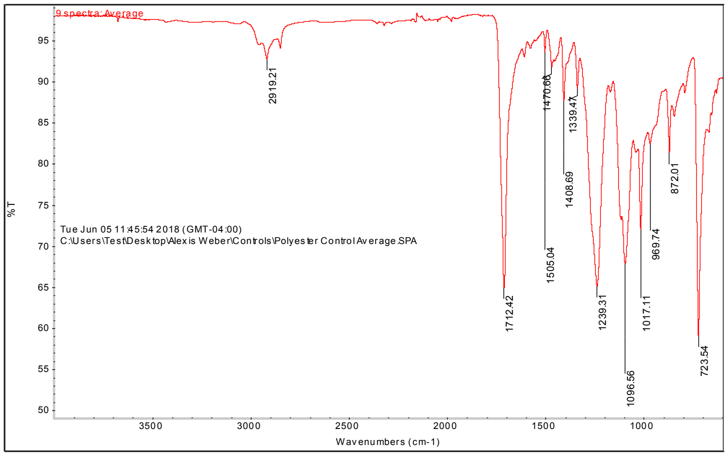

Figure 98: IR Average Spectrum of Control Polyester

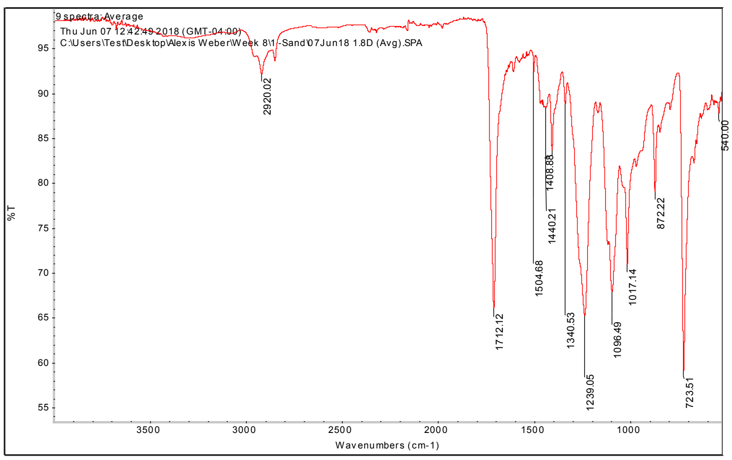

Figure 99: IR Average Spectrum of Polyester - Week 8 in Sand

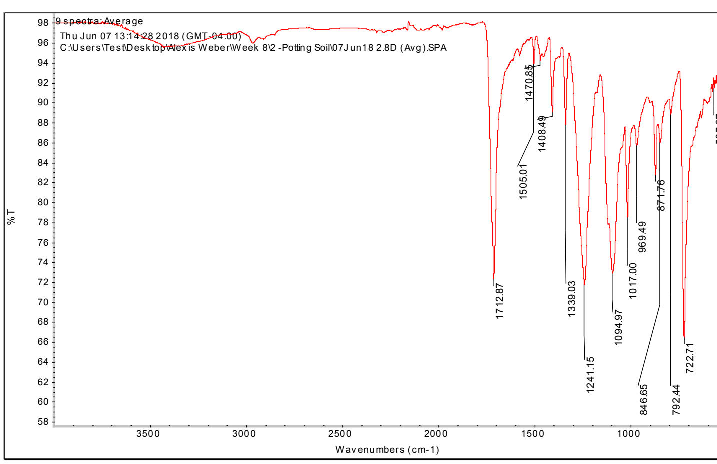

Figure 100: IR Average Spectrum of Polyester - Week 8 in Soil

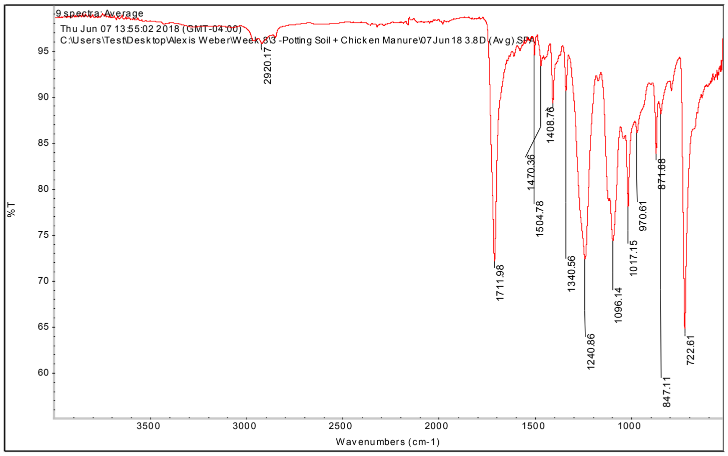

Figure 101: IR Average Spectrum of Polyester - Week 8 in Soil and Chicken Manure

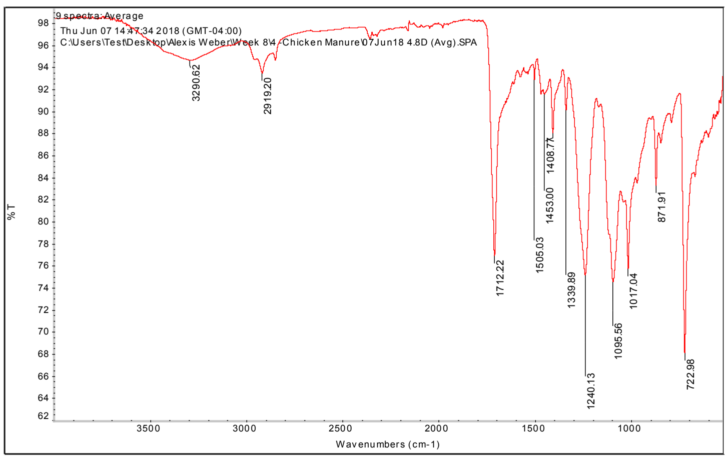

Figure 102: IR Average Spectrum of Polyester - Week 8 in Chicken Manure

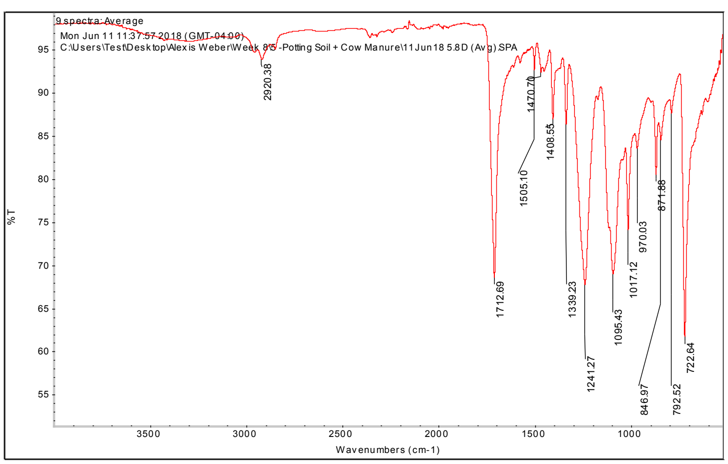

Figure 103: IR Average Spectrum of Polyester - Week 8 in Soil and Cow Manure

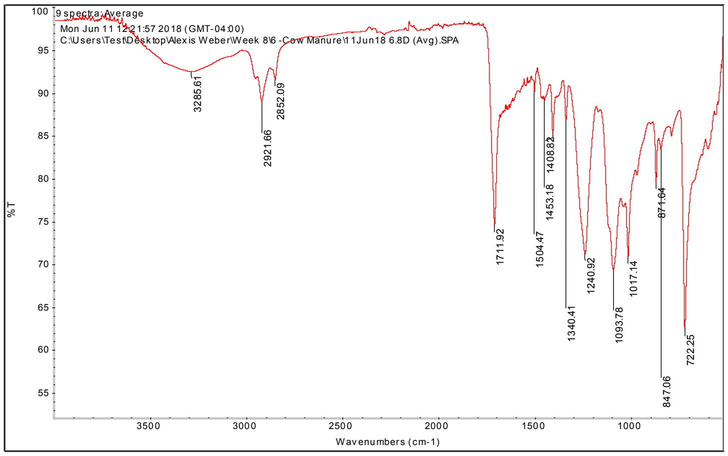

Figure 104: IR Average Spectrum of Polyester - Week 8 in Cow Manure

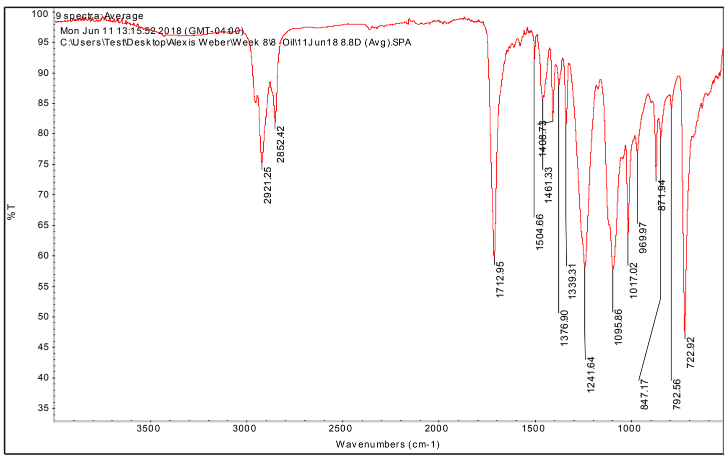

Figure 105: IR Average Spectrum of Polyester - Week 8 in Oil

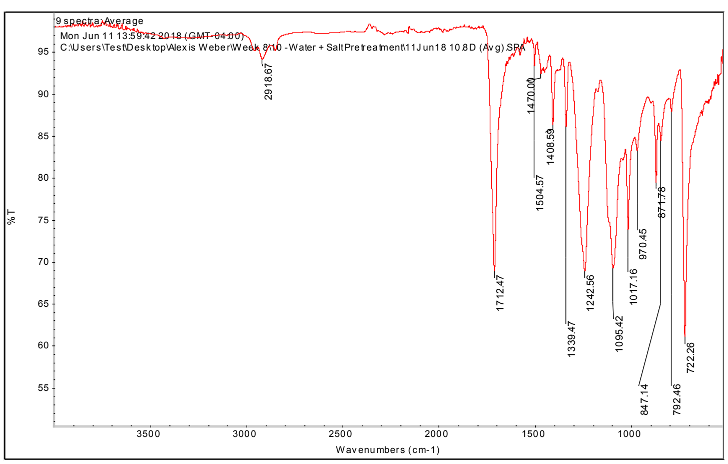

Figure 106: IR Average Spectrum of Polyester - Week 8 in Salt Pretreatment and Water

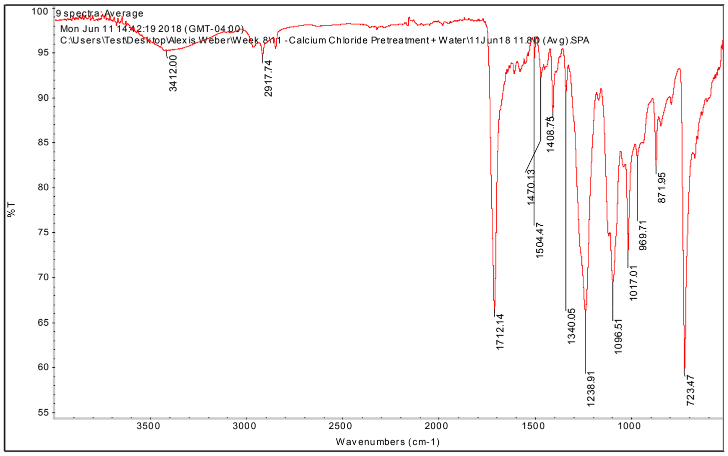

Figure 107: IR Average Spectrum of Polyester - Week 8 in Calcium Chloride Pretreatment and Water

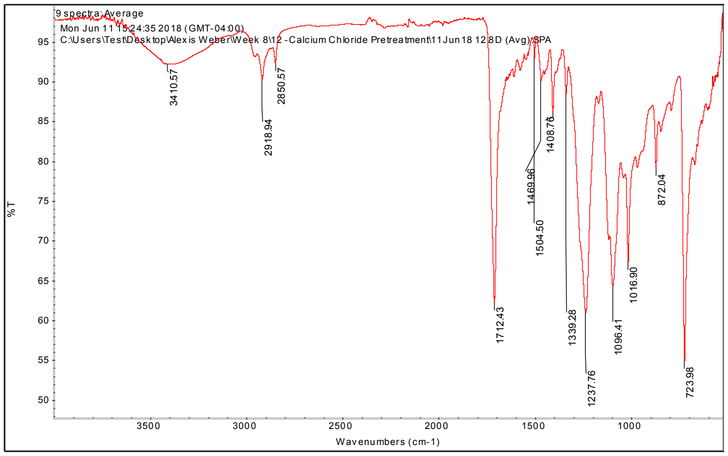

Figure 108: IR Average Spectrum of Polyester - Week 8 in Calcium Chloride Pretreatment

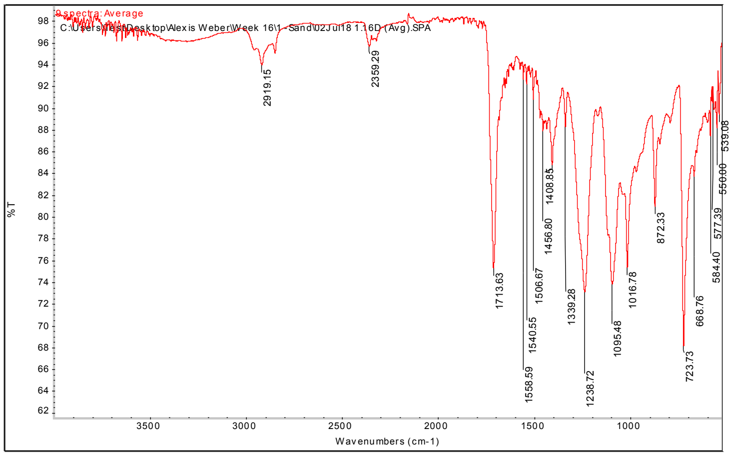

Figure 109: IR Average Spectrum of Polyester - Week 16 in Sand

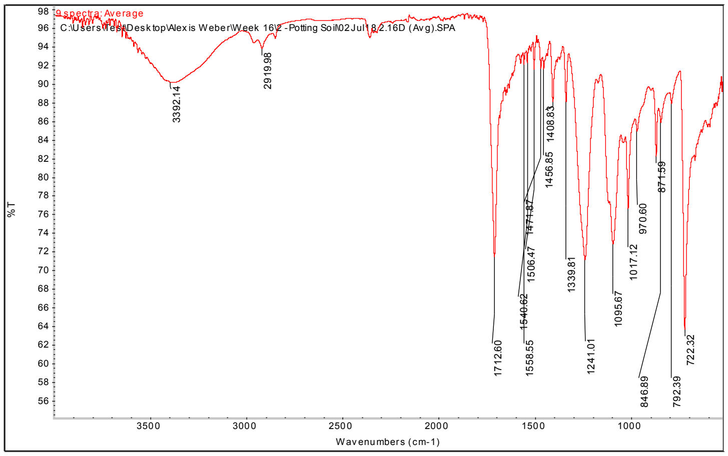

Figure 110: IR Average Spectrum of Polyester - Week 16 in Soil

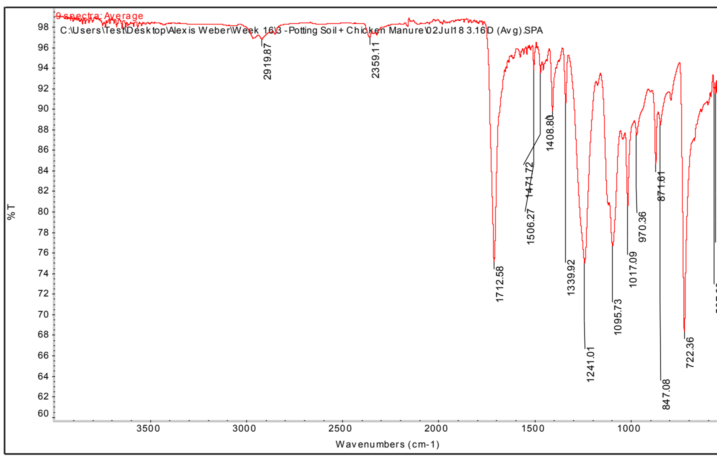

Figure 111: IR Average Spectrum of Polyester - Week 16 in Soil and Chicken Manure

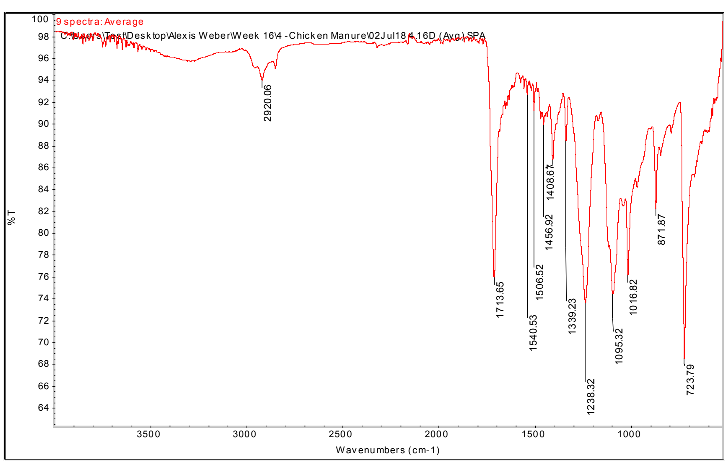

Figure 112: IR Average Spectrum of Polyester - Week 16 in Chicken Manure

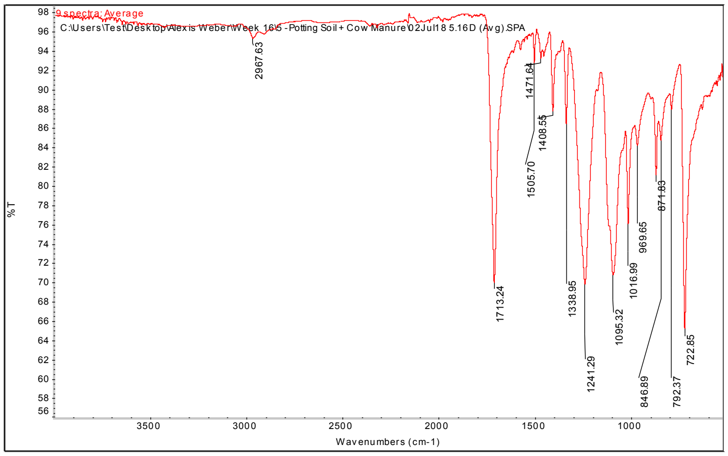

Figure 113: IR Average Spectrum of Polyester - Week 16 in Soil and Cow Manure

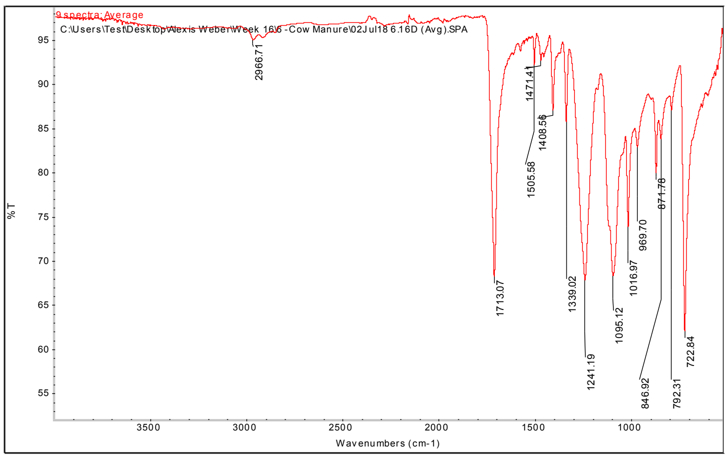

Figure 114: IR Average Spectrum of Polyester - Week 16 in Cow Manure

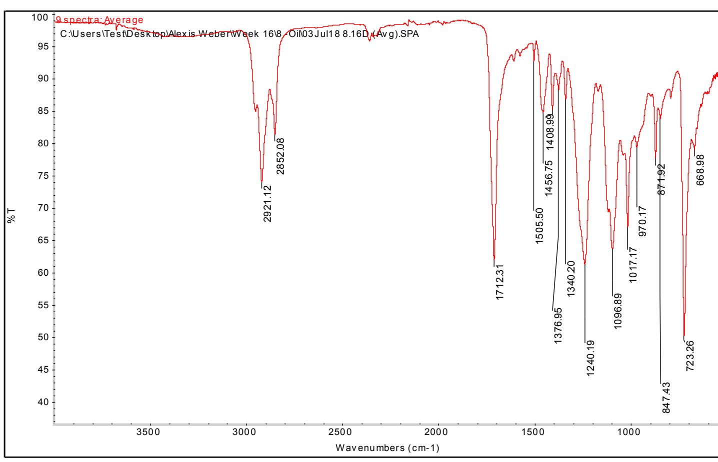

Figure 115: IR Average Spectrum of Polyester - Week 16 in Oil

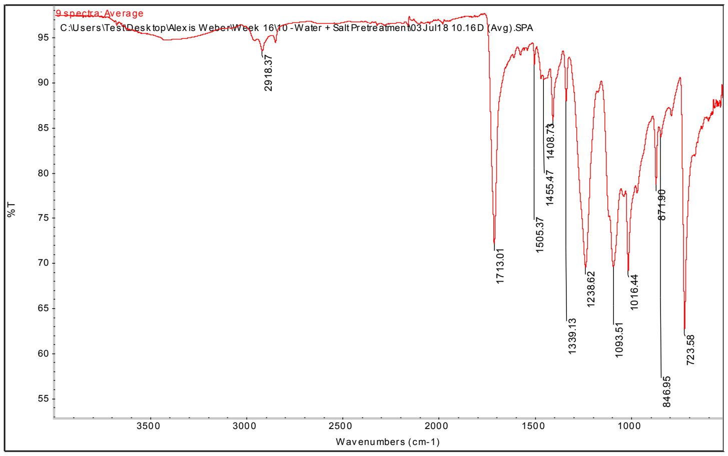

Figure 116: IR Average Spectrum of Polyester - Week 16 in Salt Pretreatment and Water

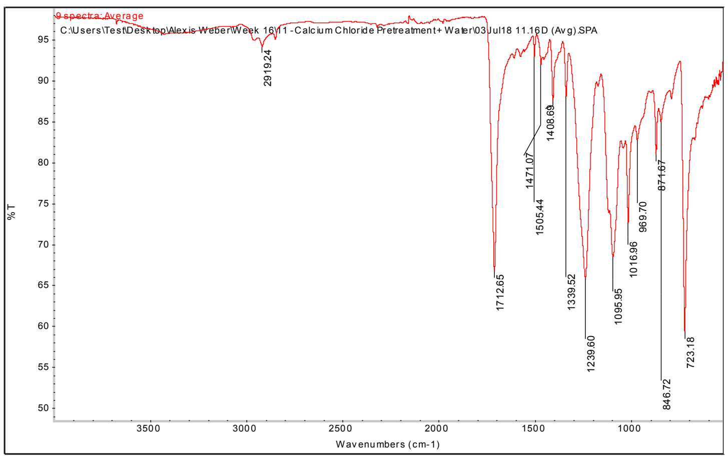

Figure 117: IR Average Spectrum of Polyester - Week 16 in Calcium Chloride Pretreatment and Water

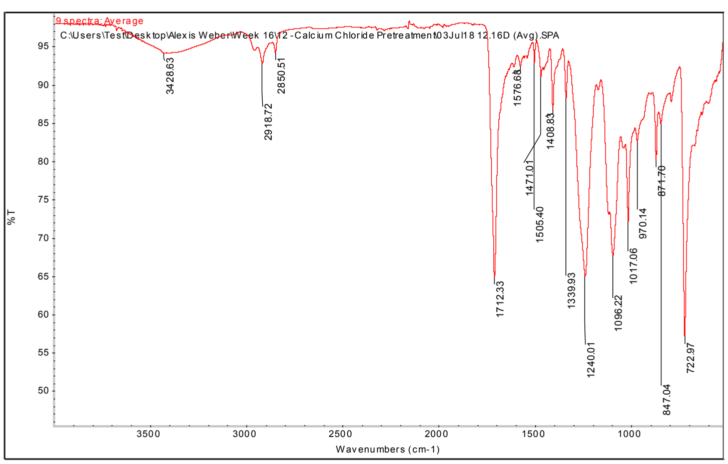

Figure 118: IR Average Spectrum of Polyester - Week 16 in Calcium Chloride Pretreatment

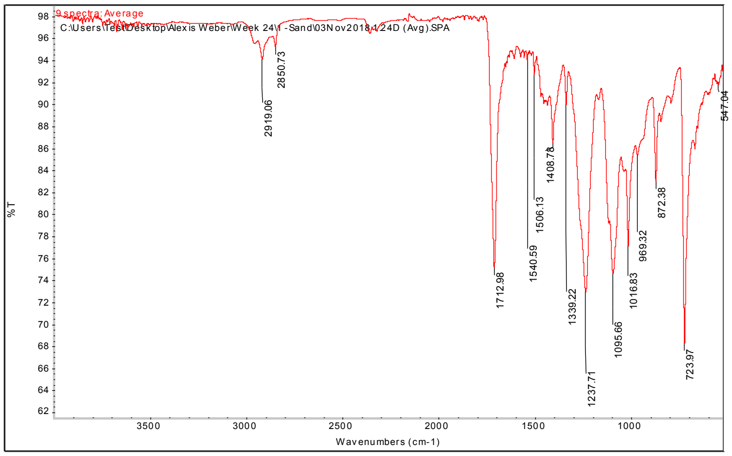

Figure 119: IR Average Spectrum of Polyester - Week 24 in Sand

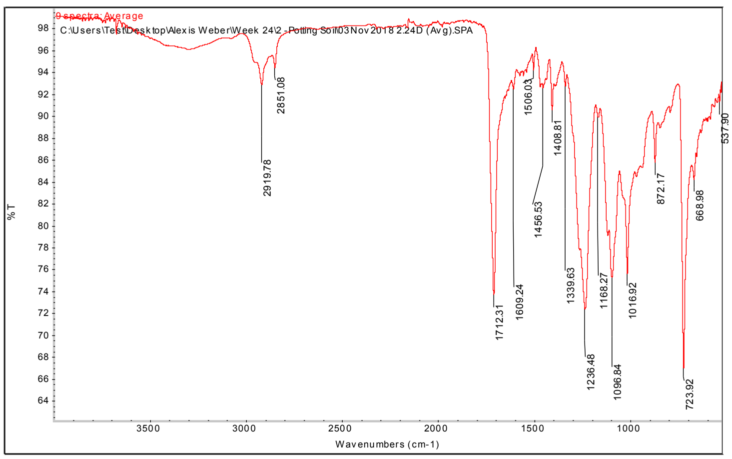

Figure 120: IR Average Spectrum of Polyester - Week 24 in Soil

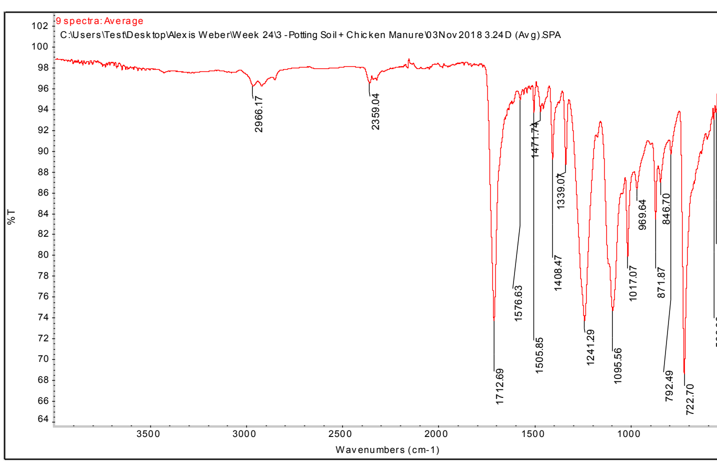

Figure 121: IR Average Spectrum of Polyester - Week 24 in Soil and Chicken Manure

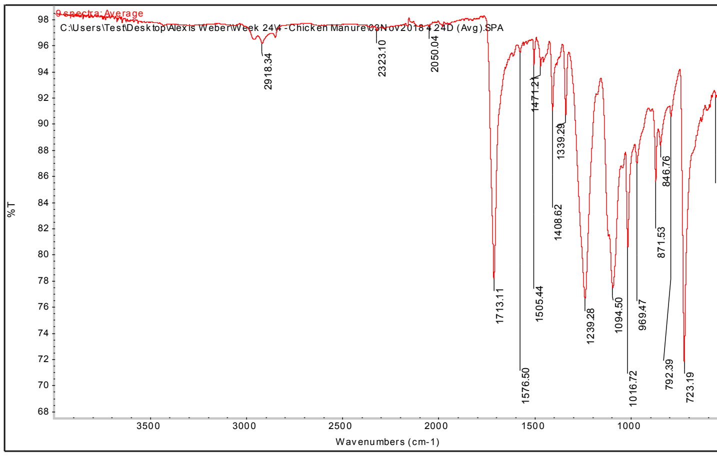

Figure 122: IR Average Spectrum of Polyester - Week 24 in Chicken Manure

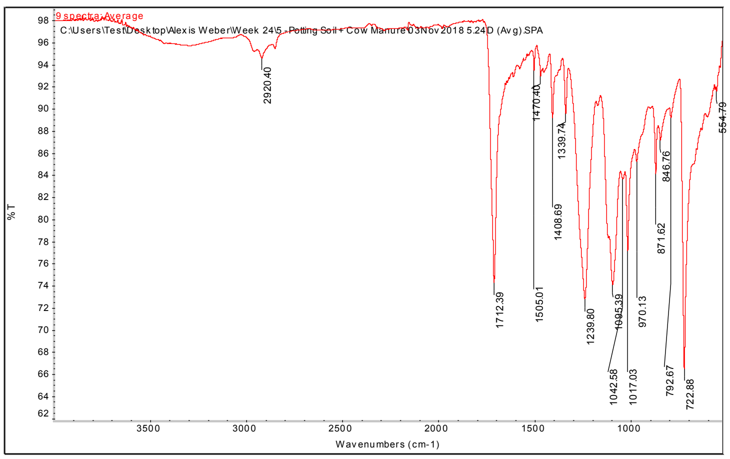

Figure 123: IR Average Spectrum of Polyester - Week 24 in Soil and Cow Manure

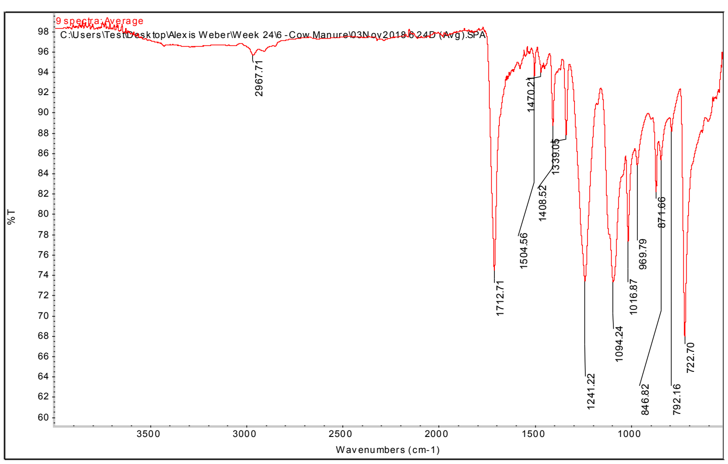

Figure 124: IR Average Spectrum of Polyester - Week 24 in Cow Manure

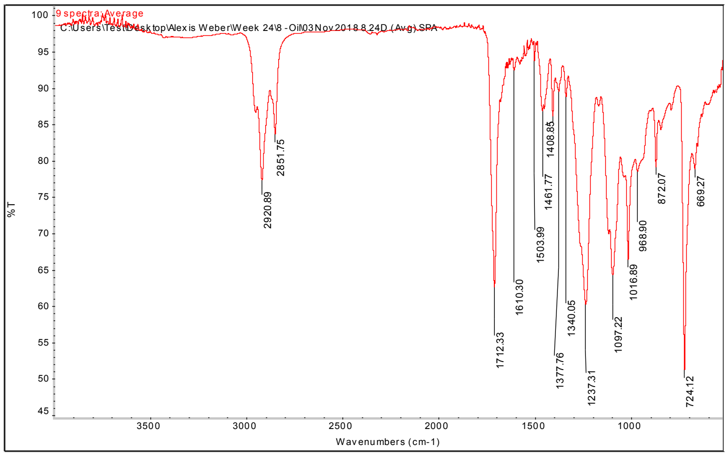

Figure 125: IR Average Spectrum of Polyester - Week 24 in Oil

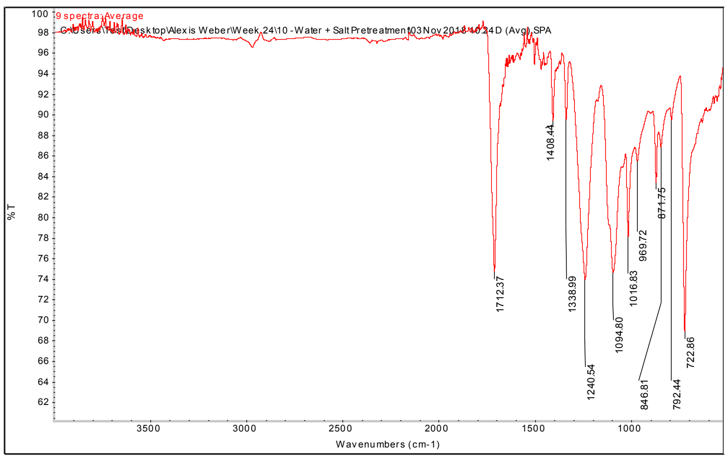

Figure 126: IR Average Spectrum of Polyester - Week 24 in Salt Pretreatment and Water

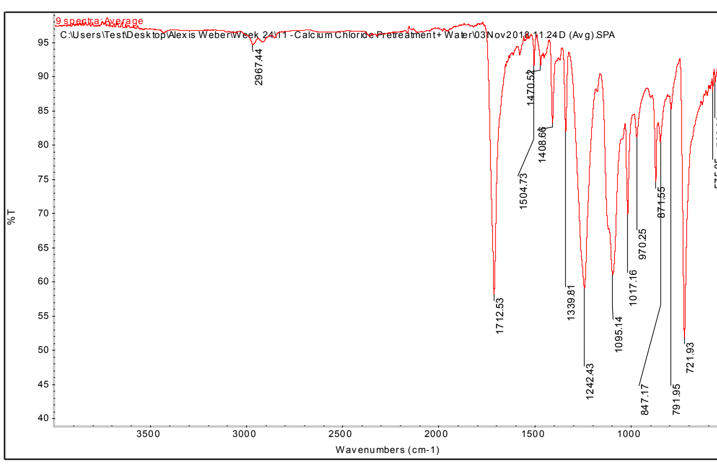

Figure 127: IR Average Spectrum of Polyester - Week 24 in Calcium Chloride Pretreatment and Water

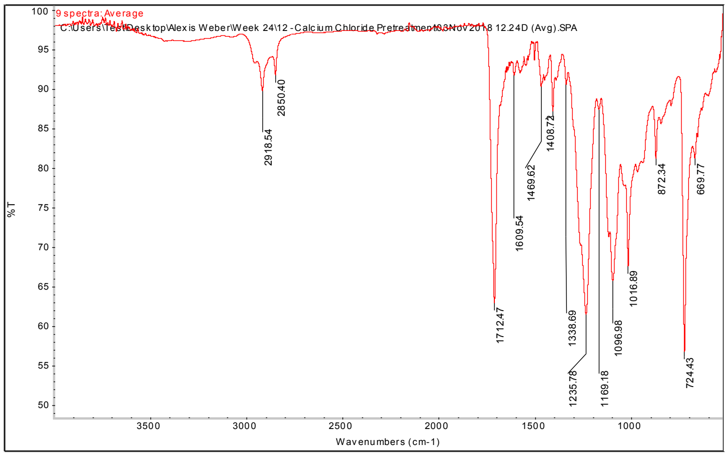

Figure 128: IR Average Spectrum of Polyester - Week 24 in Calcium Chloride Pretreatment

APPENDIX I: TABLES OF IR DATA FOR POLYESTER

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2919.21	2918		2919.09	2920.02	2919.81	2919.53	2917.36	2919.15	2919.2	2919.45	2919.15	2919.06
1712.42	1712	1712.65	1712.33	1712.12	1712.7	1712.48	1712.69	1713.63	1712.44	1712.54	1713.17	1712.98
1470.66	1470	1471.4	1470.71				1471.39					
1408.96	1408	1408.61	1408.74	1408.88	1408.82	1408.85	1408.61	1408.85	1408.9	1408.86	1408.77	1408.78
1239.31	1240	1242.31	1240.32	1239.05	1237.37	1239.94	1242.39	1238.72	1239.02	1239.83	1237.53	1237.71
1096.56	1095	1095.68	1095.81	1096.49	1094.05	1095.78	1095.98	1095.48	1095.78	1095.81	1095.03	1095.66
1017.11	1016	1017.24	1017.05	1017.14	1016.95	1016.99	1017.17	1016.78	1016.99	1016.95	1016.68	1016.83
723.54	723	722.34	722.79	723.51	723.95	723.01	722.73	723.73	723.52	723.52	724	723.97

Table 33: IR Data of Polyester in Sand

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2919.21	2919	2919.65	2919.85			2917.99	2966.58	2919.98	2920.54	2919.85	2920.57	2919.78
1712.42	1712	1712.69	1712.42	1712.87	1712.52	1713.04	1712.96	1712.6	1712.54	1713.05	1712.47	1712.31
1470.66	1470	1470.95	1470.46	1470.85	1470.66	1471.15	1471.88	1471.87	1471.21	1471.35		
1408.96	1408	1408.65	1408.68	1408.49	1408.52	1408.51	1408.5	1408.83	1408.74	1408.67	1408.76	1408.81
1239.31	1239	1236.95	1238.59	1241.15	1241.77	1240.86	1241.37	1241.01	1239.8	1237.32	1239.35	1236.48
1096.56	1095	1096.27	1096.43	1094.97	1095.77	1094.66	1095.54	1095.67	1095.94	1095.72	1095.72	1096.84
1017.11	1016	1016.82	1017.03	1017	1017.13	1016.79	1017.03	1017.12	1017	1016.69	1016.98	1016.92
723.54	723	724.05	723.6	722.1	722.32	722.71	722.75	722.23	723.05	723.92	722.98	723.92

Table 34: IR Data of Polyester in Soil

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2919.21	2918			2920.17	2921.14	2919.07	2968.02	2919.87	2921.16	2920.34		
1712.42	1712	1713	1712.89	1711.98	1712.37	1712.36	1712.93	1712.58	1713.09	1712.62	1712.89	1712.69
1470.66	1470	1471.18		1470.36	1470.34	1470.95	1471.71	1471.72	1471.17	1471.2	1471.31	1471.74
1408.96	1408	1408.57	1408.49	1408.76	1408.65	1408.6	1408.69	1408.8	1408.7	1408.72	1408.6	1408.47
1239.31	1239	1241.07	1241.08	1240.86	1241.98	1242.5	1242.6	1241.01	1237.45	1239.25	1241.76	1241.29
1096.56	1095	1095.39	1095.35	1096.14	1095.76	1095.81	1095.87	1095.73	1095.53	1095.95	1094.84	1095.56
1017.11	1016	1016.97	1016.93	1017.15	1017.19	1017.23	1017.29	1017.09	1016.81	1017	1017.06	1017.07
723.54	722	722.81	722.84	722.61	722.36	722.07	722.31	722.36	723.92	723.05	722.36	722.7

Table 35: IR Data of Polyester in Soil and Chicken Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2919.21	2917			2919.2	2918.75	2918.96	2919.37	2920.06	2917.04	2917.72	2919.72	2918.34
1712.42	1712	1713.05	1712.84	1712.22	1712.38	1712.05	1712.38	1713.65	1712.93	1712.37	1712.35	1713.11
1470.66		1470.96	1471.23			1470.24	1471.26		1471.47		1471.22	1471.21
1408.96	1408	1408.45	1408.46	1408.77	1408.42	1408.8	1408.87	1408.67	1408.58	1408.56	1408.83	1408.82
1239.31	1241	1241.06	1242.49	1240.13	1239.23	1238.42	1239.14	1238.32	1241.91	1241.88	1239.68	1239.28
1096.56	1093.66	1094.33	1095.41	1095.56	1093.56	1096.42	1096.26	1095.32	1094.88	1095.91	1096.41	1094.5
1017.11	1017	1016.86	1017.16	1017.04	1016.67	1017	1017.07	1016.82	1017.01	1017.22	1017.06	1016.76
723.54	722	722.74	722.44	722.98	723.4	723.61	723.45	723.79	722.38	722.5	722.94	723.19

Table 36: IR Data of Polyester in Chicken Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2919.21	2919	2919.3		2920.38	2920.34	2920.83	2921.29		2920.49	2917.97	2919.82	2920.4
1712.42	1712	1712.98	1712.67	1712.69	1712.83	1712.37	1712.32	1713.24	1712.69	1712.6	1712.5	1712.39
1470.66		1471.14	1470.63	1470.7	1470.63	1471.24	1471.14	1471.64	1470.87	1471.08	1470.37	1470.4
1408.96	1408	1408.49	1408.54	1408.55	1408.48	1408.73	1408.84	1408.55	1408.72	1408.55	1408.77	1408.69
1239.31	1240	1240.3	1241.98	1241.27	1240.19	1241.86	1239.93	1241.29	1238.25	1241.41	1235.12	1239.8
1096.56	1094	1095.31	1095.35	1095.43	1095.16	1095.45	1096.32	1095.32	1095.67	1095.79	1096.85	1095.39
1017.11	1016	1016.88	1017.16	1017.12	1016.84	1017.16	1017.16	1016.99	1016.86	1017.09	1016.85	1017.03
723.54	722	723.12	722.52	722.64	723.14	722.01	723.06	722.85	723.48	722.8	724.58	722.88

Table 37: IR Data of Polyester in Soil and Cow Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2919.21	2918.67	2919.82	2920.4	2921.66			2920.06		2920.18	2918.48		
1712.42	1712.32	1712.47	1712.74	1711.92	1712.77	1712.71	1712.72	1713.07	1713.23	1712.49	1713.01	1712.71
1470.66	1470.1				1470.84	1470.93	1471.13	1471.41	1471.37	1471.11	1471.49	1470.21
1408.96	1408.74	1408.78	1408.68	1408.82	1408.68	1408.77	1408.75	1408.56	1408.65	1408.68	1408.5	1408.52
1239.31	1237.84	1237.52	1236.82	1240.92	1241.72	1242.81	1237.04	1241.19	1238.47	1240.28	1241.37	1241.22
1096.56	1095.87	1094.59	1093.16	1093.73	1093.6	1096.02	1095.27	1095.12	1093.89	1095.58	1094.31	1094.24
1017.11	1016.98	1016.89	1016.73	1017.14	1017.09	1017.41	1016.83	1016.97	1016.63	1016.99	1016.94	1016.87
723.54	723.76	723.66	723.72	722.25	722.29	722.54	724.01	722.84	723.51	722.98	722.66	722.87

Table 38: IR Data of Polyester in Cow Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2919.21	2921.05	2921.06	2921.21	2921.25	2921.36	2921.16	2921.01	2921.12	2921.37	2921.38	2921.45	2920.89
1712.42	1712.85	1712.57	1713.21	1712.95	1713.55	1712.91	1712.76	1712.31	1713.04	1713.08	1712.93	1712.33
1470.66	1456.22	1461.41										
1408.96	1408.81	1408.08	1408.74	1408.73	1408.8	1408.89	1408.98	1408.99	1408.84	1408.98	1408.73	1408.85
1239.31	1239.73	1239.08	1242.07	1241.64	1242.3	1241.48	1237.19	1240.19	1243.06	1239.02	1242.32	1237.31
1096.56	1096.16	1096.8	1096.26	1095.86	1096.21	1096.38	1097.23	1096.89	1096.25	1096.48	1096.42	1097.22
1017.11	1016.95	1017.01	1017.04	1017.02	1017.08	1017.17	1016.84	1017.17	1017.35	1016.83	1017.25	1016.89
723.54	723.57	723.63	722.91	722.92	722.68	723.08	724.22	723.26	722.05	723.9	722.63	724.12

Table 39: IR Data of Polyester in Oil

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2919.21		2918.99	2920.15	2918.67	2916.55	2917.8	2918.72	2918.37				
1712.42	1712.7	1712.59	1712.84	1712.47	1712.92	1712.55	1713.2	1713.01	1713.17	1712.57	1712.66	1712.37
1470.66				1470		1470.95	1472.03		1472.15	1471.04	1471.11	
1408.96	1408.53	1408.89	1408.93	1408.58	1408.73	1408.52	1408.57	1408.73	1408.46	1408.55	1408.56	1408.44
1239.31	1242.21	1238.46	1237.14	1242.56	1238.74	1242.03	1241.95	1238.62	1240.72	1242.16	1242.52	1240.54
1096.56	1095.27	1094.9	1094.49	1095.42	1093.61	1095.73	1094.96	1093.51	1095.4	1095.17	1095.6	1094.8
1017.11	1017.16	1016.93	1016.51	1017.16	1016.56	1017.11	1017.02	1016.44	1016.87	1017.04	1017.13	1016.83
723.54	722.59	723.66	724	722.26	723.35	722.62	722.21	723.58	723.25	722.25	722.27	722.86

Table 40: IR Data of Polyester in Salt Pretreatment and Water

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2919.21	2918.23	2918.63		2917.74	2919.91	2917.89		2919.24	2919.12	2918.64	2918.43	
1712.42	1712.35	1712.28	1712.61	1712.14	1712.76	1712.7	1712.79	1712.65	1713.01	1712.61	1712.43	1712.53
1470.66	1470.81	1470.52		1470.13	1471.46	1470.73	1470.33	1471.07	1471.37	1471.31	1471.37	1470.52
1408.96	1408.87	1408.75	1408.7	1408.75	1408.5	1408.42	1408.51	1408.69	1408.68	1408.84	1408.78	1408.66
1239.31	1239.75	1238.88	1238.29	1238.91	1242.66	1241.04	1241.2	1239.6	1238.99	1238.02	1239.12	1242.43
1096.56	1096.39	1096.88	1096.26	1096.51	1096.16	1096.1	1095.59	1095.95	1095.18	1096.75	1096.23	1095.14
1017.11	1017.07	1017.06	1016.9	1017.01	1017.15	1016.99	1016.92	1016.96	1016.73	1016.95	1016.94	1017.16
723.54	723.19	723.66	723.1	723.47	722.45	723.17	722.85	723.18	723.45	723.86	723.36	721.93

Table 41: IR Data of Polyester in Calcium Chloride Pretreatment and Water

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2919.21	2918.49			2918.94	2917.18		2918.67	2918.72	2917.23	2918.37	2919.01	2918.54
1712.42	1712.83	1712.7	1712.88	1712.43	1712.89	1712.62	1712.4	1712.33	1712.47	1712.5	1712.84	1712.47
1470.66	1471	1470.32		1469.96	1471.68	1471.06	1470.11	1471.01	1471.32	1471.15	1471.09	1469.62
1408.96	1408.63	1408.53	1408.48	1408.76	1408.48	1408.6	1408.64	1408.83	1408.58	1408.8	1408.7	1408.72
1239.31	1240.6	1241.63	1241.06	1237.76	1241.68	1242.3	1242.05	1240.01	1242.54	1238.43	1238.18	1235.78
1096.56	1095.81	1096.02	1095.19	1096.41	1095.91	1095.8	1095.15	1096.22	1096.03	1096.8	1095.77	1096.96
1017.11	1016.94	1017.07	1016.84	1016.91	1017.01	1017.19	1017.1	1017.06	1017.2	1017	1016.83	1016.89
723.54	723.01	722.84	722.79	723.98	722.71	722.26	722.03	722.97	722.25	723.87	723.75	724.43

Table 42: IR Data of Polyester in Calcium Chloride Pretreatment

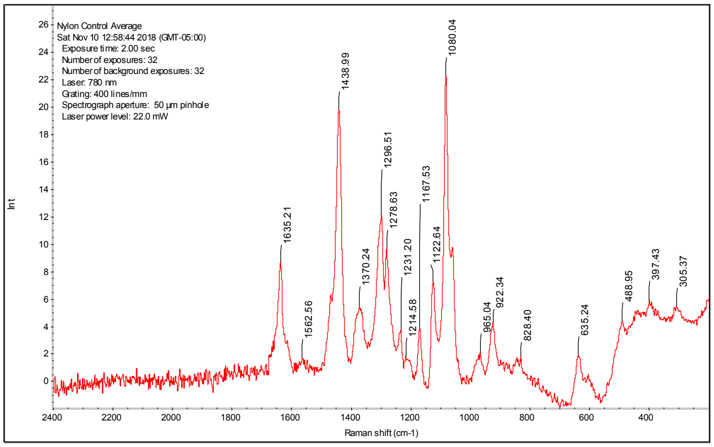

Figure 129: Raman Average Spectrum of Control Nylon

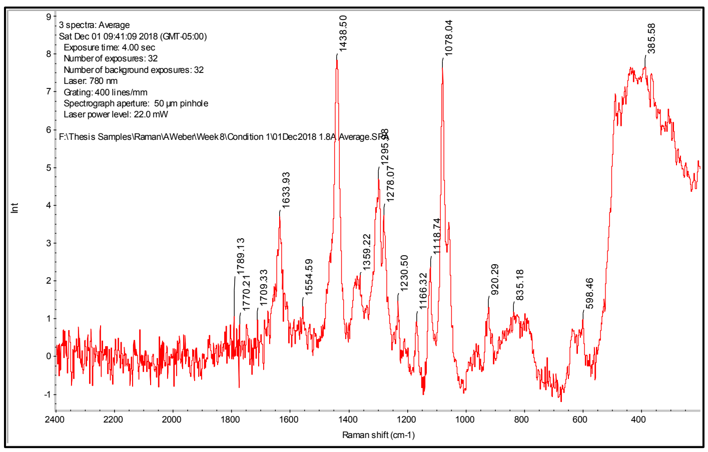

Figure 130: Raman Average Spectrum of Nylon - Week 8 in Sand

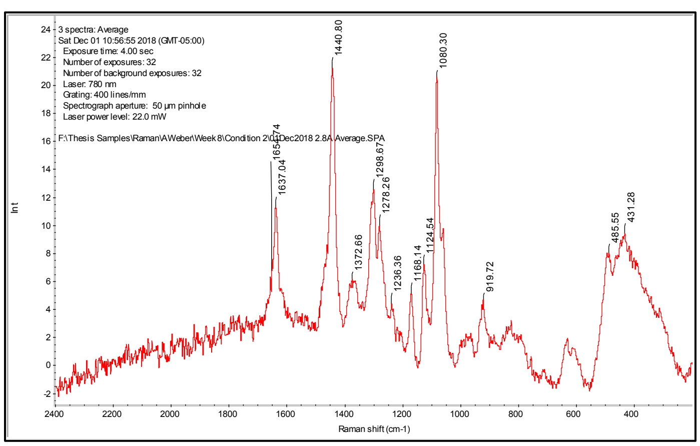

Figure 131: Raman Average Spectrum of Nylon - Week 8 in Soil

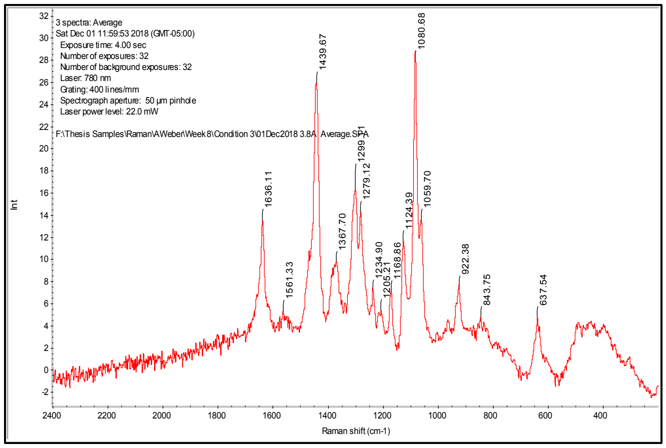

Figure 132: Raman Average Spectrum of Nylon - Week 8 in Soil and Chicken Manure

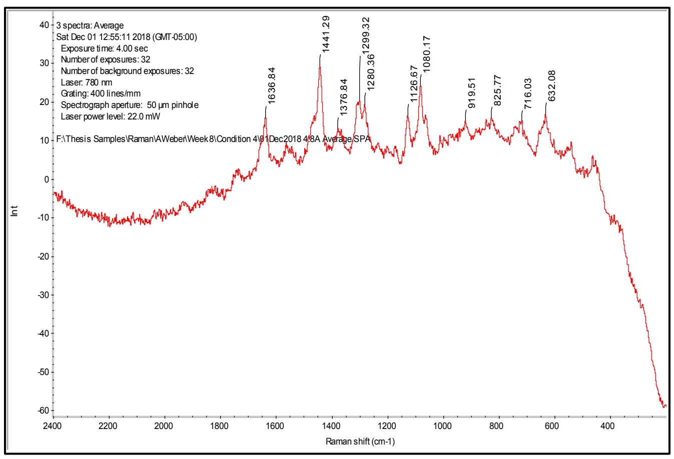

Figure 133: Raman Average Spectrum of Nylon - Week 8 in Chicken Manure

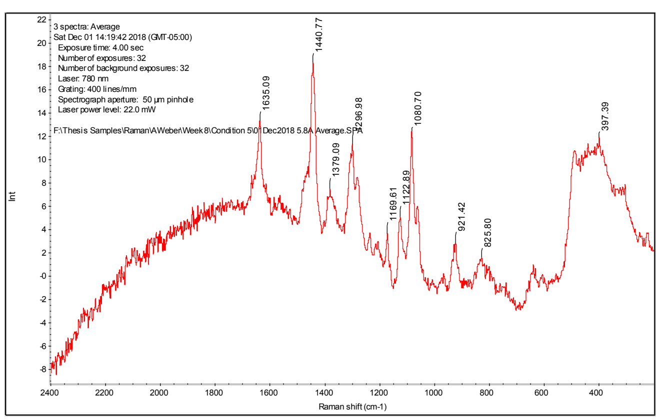

Figure 134: Raman Average Spectrum of Nylon - Week 8 in Soil and Cow Manure

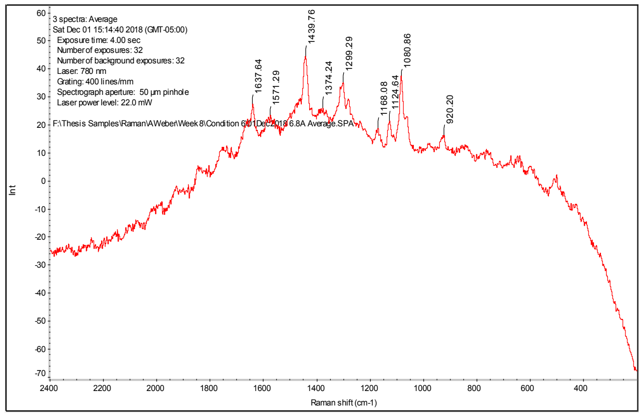

Figure 135: Raman Average Spectrum of Nylon - Week 8 in Cow Manure

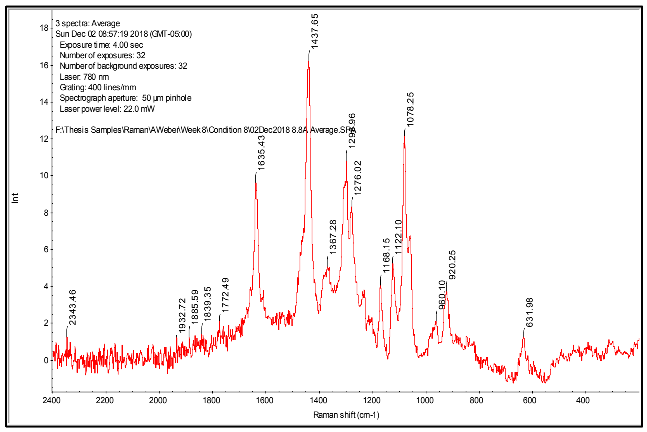

Figure 136: Raman Average Spectrum of Nylon - Week 8 in Oil

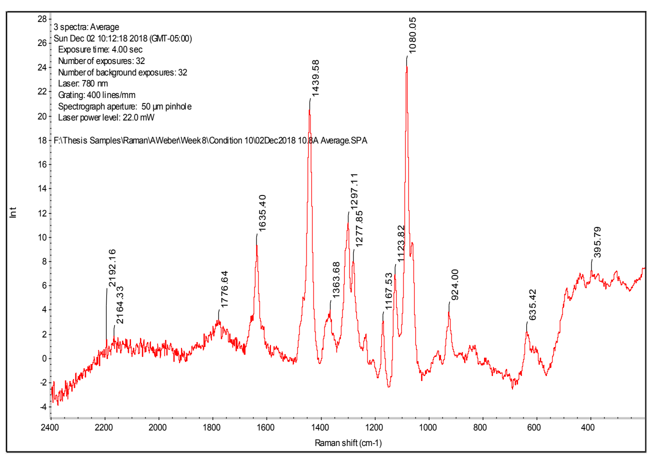

Figure 137: Raman Average Spectrum of Nylon - Week 8 in Salt Pretreatment and Water

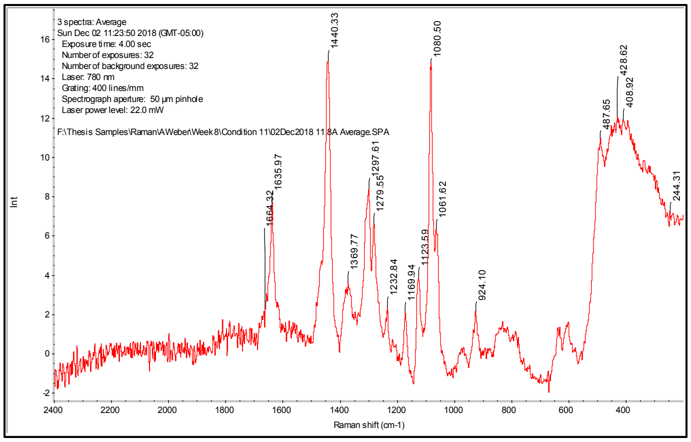

Figure 138: Raman Average Spectrum of Nylon - Week 8 in Calcium Chloride Pretreatment and Water

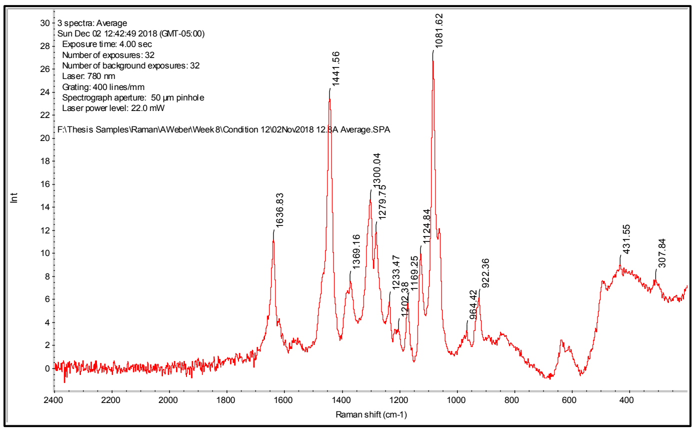

Figure 139: Raman Average Spectrum of Nylon - Week 8 in Calcium Chloride Pretreatment

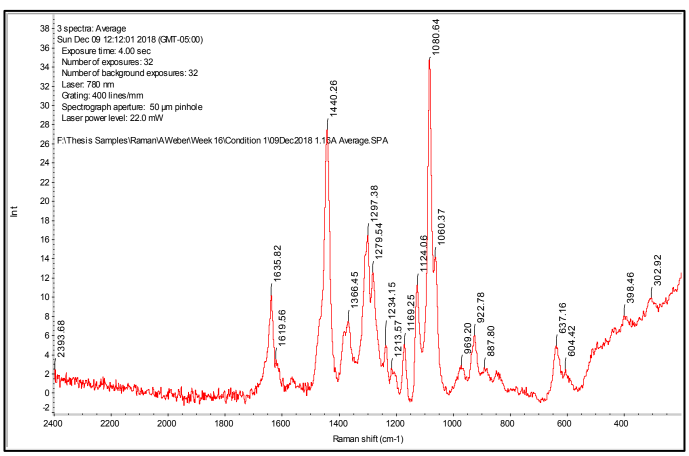

Figure 140: Raman Average Spectrum of Nylon - Week 16 in Sand

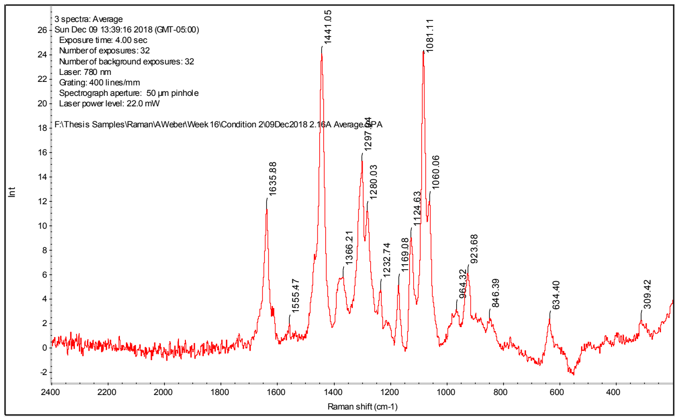

Figure 141: Raman Average Spectrum of Nylon - Week 16 in Soil

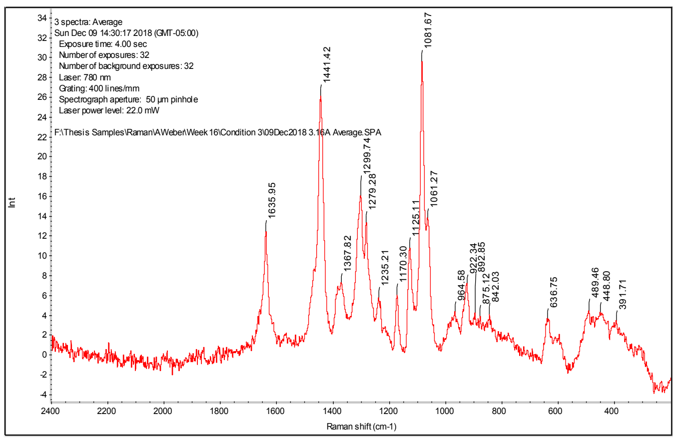

Figure 142: Raman Average Spectrum of Nylon - Week 16 in Soil and Chicken Manure

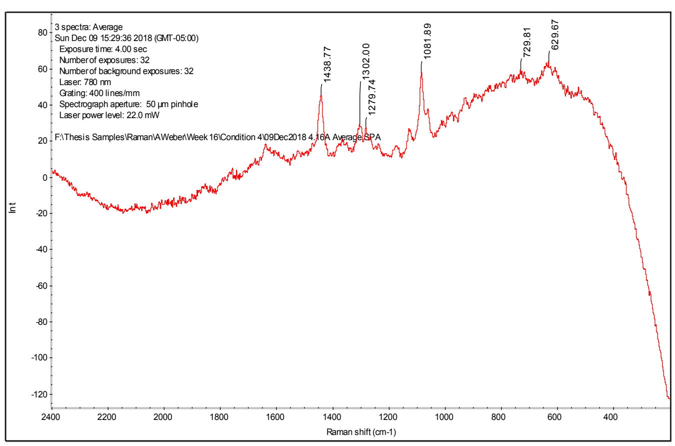

Figure 143: Raman Average Spectrum of Nylon - Week 16 in Chicken Manure

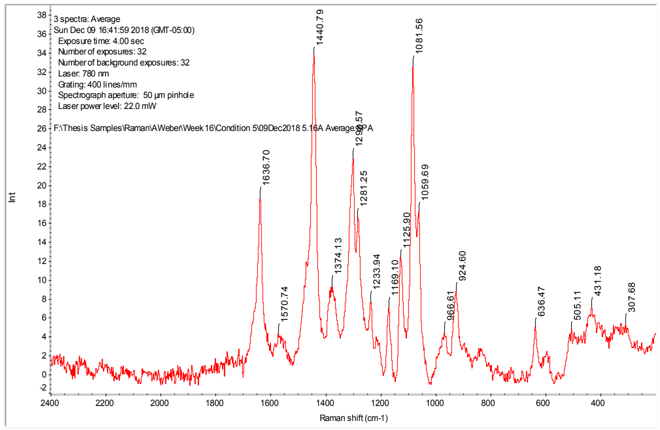

Figure 144: Raman Average Spectrum of Nylon - Week 16 in Soil and Cow Manure

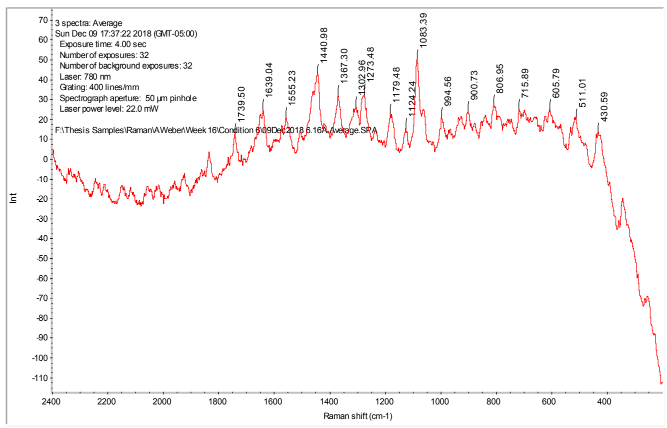

Figure 145: Raman Average Spectrum of Nylon - Week 16 in Cow Manure

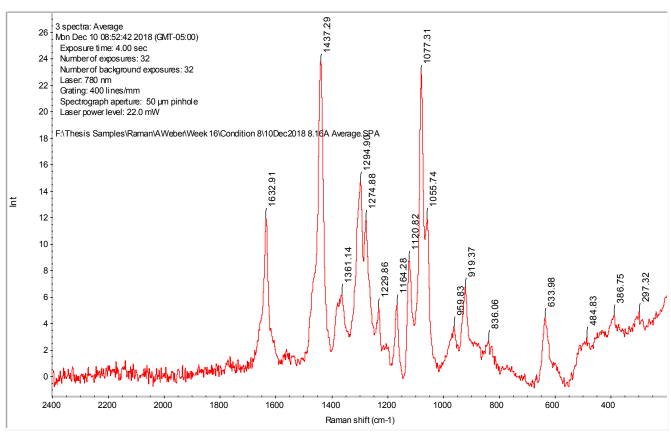

Figure 146: Raman Average Spectrum of Nylon - Week 16 in Oil

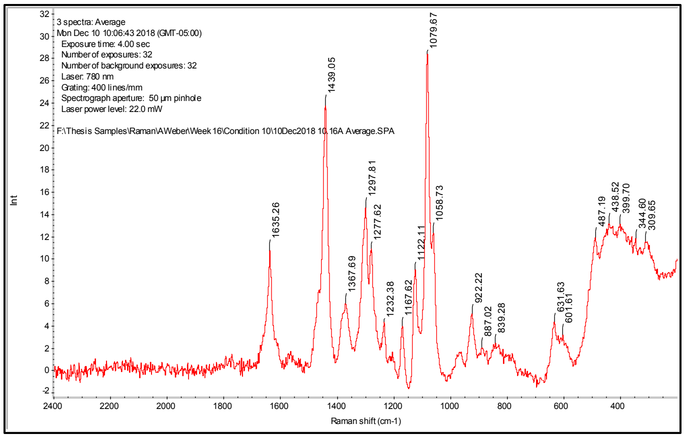

Figure 147: Raman Average Spectrum of Nylon - Week 16 in Salt Pretreatment and Water

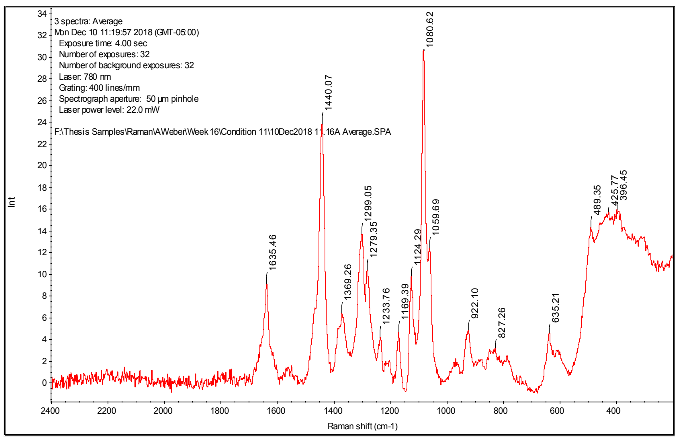

Figure 148: Raman Average Spectrum of Nylon - Week 16 in Calcium Chloride Pretreatment and Water

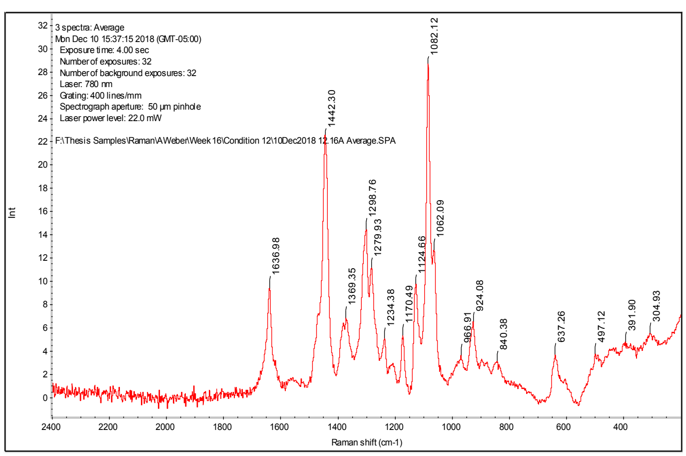

Figure 149: Raman Average Spectrum of Nylon - Week 16 in Calcium Chloride Pretreatment

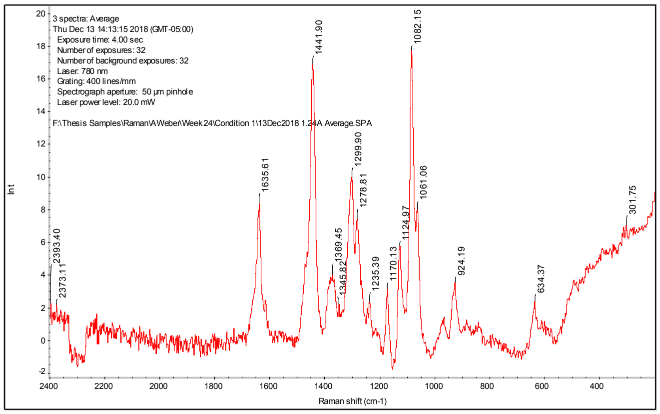

Figure 150: Raman Average Spectrum of Nylon - Week 24 in Sand

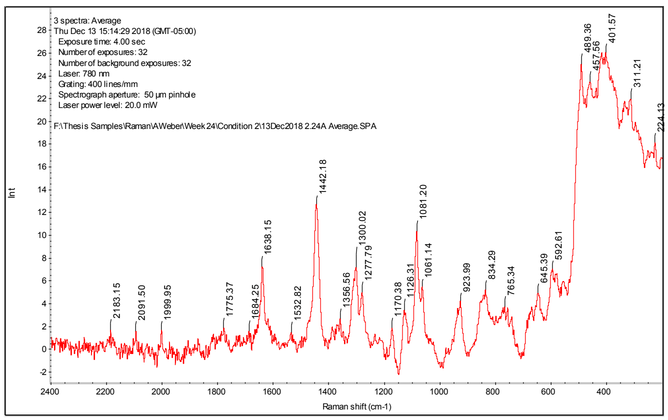

Figure 151: Raman Average Spectrum of Nylon - Week 24 in Soil

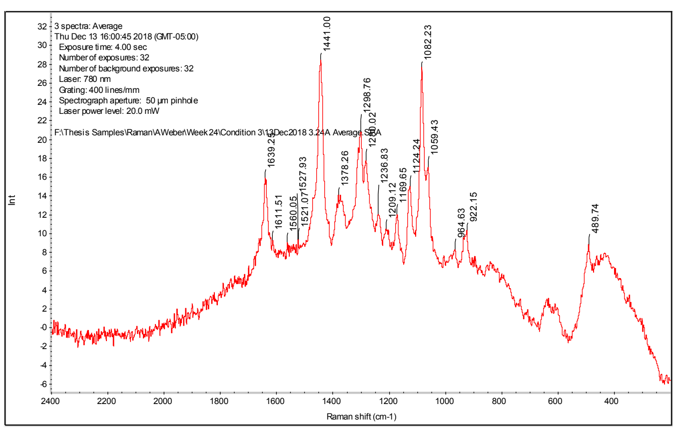

Figure 152: Raman Average Spectrum of Nylon - Week 24 in Soil and Chicken Manure

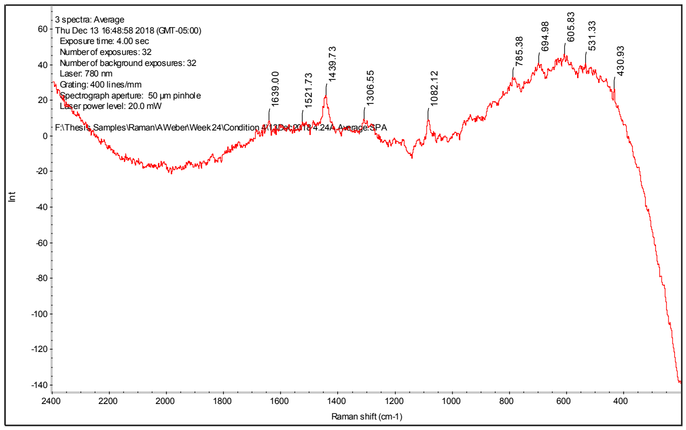

Figure 153: Raman Average Spectrum of Nylon - Week 24 in Chicken Manure

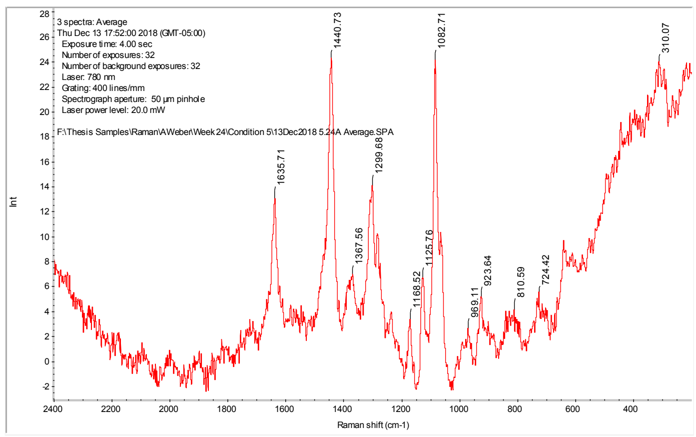

Figure 154: Raman Average Spectrum of Nylon - Week 24 in Soil and Cow Manure

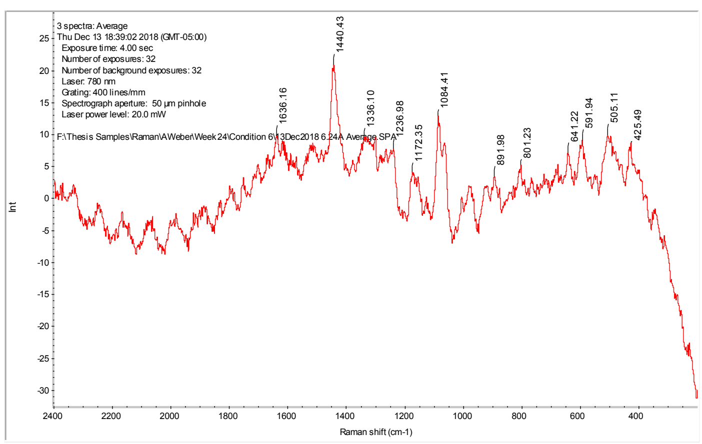

Figure 155: Raman Average Spectrum of Nylon - Week 24 in Cow Manure

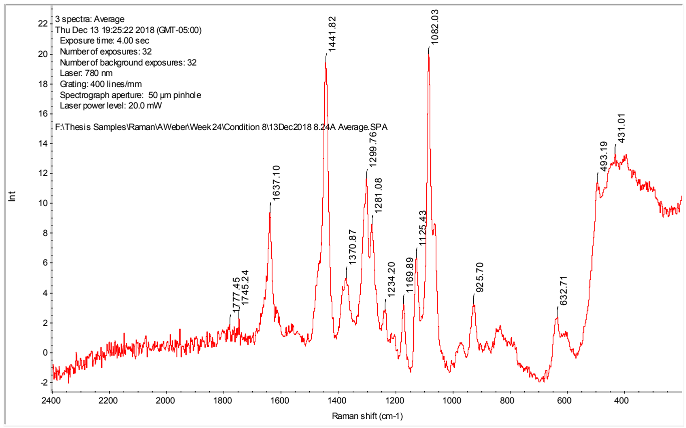

Figure 156: Raman Average Spectrum of Nylon - Week 24 in Oil

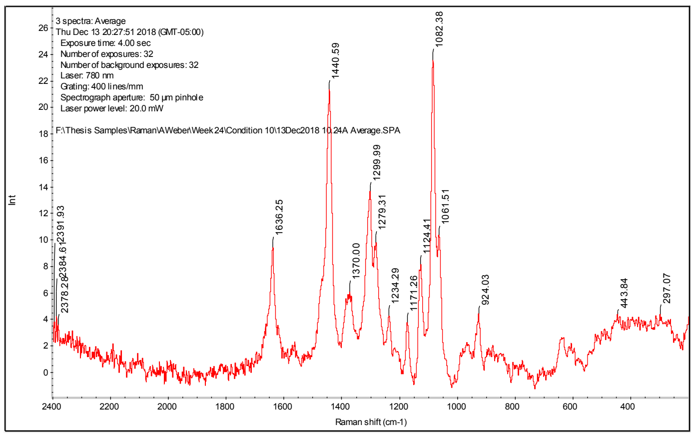

Figure 157: Raman Average Spectrum of Nylon - Week 24 in Salt Pretreatment and Water

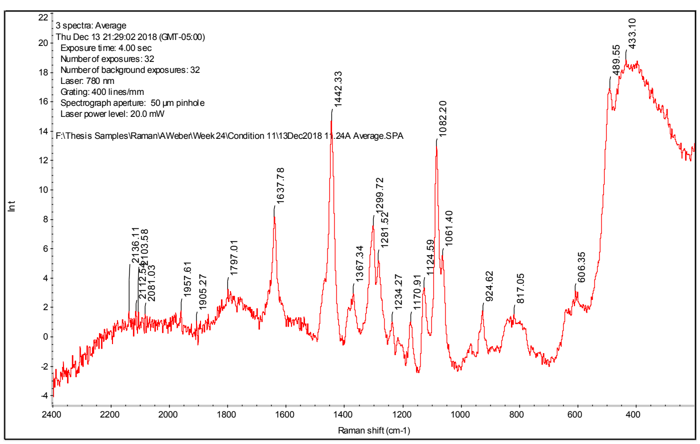

Figure 158: Raman Average Spectrum of Nylon - Week 24 in Calcium Chloride Pretreatment and Water

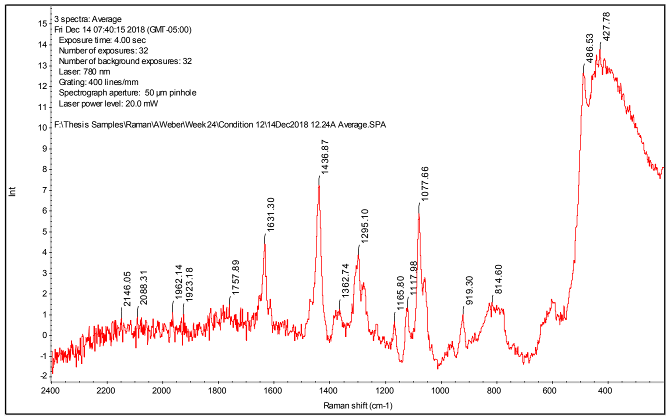

Figure 159: Raman Average Spectrum of Nylon - Week 24 in Calcium Chloride Pretreatment

APPENDIX K: TABLES OF RAMAN DATA OF NYLON

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1635.21	1635.59	1635.37	1635.98	1633.93	1636.1	1636.4	1637.88	1635.82	1636.72	1635.99	1635.68	1635.61
1438.99	1440.29	1442.2	1440.45	1438.5	1441.92	1440.73	1442.87	1440.26	1440.96	1441.05	1441.02	1441.9
1296.51	1299.07	1300.68	1299.51	1295.28	1299.01	1298.52	1299.5	1297.38	1300.87	1300.11	1299.48	1299
1278.63	1278.58	1279.94	1278.27	1278.07	1280.24	1278.37	1280.71	1279.54	1281.77	1280.59	1280.77	1278.81
1122.64	1124.85	1122.85	1122.83	1118.74	1124.63	1124.36	1124.81	1124.06	1126.64	1125.85	1125.98	1124.97
1080.04	1081.03	1081	1079.55	1078.04	1081.95	1081.76	1082.42	1080.64	1082.54	1082	1082.18	1082.15
922.34	924.41	922.87	922.05	920.29	924.18	923.89	**	922.78	925.99	925.52	921.74	924.19

Table 43: Raman Data of Nylon in Sand

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1635.21	1635.55	1632.46	1631.71	1637.04	1636.61	1639.07	1633.74	1635.88	1637.65	1635.95	1636.8	1638.15
1438.99	1441.07	1437.48	1435.99	1440.8	1141.81	1441.49	1438.18	1441.05	1442.64	1441.76	1440.89	1442.18
1296.51	1298.92	1295.89	1294.19	1298.67	1298.91	1299.5	1294.65	1297.04	1300.68	1298.5	1298.33	1300.02
1278.63	1279.58	1276.47	1276.45	1278.26	1279.6	1280.34	1277.11	1280.03	1281.96	1280.6	1280.76	1277.79
1122.64	1124.99	1121.88	1118.33	1124.54	1124.61	1124.9	1121.49	1124.63	1126.26	1124.54	1124.81	1126.31
1080.04	1081.63	1078.32	1075.99	1080.3	1081.52	1081.99	1078.25	1081.11	1082.96	1081.92	1081.69	1081.2

Table 44: Raman Data of Nylon in Soil

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1635.21	1636.74	1634.87	1634.24	1636.11	1635.81	1637.03	1634.3	1635.95	1639.98	1636.93	1636.69	1639.25
1438.99	1442.33	1440.83	1438.31	1439.67	1441	1441.02	1439.5	1441.42	1441.92	1442.52	1441.32	1441
1296.51	1301.08	1298.26	1295.24	1299.31	1298.94	1298.97	1296.84	1299.5	1300.9	1298.52	1297.8	1298.76
1278.63	1280.72	1278.37	1278.22	1279.12	1279.78	1280.85	1278.44	1279.28	1279.98	1282.01	1279.6	1280.02
1122.64	1126.38	1123.48	1123.32	1124.39	1123.89	1125.13	1124.17	1125.11	1126.73	1124.45	1125.45	1124.24
1080.04	1082.64	1080.49	1078.61	1080.68	1080.69	1082.56	1079.53	1081.67	1082.86	1082.53	1082.27	1082.23
922.34	927.17	922.09	920.74	922.38	922.27	924.61	924.54	922.24		924.03	928.23	922.15

Table 45: Raman Data of Nylon in Soil and Chicken Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1635.21	**	1632.92	1636.16	1636.84	1634.52	1637.72	**	**	1639.19	1635.65	**	**
1438.99	1439.79	1435.19	1439.77	1441.29	1441.04	1442.07	1440.81	1438.77	1443.55	**	**	1439.73
1296.51		1296.3	1297.38	1299.32	1299.5	1300.74	1298.74		**	**	**	**
1278.63			1278.2	1280.38			1279.72	1279.74	**	**	**	**
1122.64	1125.6	1122.43	1122.89	1126.97	1124.57	1123.96		**	**		**	**
1080.04	1080.24	1076.94	1080.25	1080.17	1082.63	1013.61	1080.35	1081.89	**	**	**	**
922.34	**		921.83	**		922.14	920.35		**		**	**

Table 46: Raman Data of Nylon in Chicken Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1635.21	1637.48	1633.86	1634.34	1635.09	1635.81	1633.74	1636.2	1636.7	1638.63	1639.29	1635.26	1635.26
1438.99	1442.92	1440.23	1439.89	1440.77	1441.49	1438.54	1439.62	1440.79	1443.5	1441.74	1438.12	1440.73
1296.51	1302.17	1296.64	1298.77	1296.98	1298.82	1294.31	1299.51	1298.57	1300.88	1300.55	1296.08	1299.51
1278.63	1284.14	1276.92	1278.86		1278.74	1278.19		1281.25	1283.72	1281.68	1276.75	**
1122.64	1126.09	1123.38	1124.33	1122.89	1124.27	1120.59	1126.37	1125.9	1130.04	1124.31	**	1125.6
1080.04	1084.01	1079.1	1080.67	1080.7	1080.62	1079.57	1081.43	1081.56	1083.72	1082.44	1077.78	1082.71
922.34	925.46	920.13	924.15	921.42	922.79	920.25	924.32	924.6	923.88	923.86		923.64

Table 47: Raman Data of Nylon in Soil and Cow Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1635.21	1640.28	1635.43	1633.11	1637.64	1637.69		1637.37	1639.04	**	1633.65	1634.16	**
1438.99	1443.87	1441.06	1440.19	1439.76	1441.47	1439.79	1442.29	1440.98	**	1438.67	1438.27	1440.43
1296.51	1301.18	1299.5		1299.29	1296.46		1299.4		**	1295.28	1297.97	**
1278.63		1277.5	1278.6		1275.76		1280.55	1273.48	**	**	**	**
1122.64	1128.48	1126.32	1124.56	1124.49	1122.9		1125.11	1124.24	**	1120.62	1119.93	**
1080.04	1082.97	1080.43	1080.16	1080.86	1078.82		1082.81	1083.39	**	1077.46	1078.49	**
922.34	917.24	922.02		920.2			922.49		**		**	**

Table 48: Raman Data of Nylon in Cow Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1635.21	1639.59	1635.9	1636.16	1635.43	1637.21	1637.34	1637.57	1632.91	1634.36	1633.17	1634.97	1637.1
1438.99	1444.72	1440.9	1441.08	1437.65	1440.81	1441.29	1441.49	1437.29	1437.99	1439.34	1438.82	1441.82
1296.51	1301.59	1298.25	1298.8	1294.96	1297.41	1299.24	1299.5	1294.9	1296.8	1296.26	1296.35	1299.46
1278.63	1283.09	1280.23	1279.12	1276.02	1278.93	1280.53	1281.65	1274.88	1277.68	1277.86	1278.11	1281.08
1122.64	1127.62	1124.57	1123.26	1122.1	1123.43	1124.65	1125.01	1120.82	1123.39	1120.34	1125.34	1125.48
1080.04	1084.7	1081.01	1080.5	1078.25	1080.84	1082.01	1082.13	1077.31	1080	1078.68	1080.02	1082.03
922.34	925.92	924.26	923.26	920.25	923.24	924.15	925.49	919.37	921.06	922.66	923.93	925.34

Table 49: Raman Data of Nylon in Oil

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1635.21	1638.5	1634.36	1636.08	1635.4	1637.3	1637.45	1636.22	1635.26	1637.07	1636.17	1635.19	1636.25
1438.99	1443.42	1440.48	1440.62	1439.58	1440.18	1441.27	1441.62	1439.05	1440.31	1439.38	1440.08	1440.59
1296.51	1302.9	1298.47	1298.46	1297.11	1298.11	1300.2	1299.16	1297.81	1297.65	1298.78	1298.8	1299.99
1278.63	1283.7	1279.58	1278.5	1277.85	1279.2	1280.38	1280.08	1277.62	1279.04	1277.89	1278.63	1279.31
1122.64	1128.28	1124.46	1123.13	1123.82	1124.43	1125.02	1126.4	1122.11	1122.98	1123.75	1126.02	1124.41
1080.04	1084.93	1081.05	1080.83	1080.05	1080.9	1082.23	1082.05	1079.67	1080.32	1080.48	1081.72	1082.38
922.34	928.28	923.9	922.12	924	922.17	922.54	923.86	922.22	923.1	923.99	923.64	924.03

Table 50: Raman Data of Nylon in Salt Pretreatment and Water

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1635.21	1635.87	1631.95	1634.55	1635.97	1633.18	1637.83	1631.88	1635.46	1637.01	1636.66	1636.82	1637.78
1438.99	1440.71	1437.29	1438.91	1440.33	1437.69	1441.79	1437.72	1440.07	1442.26	1440.8	1440.82	1442.33
1296.51	1298.46	1295.74	1296.82	1297.61	1295.29	1300	1295.75	1299.05	1299.32	1298.02	1298.13	1299.72
1278.63	1277.74	1274.56	1277.24	1279.55	1276.4	1279.36	1275.68	1279.35	1279.46	1280.48	1279.01	1281
1122.64	1123.9	1121.71	1121.63	1123.59	1121.24	1124.97	1120.99	1124.29	1124.45	1124.19	1124.72	1124.59
1080.04	1080.98	1077.91	1078.97	1080.5	1078.45	1082.14	1077.21	1080.62	1080.85	1081.51	1081.41	1082.2
922.34	923.71	919.97	921.35	924.1	920.57	924.23	917.26	922.1	923.28	923.33	925.53	924.62

Table 51: Raman Data of Nylon in Calcium Chloride Pretreatment and Water

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1635.21	1635.05	1635.82	1636.05	1636.83	1635.03	1636.05	1634.04	1636.98	1637.03	1637.36	1635.44	1631.3
1438.99	1441.36	1440.12	1440.3	1441.56	1439.91	1441.44	1439.11	1442.3	1441.3	1441.15	1441.5	1436.87
1296.51	1297.37	1298.1	1297.51	1300.04	1296.71	1299.26	1297.75	1298.76	1298.46	1298.24	1298.1	1295.1
1278.63	1278.67	1278.87	1279.51	1279.75	1278.8	1280.78	1277.42	1279.93	1279.48	1278.45	1279.45	
1122.64	1124.72	1124.37	1123.42	1124.84	1123.9	1125.01	1123.16	1124.66	1125.65	1122.61	1124.5	1117.98
1080.04	1080.8	1080.45	1080.89	1081.62	1080.19	1082.25	1079.33	1082.12	1081.67	1081.85	1081.735	1077.66
922.34	922.95	921.93	922.36	922.36	920.88	925.97	921.85	924.08	923.94	926.05		919.36

Table 52: Raman Data of Nylon in Calcium Chloride Pretreatment

APPENDIX L: RAMAN SPECTRA OF ACRYLIC

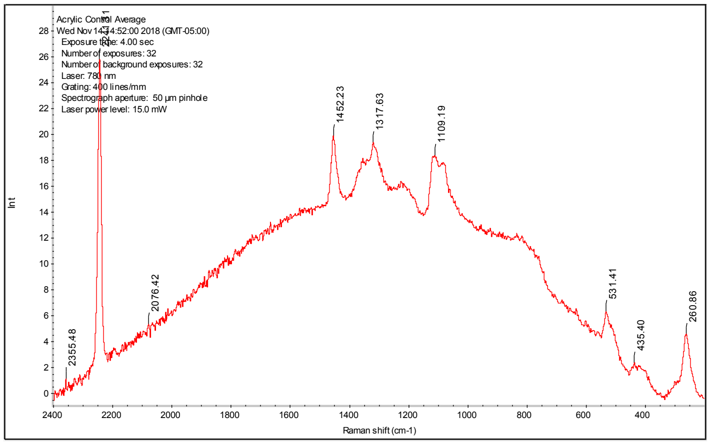

Figure 160: Raman Average Spectrum of Control Acrylic

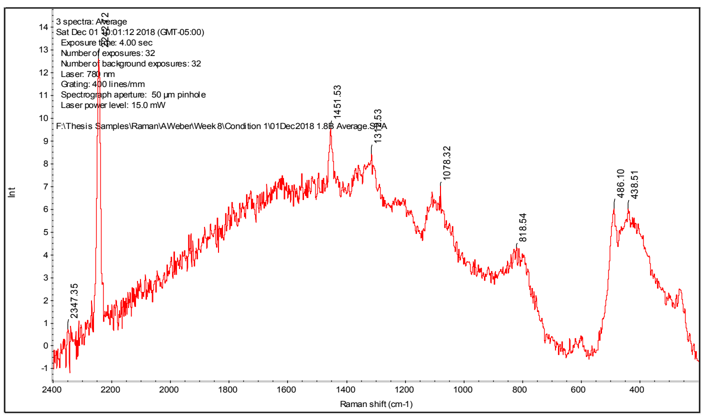

Figure 161: Raman Average Spectrum of Acrylic - Week 8 in Sand

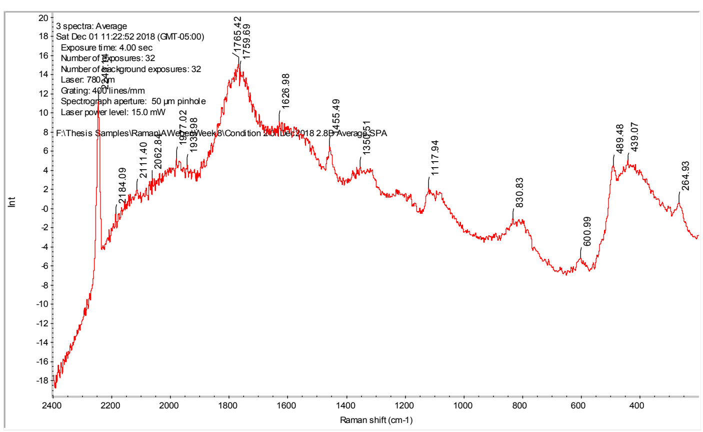

Figure 162: Raman Average Spectrum of Acrylic - Week 8 in Soil

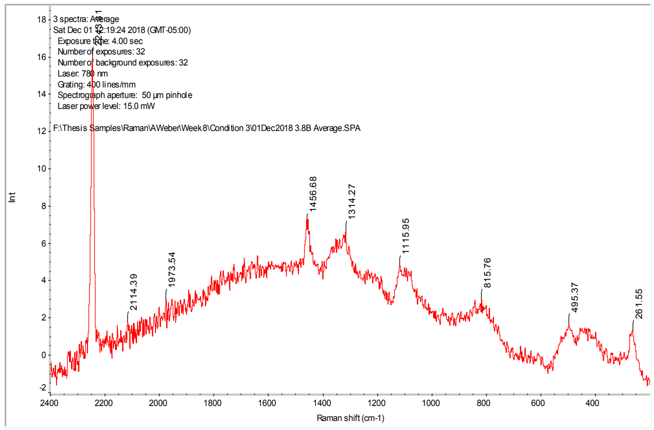

Figure 163: Raman Average Spectrum of Acrylic - Week 8 in Soil and Chicken Manure

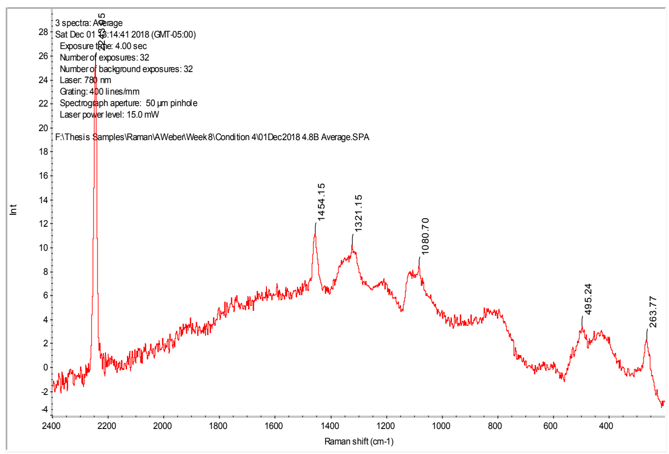

Figure 164: Raman Average Spectrum of Acrylic - Week 8 in Chicken Manure

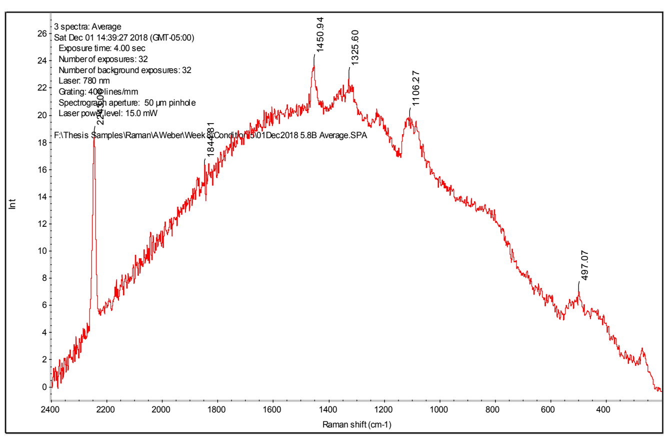

Figure 165: Raman Average Spectrum of Acrylic - Week 8 in Soil and Cow Manure

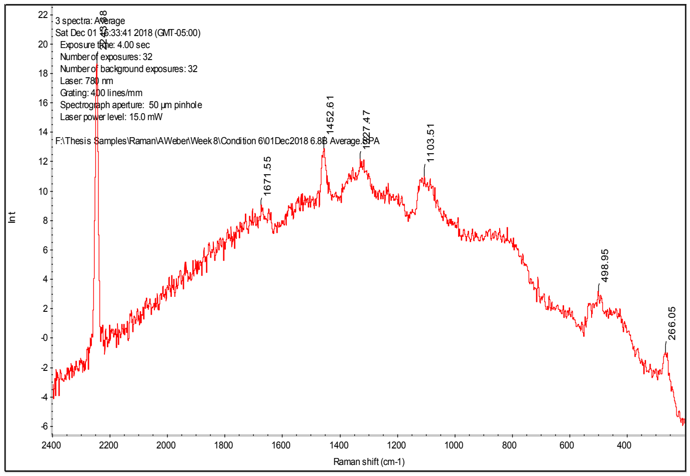

Figure 166: Raman Average Spectrum of Acrylic - Week 8 in Cow Manure

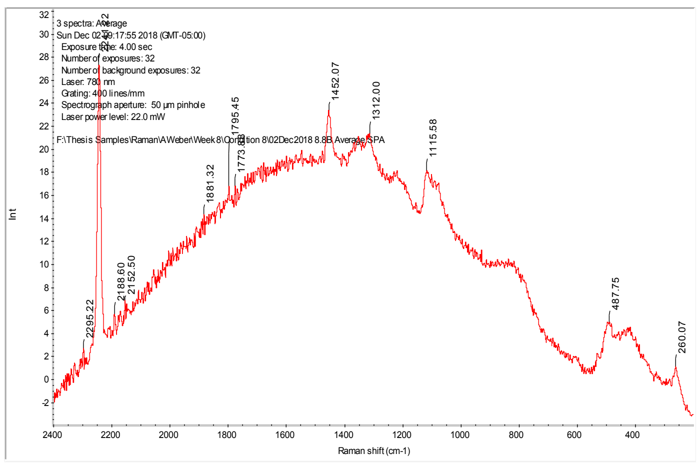

Figure 167: Raman Average Spectrum of Acrylic - Week 8 in Oil

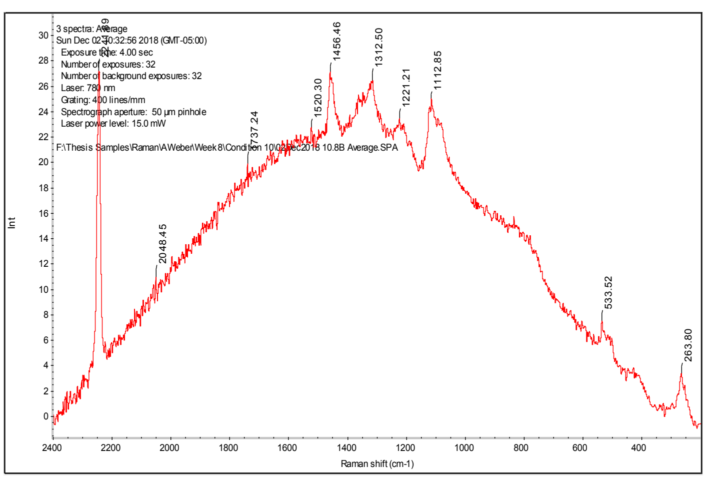

Figure 168: Raman Average Spectrum of Acrylic - Week 8 in Salt Pretreatment and Water

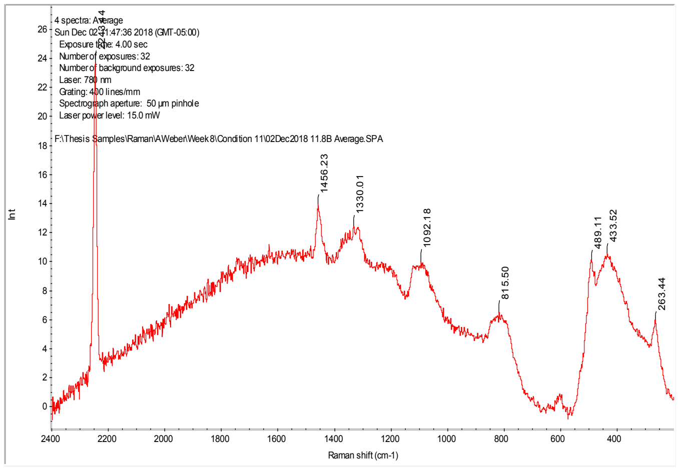

Figure 169: Raman Average Spectrum of Acrylic - Week 8 in Calcium Chloride Pretreatment and Water

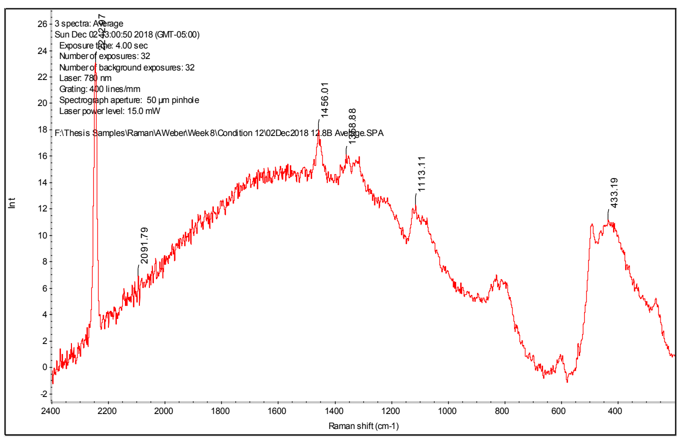

Figure 170: Raman Average Spectrum of Acrylic - Week 8 in Calcium Chloride Pretreatment

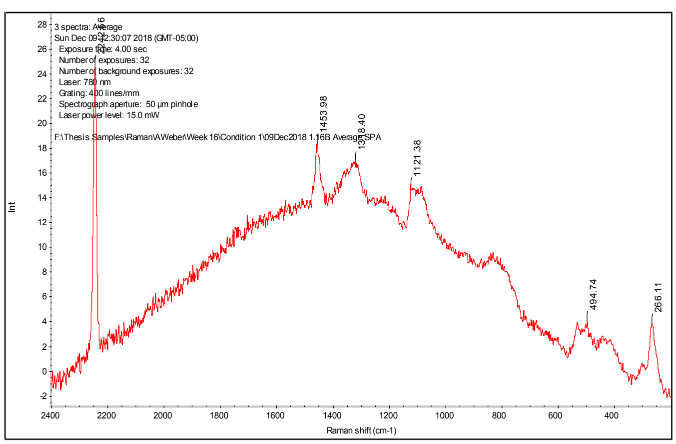

Figure 171: Raman Average Spectrum of Acrylic - Week 16 in Sand

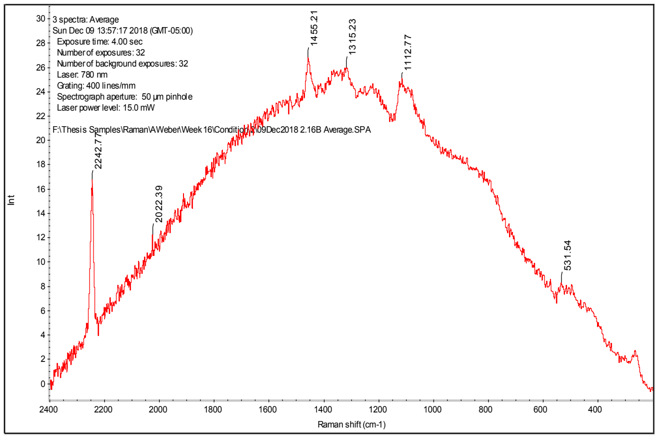

Figure 172: Raman Average Spectrum of Acrylic - Week 16 in Soil

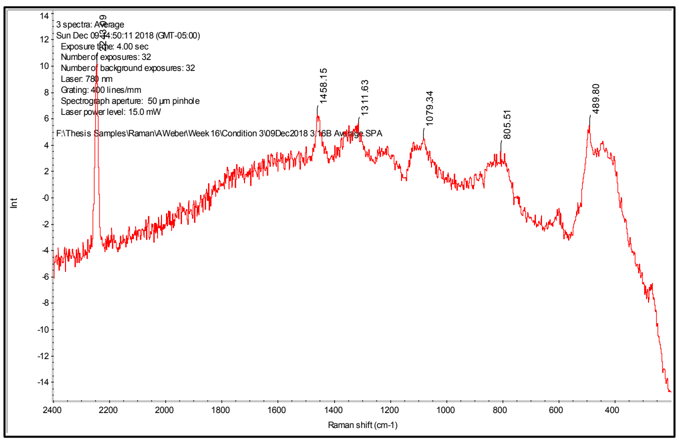

Figure 173: Raman Average Spectrum of Acrylic - Week 16 in Soil and Chicken Manure

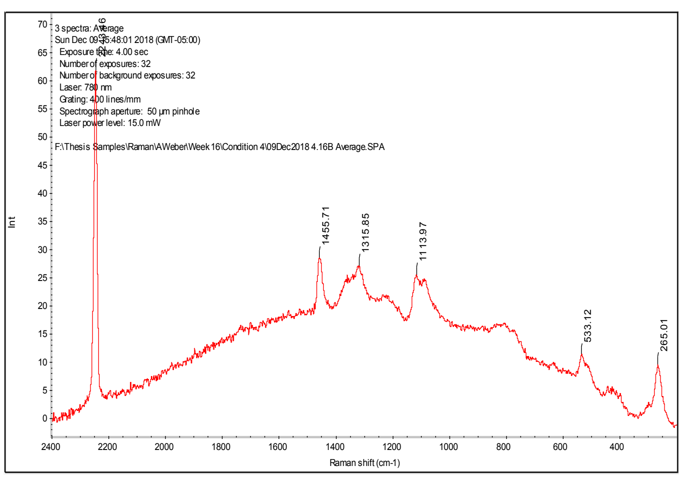

Figure 174: Raman Average Spectrum of Acrylic - Week 16 in Chicken Manure

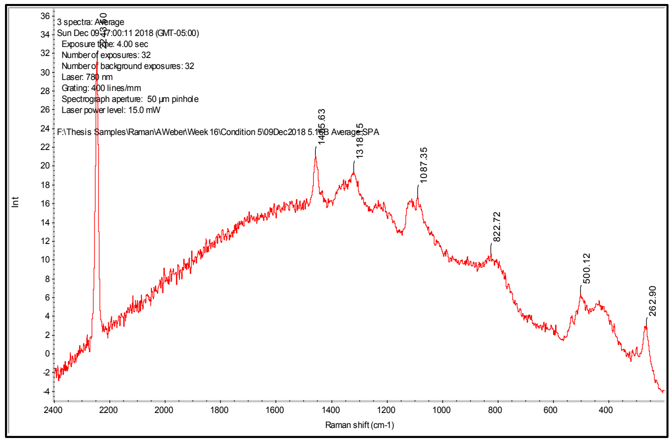

Figure 175: Raman Average Spectrum of Acrylic - Week 16 in Soil and Cow Manure

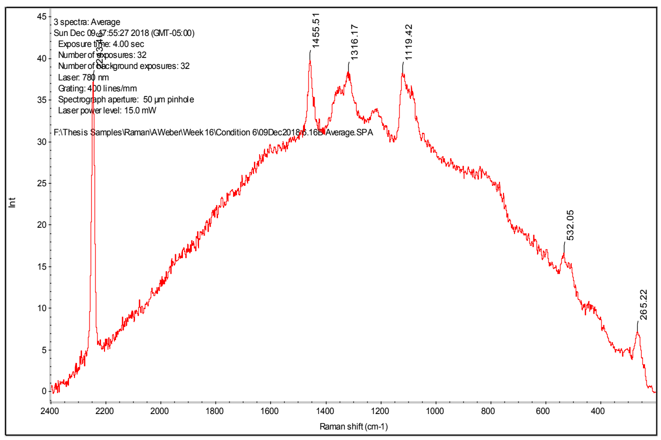

Figure 176: Raman Average Spectrum of Acrylic - Week 16 in Cow Manure

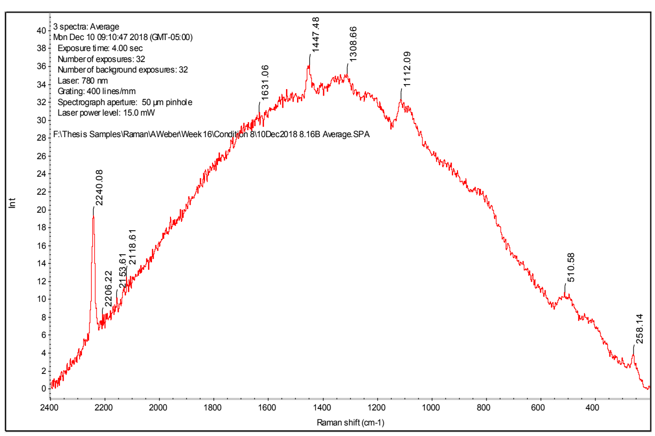

Figure 177: Raman Average Spectrum of Acrylic - Week 16 in Oil

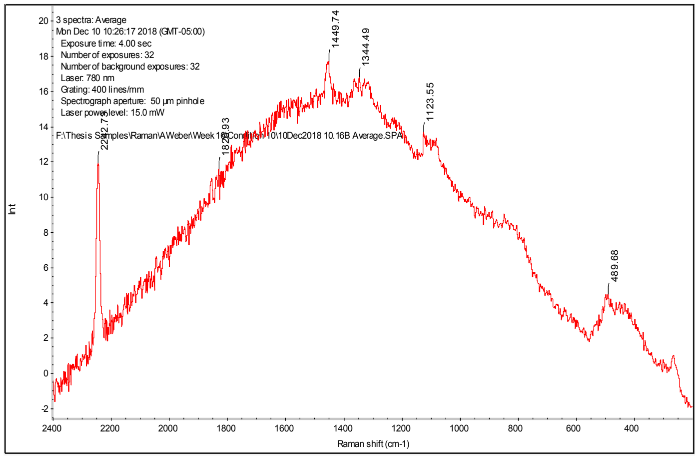

Figure 178: Raman Average Spectrum of Acrylic - Week 16 in Salt Pretreatment and Water

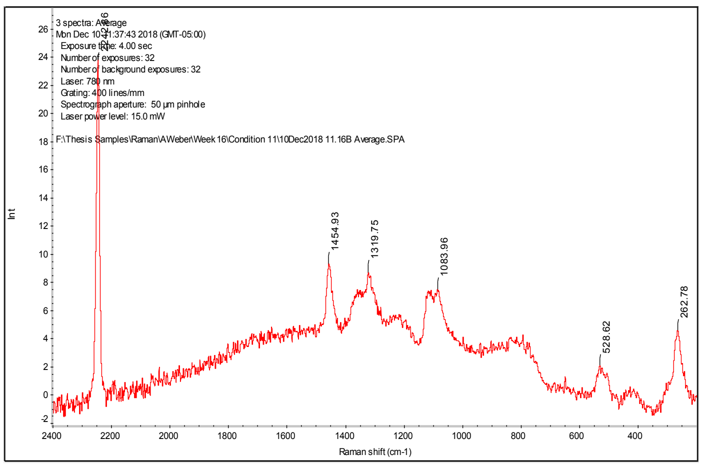

Figure 179: Raman Average Spectrum of Acrylic - Week 16 in Calcium Chloride Pretreatment and Water

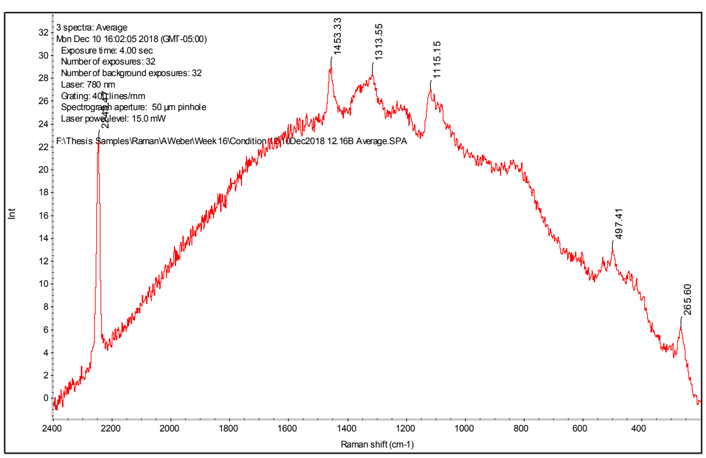

Figure 180: Raman Average Spectrum of Acrylic - Week 16 in Calcium Chloride Pretreatment

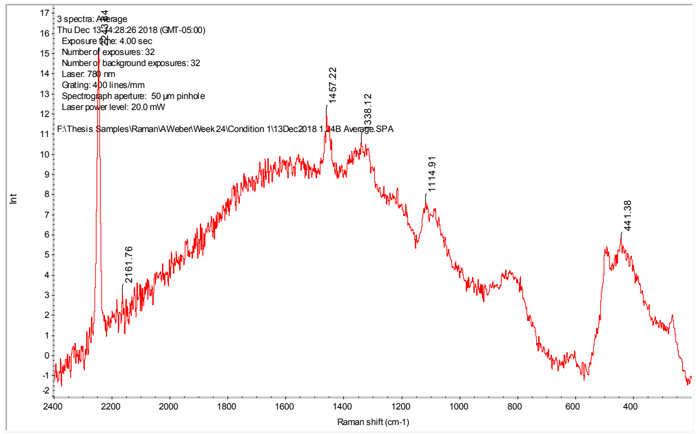

Figure 181: Raman Average Spectrum of Acrylic - Week 24 in Sand

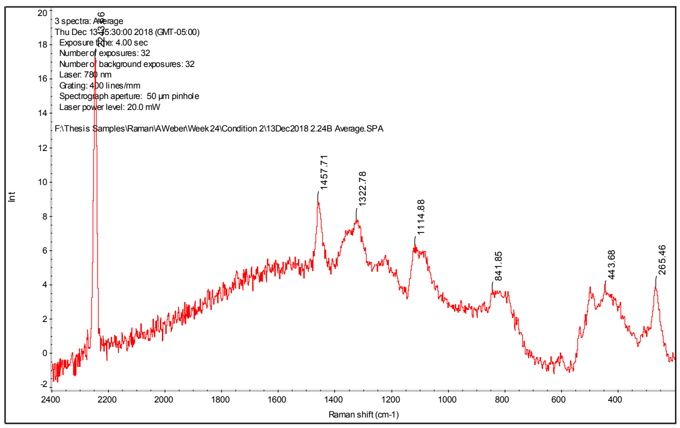

Figure 182: Raman Average Spectrum of Acrylic - Week 24 in Soil

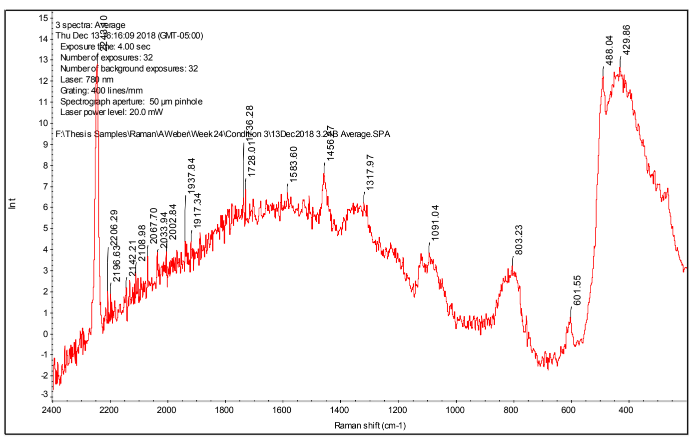

Figure 183: Raman Average Spectrum of Acrylic - Week 24 in Soil and Chicken Manure

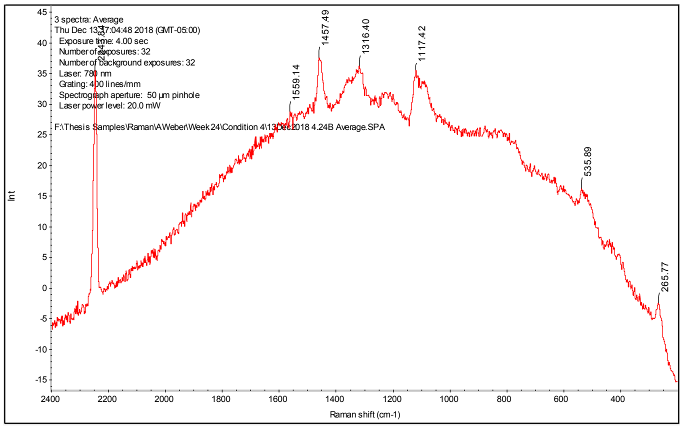

Figure 184: Raman Average Spectrum of Acrylic - Week 24 in Chicken Manure

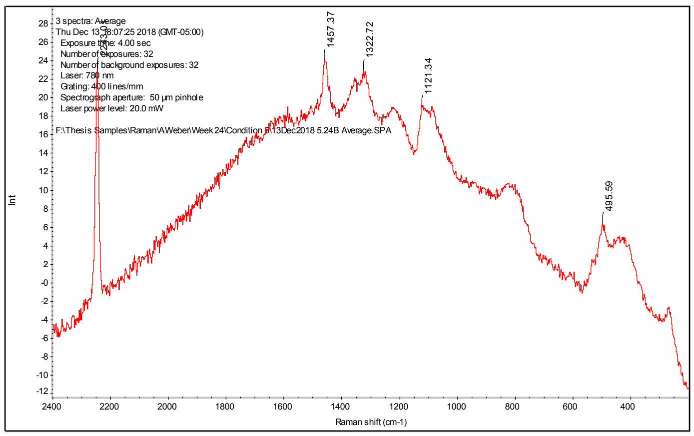

Figure 185: Raman Average Spectrum of Acrylic - Week 24 in Soil and Cow Manure

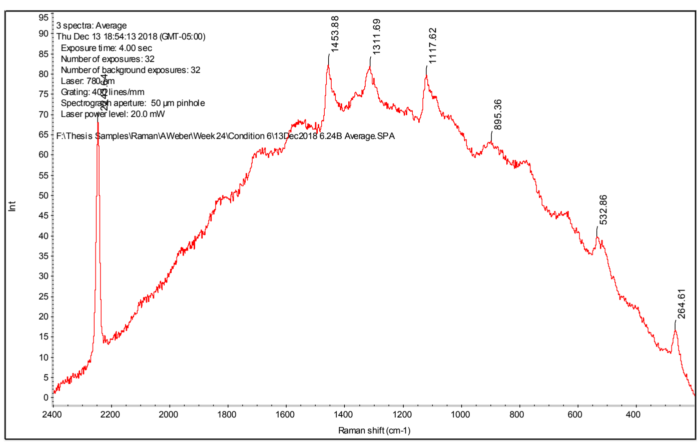

Figure 186: Raman Average Spectrum of Acrylic - Week 24 in Cow Manure

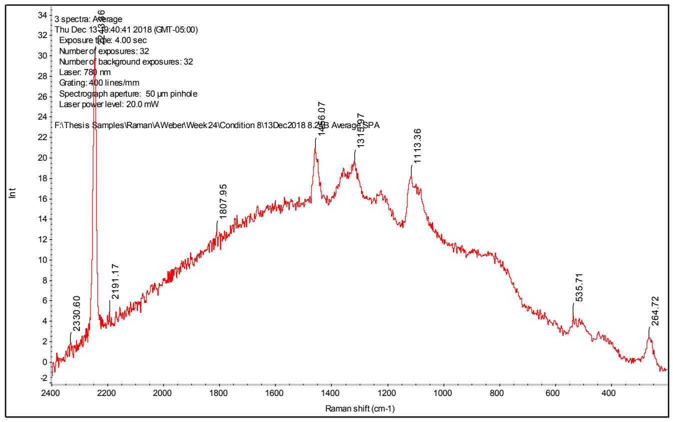

Figure 187: Raman Average Spectrum of Acrylic - Week 24 in Oil

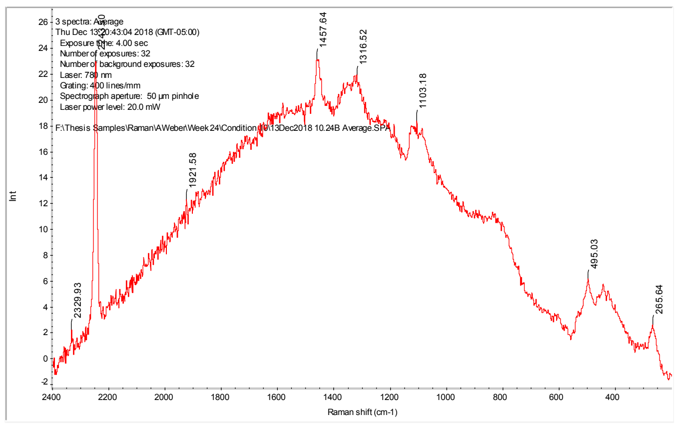

Figure 188: Raman Average Spectrum of Acrylic - Week 24 in Salt Pretreatment and Water

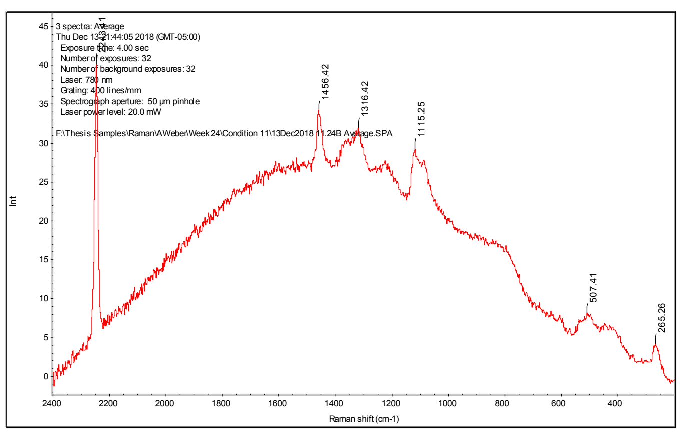

Figure 189: Raman Average Spectrum of Acrylic - Week 24 in Calcium Chloride Pretreatment and Water

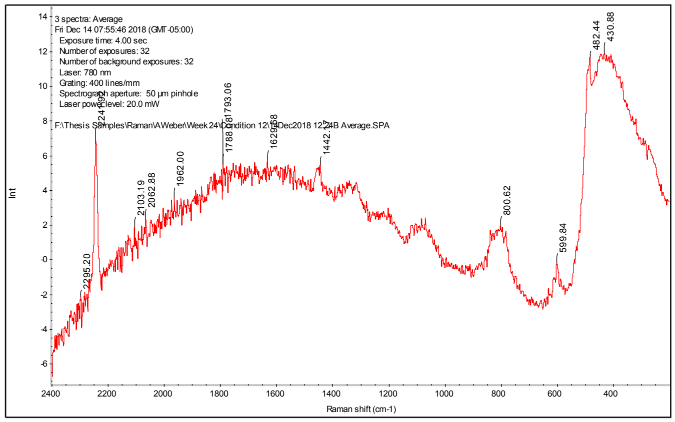

Figure 190: Raman Average Spectrum of Acrylic - Week 24 in Calcium Chloride Pretreatment

APPENDIX M: TABLES OF RAMAN DATA OF ACRYLIC

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2241.31	2243.05	2243.23	2242.75	2242.72	2243.46	2242.51	2244	2242.56	2244.87	2242.18	2243.27	2243.14
1452.23	1455.28	1455.89	1453.91	**	**	1452.03	1454.76	1453.98	1455.99	**	1455.11	**
1317.63	1315.1	**	**	**	**	**	**	**	**	**	**	**
1109.19	1114.46					**	**		**	**	**	
531.41	530.12						**		**		**	
260.86	263.4					**	263.66	266.11	264.87	263.66	262.64	

Table 53: Raman Data of Acrylic in Sand

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2241.31	2243.79	2241.34	2238.99	2242.14	2244.28	2244.04	2244	2242.77	2244.6	2244.3	2243.73	2243.56
1452.23	1455.89	1450.12	**	**	1457.61	1456.23	1452.21	**	1457.21	1457.14	1454.43	1457.71
1317.63	**		**	**	**	**	**	**	**	**	**	**
1109.19		**	**		**	**	**	**	**	**	**	**
531.41	**					**		**	**	**		
260.86	264.37	263.19		**	**	263.35	**		**	262.96	**	265.46

Table 54: Raman Data of Acrylic in Soil

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2241.31	2244.79	2242.99	2241.39	2243.31	2243.05	2244.15	2242.11	2243.09	2244.65	2243.57	2243.15	2243.1
1452.23	1455.96	1453.83	1452.86	**	**	1456.53	1451.72	**	1454.36	1452.06	**	**
1317.63	**	**	**	**		**	**	**	**	**	**	**
1109.19		**	**	**		**	**		**	**	**	
531.41	**		**						**	**		
260.86	265.14	263.94	**	**		**	**		**	**		

Table 55: Raman Data of Acrylic in Soil and Chicken Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2241.31	2243.78	2240.7	2242.24	2243.05	2244.26	2243.7	2242.48	2243.16	2246.84	2244.52	2243.53	2243.84
1452.23	1451.31	**	1454.32	1454.15	1454.89	**	1455.48	1455.71	**	1456.33	**	1457.49
1317.63	**	**	**	**	**	**	**	**	**	**	**	**
1109.19			**	**	**		**	**	**	**	**	**
531.41					**			**	**	**		**
260.86	266.78			263.7	**	**	**	**	**	**	**	**

Table 56: Raman Data of Acrylic in Chicken Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2241.31	2245.53	2243.23	2243.1	2243.38	2242.08	2242.16	2243.27	2243.46	2230.89	2240.22	2241.25	2243.64
1452.23	1456.62	1454.74	1453.15	1452.61	1454.1	1454.49	**	1455.51	**	1451.03	**	1453.88
1317.63	**	**	**	**	**	**	**	**	**	**	**	**
1109.19	**		**	**	**	**	**		**	**	**	**
531.41						**		**	**			**
260.86	270.4	261.04	**	**		**		**	**	259.13		**

Table 57: Raman Data of Acrylic in Soil and Cow Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2241.31	2245.17	2242.46	2242.39	2241.22	2243.27	2243.58	2243.22	2240.08	2241.66	2241.09	2242.59	2243.36
1452.23	1459.86	1453	1453.56	1452.07	1453.94	1456.35	1449.89	**	**	**	**	1456.07
1317.63	**	**	**	**	**	**	**	**	**	**	**	**
1109.19	**	**	**	**	**	**	**	**	**	**	**	**
531.41						**		**	**		**	**
260.86	267.85		260.97	**	**	**	265.32	**	**			**

Table 58: Raman Data of Acrylic in Cow Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2241.31	2245.17	2242.46	2242.39	2241.22	2243.27	2243.58	2243.22	2240.08	2241.66	2241.09	2242.59	2243.36
1452.23	1459.86	1453	1453.56	1452.07	1453.94	1456.35	1449.89	**	**	**	**	1456.07
1317.63	**	**	**	**	**	**	**	**	**	**	**	**
1109.19	**	**	**	**	**	**	**	**	**	**	**	**
531.41						**		**	**		**	**
260.86	267.85		260.97	**	**	**	265.32	**	**			**

Table 59: Raman Data of Acrylic in Oil

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2241.31	2245.58	2242.82	2239.17	2241.89	2243.12	2243.59	2242.67	2242.76	2242.5	2243.04	2243.37	2243.5
1452.23	1456.64	1456.37	**	1456.46	1456.27	**	1454.36	**	**	1455.1	**	**
1317.63	**	**	**	**	**	**	**	**	**	**	**	**
1109.19		**	**	**	**	**	**		**	**		**
531.41		**		**			**			**		
260.86	267.97	**		**	**	**	265.83	**	**	262.01		**

Table 60: Raman Data of Acrylic in Salt Pretreatment and Water

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2241.31	2242.45	2241.14	2241.33	2243.14	2241.13	2243.14	2240.31	2242.36	2243.06	2242.52	2243.52	2243.41
1452.23	1454.89	**	1456.32	1456.23	1454.14	1454.84	1448.29	1454.93	1454.2	1453.12	1457.82	1456.42
1317.63	**	**	**	**	**	**	**	1319.75	**	**	**	**
1109.19		**	**	**	**	**	**	**	**	**	**	**
531.41			**	**	**	**		**	**	**	**	**
260.86	263.26	**	260.48	**	**		259.37	262.78	267.42	261.79	**	**

Table 61: Raman Data of Acrylic in Calcium Chloride Pretreatment and Water

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
2241.31	2243.1	2242.42	2243.15	2242.07	2242.8	2244.66	2241.5	2243.47	2244	2243.87	2243.06	2241.92
1452.23	1451.94	1447.56	**	1456.01	1456.06	**	1451.53	1453.33	1456.39	**	1454.07	**
1317.63	**	**	**	**	**	**	**	**	**	**	**	**
1109.19	**	**	**	**	**	**	**	**	**	**	**	**
531.41		**	**						**			
260.86	267.55	**	**		262.69	**	**	**	**	**	**	

Table 62: Raman Data of Acrylic in Calcium Chloride Pretreatment

APPENDIX N: RAMAN SPECTRA OF RAYON

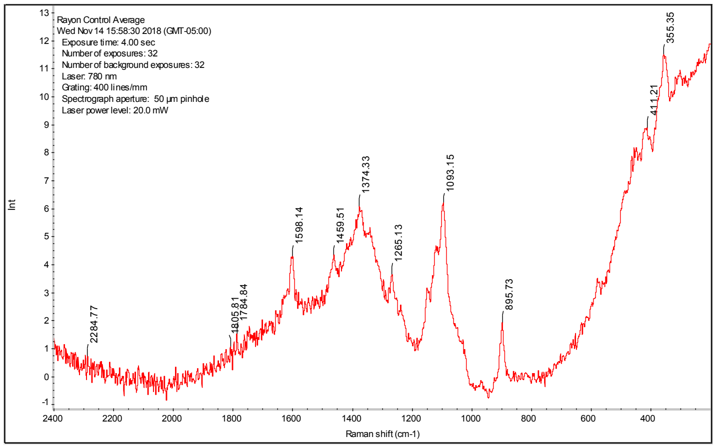

Figure 191: Raman Average Spectrum of Control Rayon

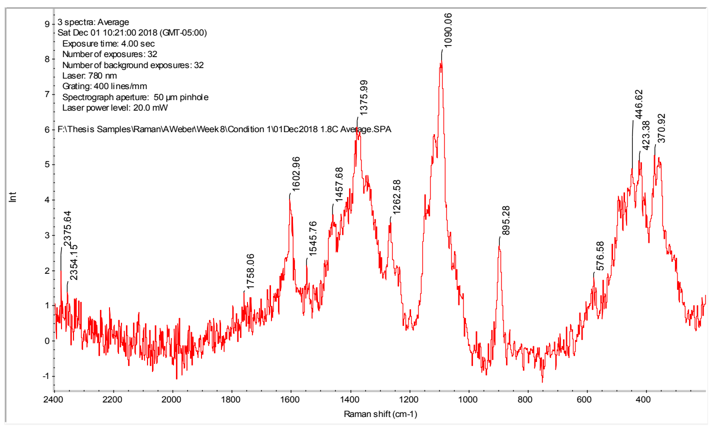

Figure 192: Raman Average Spectrum of Rayon - Week 8 in Sand

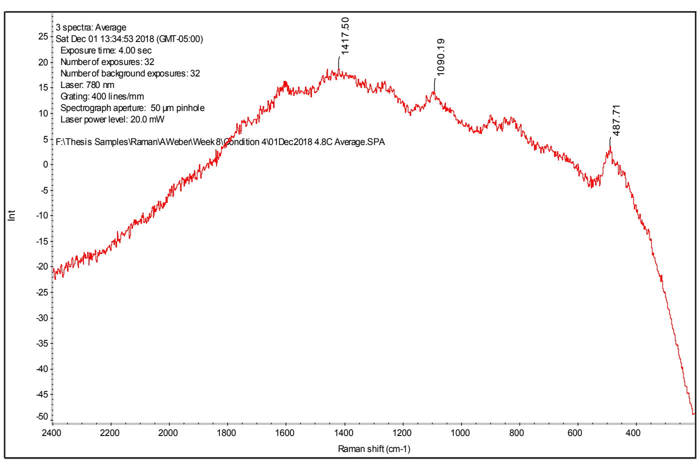

Figure 193: Raman Average Spectrum of Rayon - Week 8 in Chicken Manure

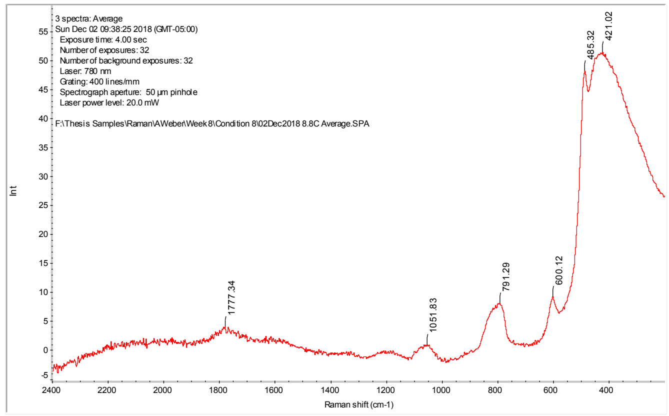

Figure 194: Raman Average Spectrum of Rayon - Week 8 in Oil

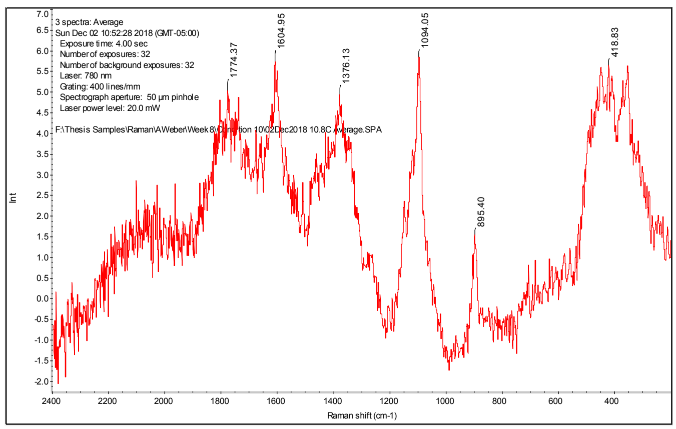

Figure 195: Raman Average Spectrum of Rayon - Week 8 in Salt Pretreatment and Water

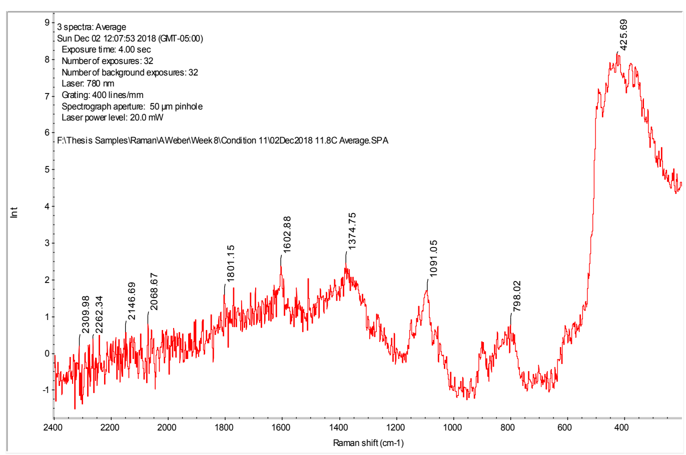

Figure 196: Raman Average Spectrum of Rayon - Week 8 in Calcium Chloride Pretreatment and Water

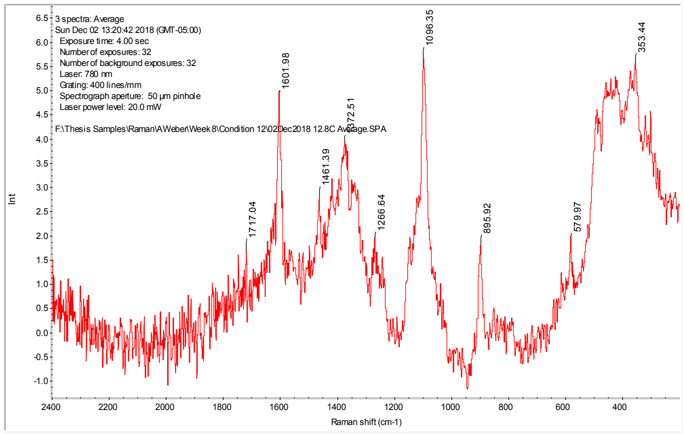

Figure 197: Raman Average Spectrum of Rayon - Week 8 in Calcium Chloride Pretreatment

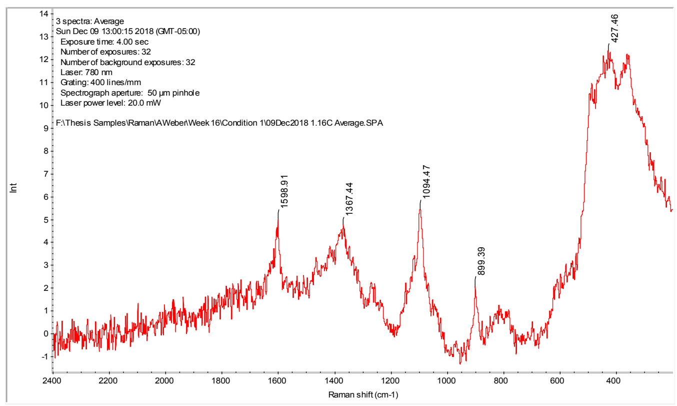

Figure 198: Raman Average Spectrum of Rayon - Week 16 in Sand

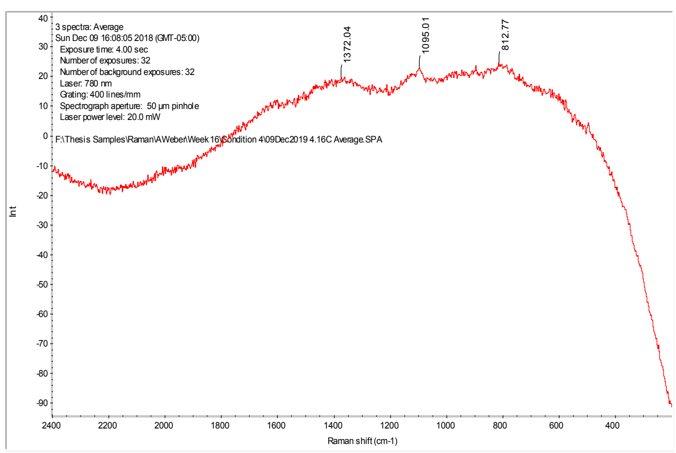

Figure 199: Raman Average Spectrum of Rayon - Week 16 in Chicken Manure

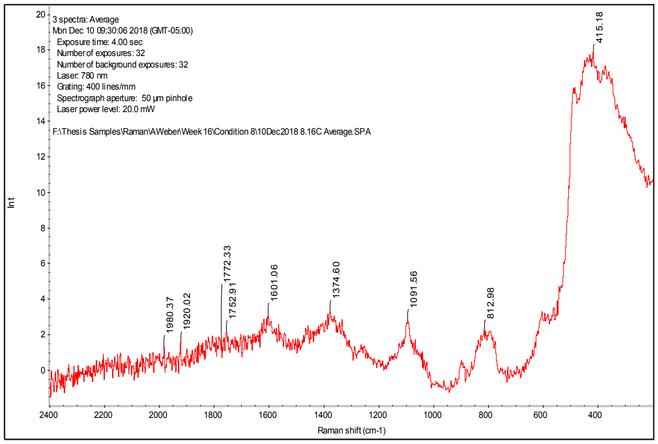

Figure 200: Raman Average Spectrum of Rayon - Week 16 in Oil

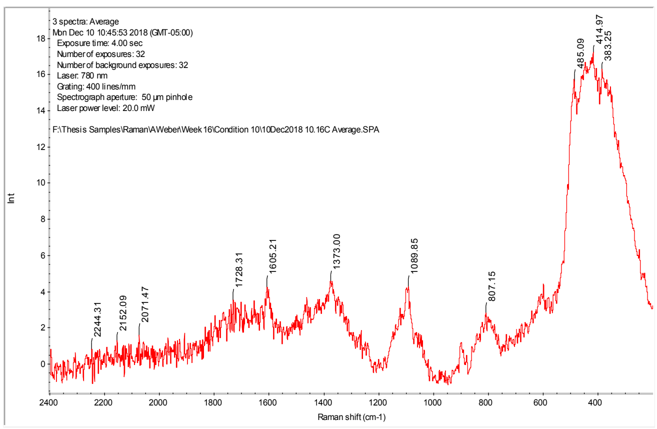

Figure 201: Raman Average Spectrum of Rayon - Week 16 in Salt Pretreatment and Water

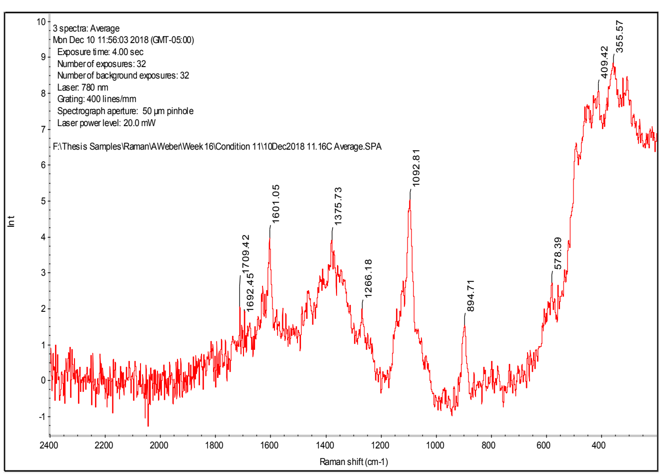

Figure 202: Raman Average Spectrum of Rayon - Week 16 in Calcium Chloride Pretreatment and Water

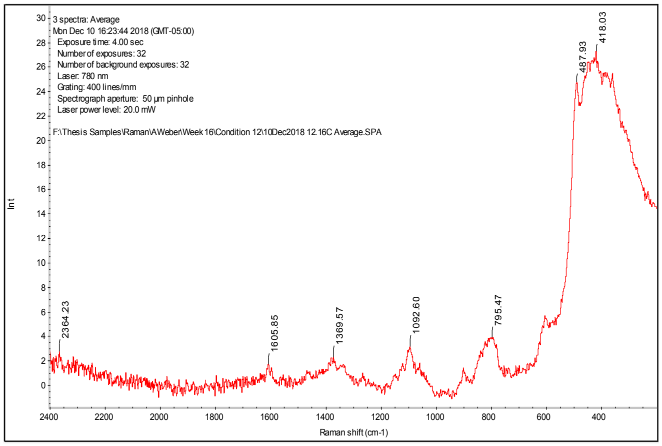

Figure 203: Raman Average Spectrum of Rayon - Week 16 in Calcium Chloride Pretreatment

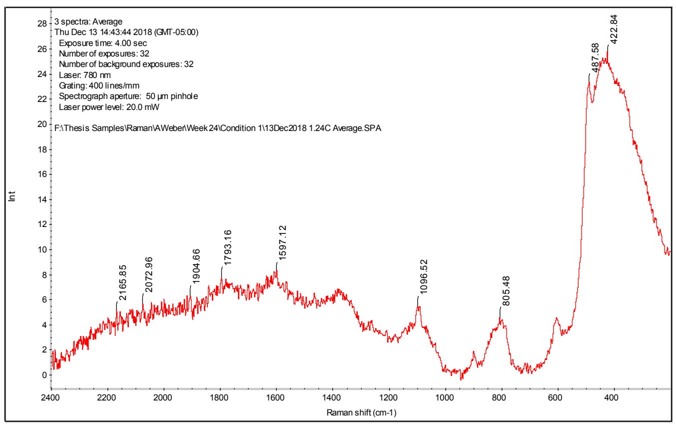

Figure 204: Raman Average Spectrum of Rayon - Week 24 in Sand

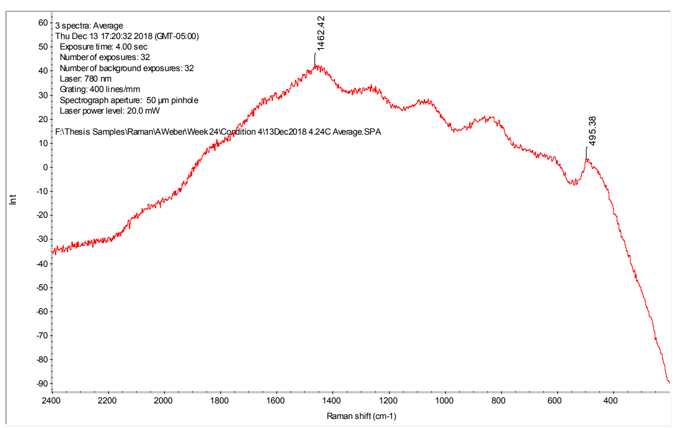

Figure 205: Raman Average Spectrum of Rayon - Week 24 in Chicken Manure

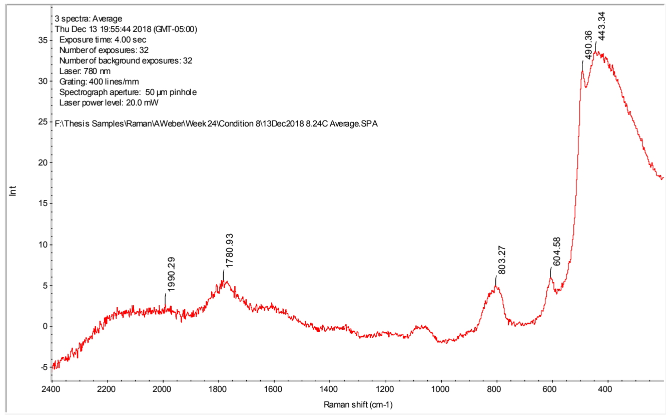

Figure 206: Raman Average Spectrum of Rayon - Week 24 in Oil

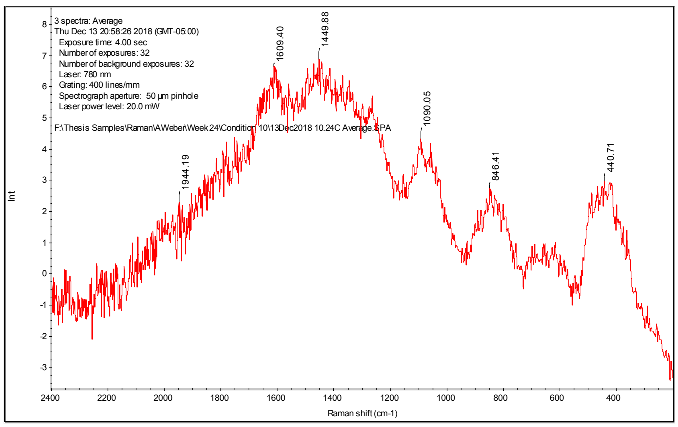

Figure 207: Raman Average Spectrum of Rayon - Week 24 in Salt Pretreatment and Water

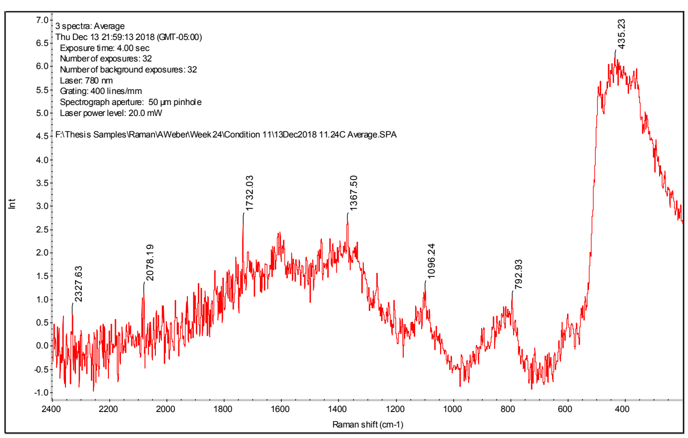

Figure 208: Raman Average Spectrum of Rayon - Week 24 in Calcium Chloride Pretreatment and Water

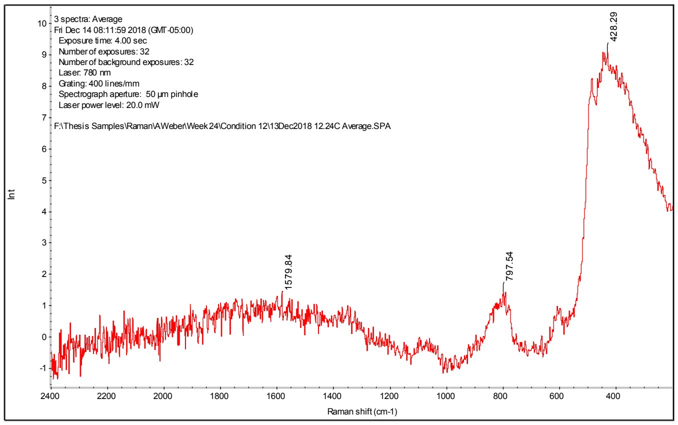

Figure 209: Raman Average Spectrum of Rayon - Week 24 in Calcium Chloride Pretreatment

APPENDIX O: TABLES OF RAMAN DATA OF RAYON

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1598.14	1601.81	1597.19		1602.92	**	**	**	**	**	1601.69		**
1374.33	1369.69			1375.99	**	**	**	**	**	**		
1093.15	1095.87	1096.53		1090.06	1090	1094.19	1092.3	1094.47	1098.56	1094.85		**
895.73	896.63	895.34		895.28	**	**	**	**	898.45	896.54	**	**

Table 63: Raman Data of Rayon in Sand

Control Wave Numbers	Week 2	Week 4
1598.14	**	**
1374.33	**	
1093.15	1098.93	
895.73	**	

Table 64: Raman Data of Rayon in Soil

Control Wave Numbers	Week 2	Week 4	Week 6
1598.14			
1374.33			
1093.15	**	**	
895.73	**	**	**

Table 65: Raman Data of Rayon in Soil and Chicken Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1598.14	**					**						
1374.33	**	**	**				**	**			**	
1093.15	1093.76	**	**	**				**				
895.73	**		**		**				**			

Table 66: Raman Data of Rayon in Chicken Manure

Control Wave Numbers	Week 2	Week 4
1598.14	**	**
1374.33	**	
1093.15	1098.47	**
895.73	897.99	

Table 67: Raman Data of Rayon in Soil and Cow Manure

Control Wave Numbers	Week 2	Week 4
1598.14		**
1374.33	**	**
1093.15	1093.1	1094.72
895.73	900.25	**

Table 68: Raman Data of Rayon in Cow Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1598.14		**	**		**	**		**	**	**	**	
1374.33		**	**		**	**	**	**	**	**	**	
1093.15	**	1092.72	1090.22		1098.82	**	1094.52	**	**	1093.4	1093.66	
895.73		898.73	**		897.43	**	**	**	**	**	**	**

Table 69: Raman Data of Rayon in Oil

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1598.14		**		**	**	**	**	**	**	**	**	**
1374.33	**	**		**	**		**	**	**	**	**	**
1093.15	1100.92	1096.53	**	1094.05	1095.2		1095.18	**	1096.11	1091.81	1096.03	**
895.73	898.38	898.11		895.4	**	**	**	**	**	894.27	896.35	**

Table 70: Raman Data of Rayon in Salt Pretreatment and Water

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1598.14	**	**	**	**	**	**	**	**	**	**		**
1374.33	**	**	**	**	**	**	**	**	**	**		**
1093.15	1096.67	1093.21	1096.05	**	1091.94	**	**	1092.81	**	1093.66	**	**
895.73	896.34	891.65	895.35	**	**	**	**	**	**			**

Table 71: Raman Data of Rayon in Calcium Chloride Pretreatment and Water

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1598.14	1607.91	**	**	1601.98		**	**	**	**	**		**
1374.33	**	**	**	**		**	**	**	**	**		
1093.15	1092.36	**	1096.49	1096.35		1097.06	**	**	1095.39	**	**	
895.73	898.37	**	**	**		**		**	**	**		

Table 72: Raman Data of Rayon in Calcium Chloride Pretreatment

APPENDIX P: RAMAN SPECTRA OF POLYESTER

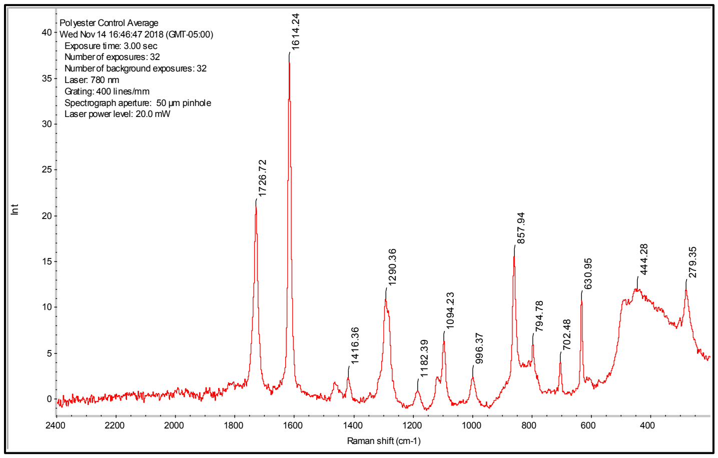

Figure 210: Raman Average Spectrum of Control Polyester

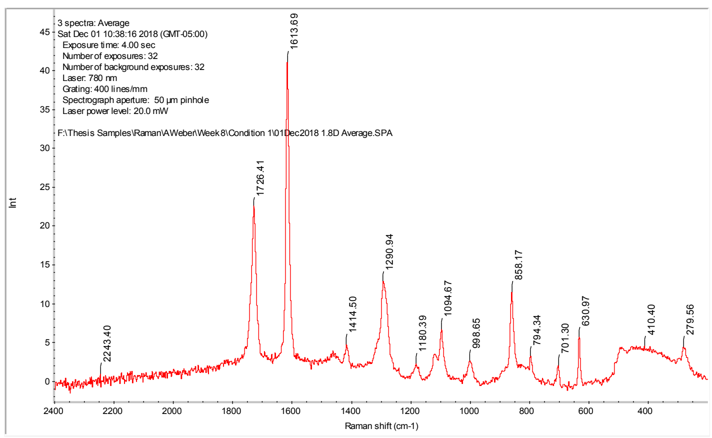

Figure 211: Raman Average Spectrum of Polyester - Week 8 in Sand

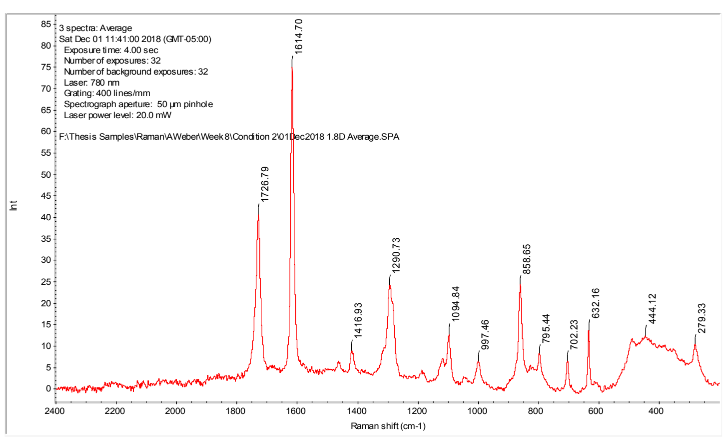

Figure 212: Raman Average Spectrum of Polyester - Week 8 in Soil

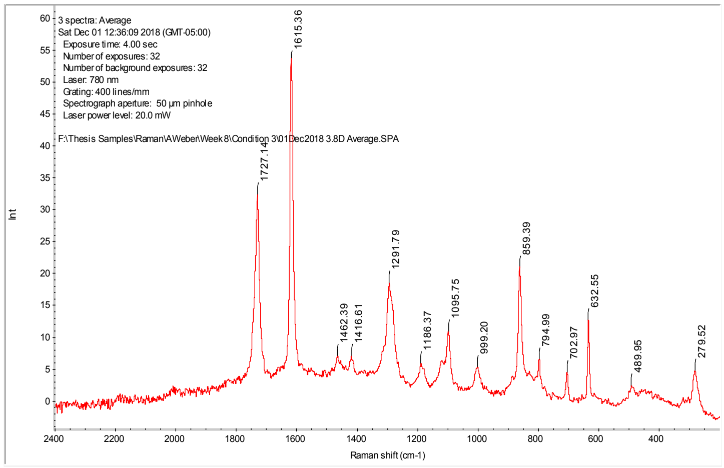

Figure 213: Raman Average Spectrum of Polyester - Week 8 in Soil and Chicken Manure

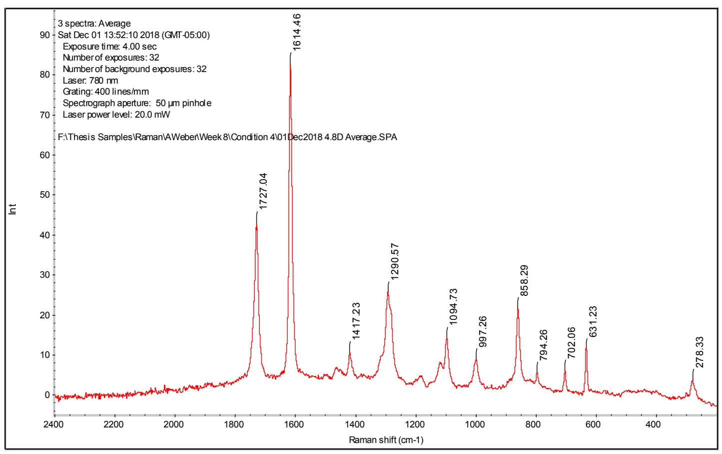

Figure 214: Raman Average Spectrum of Polyester - Week 8 in Chicken Manure

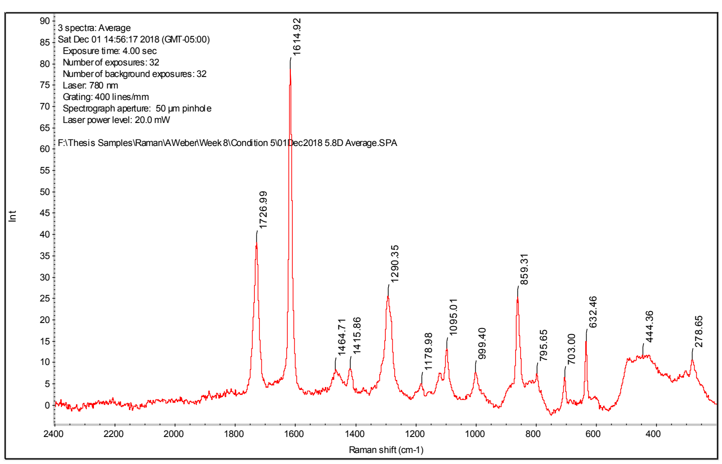

Figure 215: Raman Average Spectrum of Polyester - Week 8 in Soil and Cow Manure

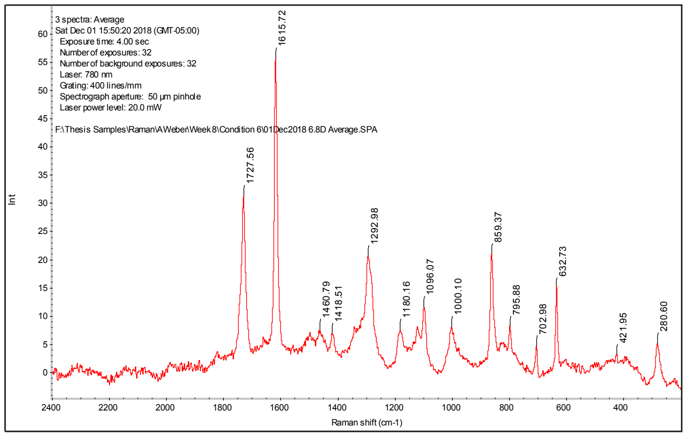

Figure 216: Raman Average Spectrum of Polyester - Week 8 in Cow Manure

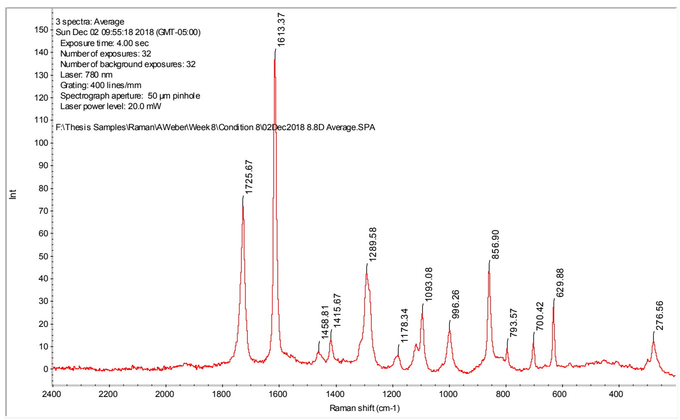

Figure 217: Raman Average Spectrum of Polyester - Week 8 in Oil

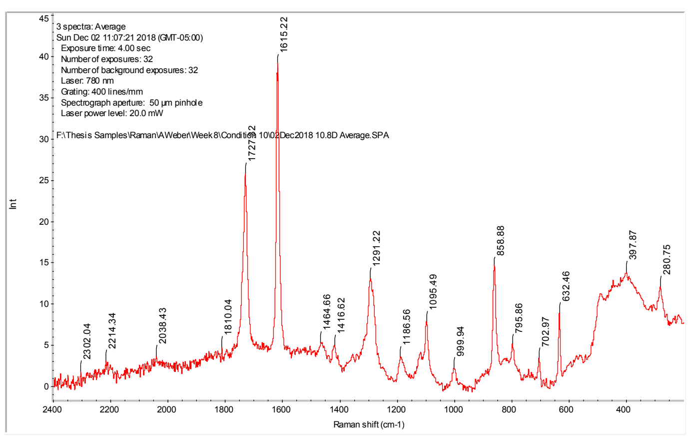

Figure 218: Raman Average Spectrum of Polyester - Week 8 in Salt Pretreatment and Water

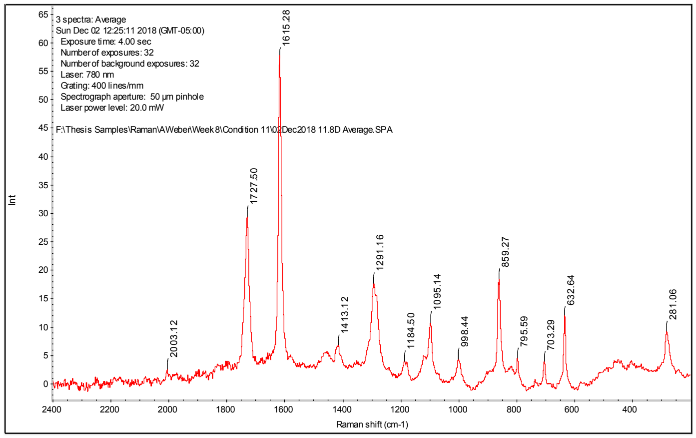

Figure 219: Raman Average Spectrum of Polyester - Week 8 in Calcium Chloride Pretreatment and Water

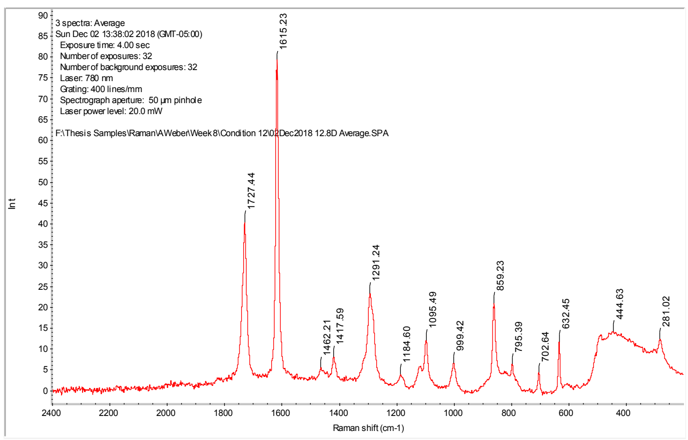

Figure 220: Raman Average Spectrum of Polyester - Week 8 in Calcium Chloride Pretreatment

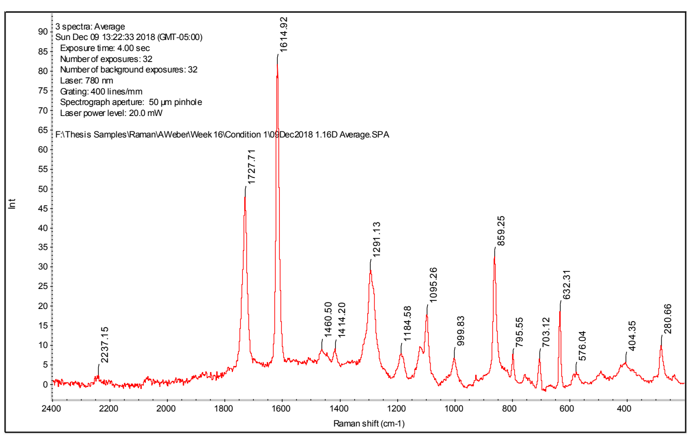

Figure 221: Raman Average Spectrum of Polyester - Week 16 in Sand

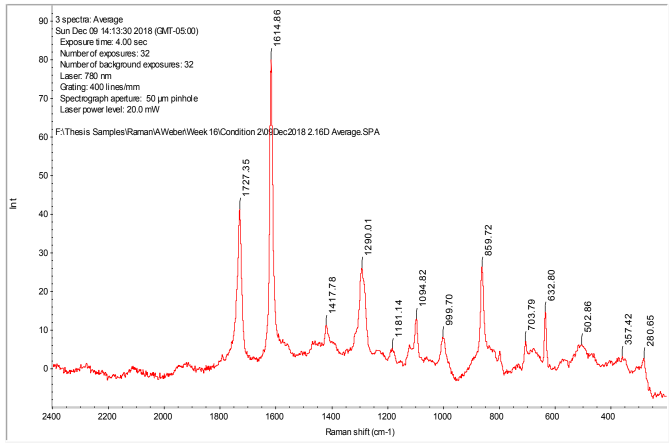

Figure 222: Raman Average Spectrum of Polyester - Week 16 in Soil

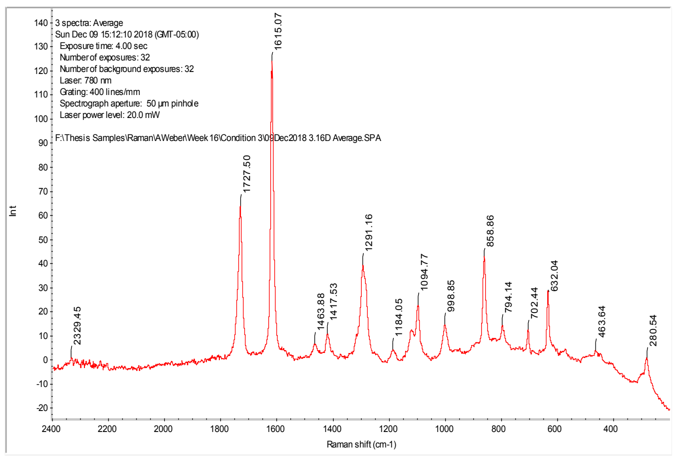

Figure 223: Raman Average Spectrum of Polyester - Week 16 in Soil and Chicken Manure

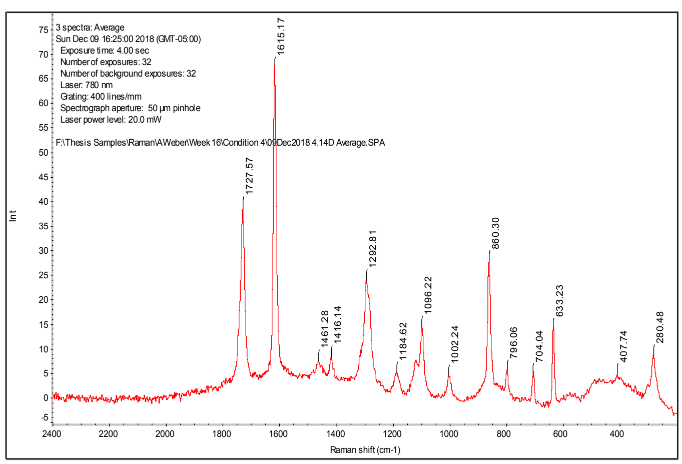

Figure 224: Raman Average Spectrum of Polyester - Week 16 in Chicken Manure

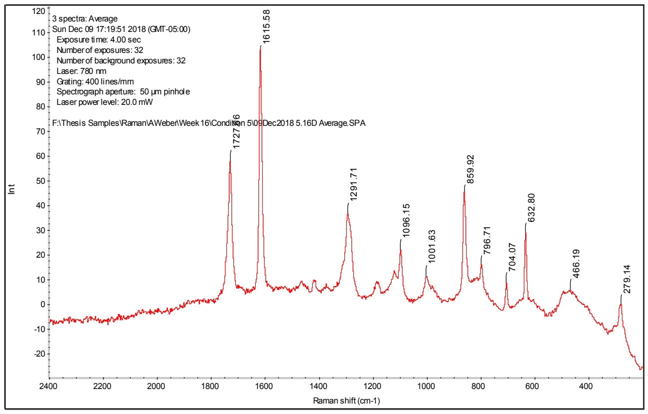

Figure 225: Raman Average Spectrum of Polyester - Week 16 in Soil and Cow Manure

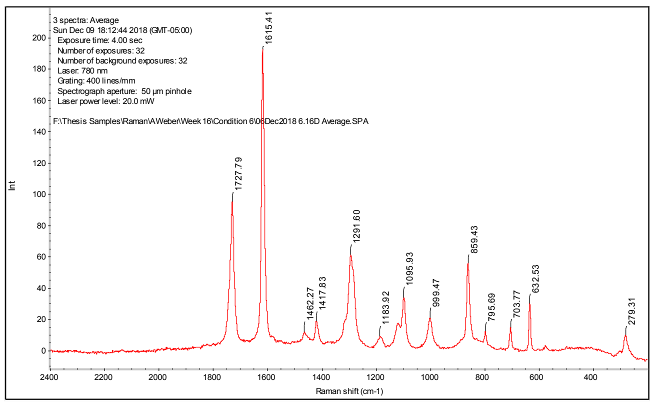

Figure 226: Raman Average Spectrum of Polyester - Week 16 in Cow Manure

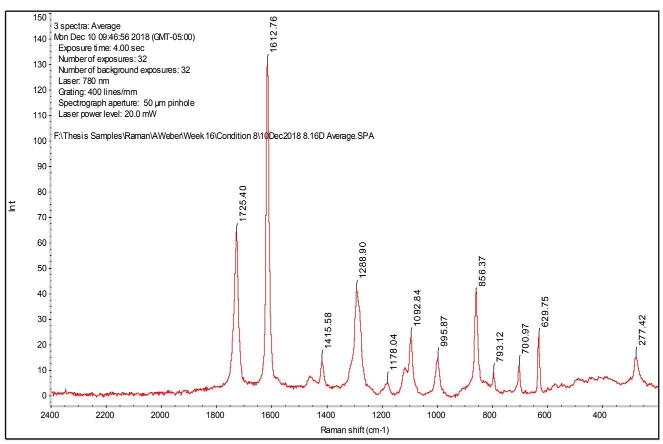

Figure 227: Raman Average Spectrum of Polyester - Week 16 in Oil

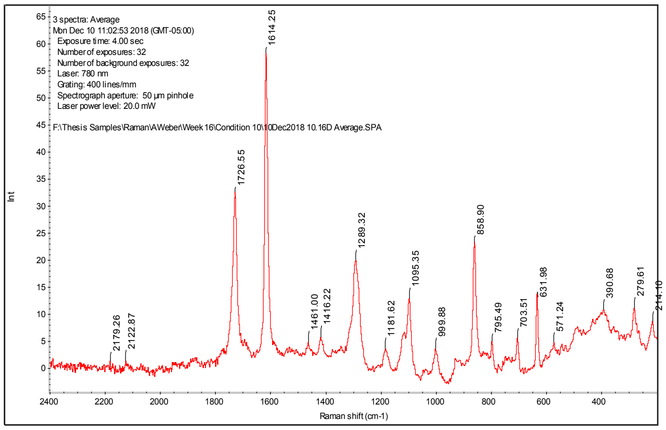

Figure 228: Raman Average Spectrum of Polyester - Week 16 in Salt Pretreatment and Water

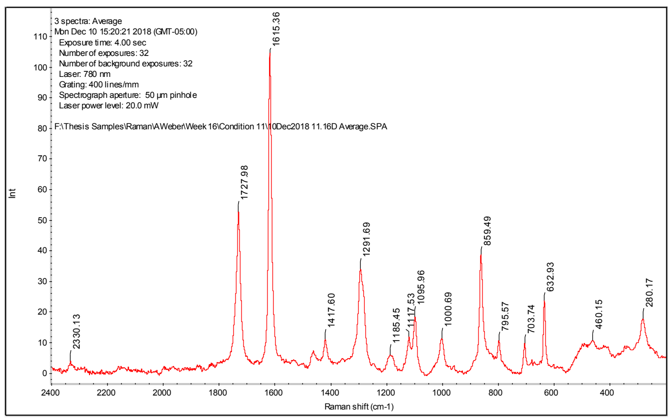

Figure 229: Raman Average Spectrum of Polyester - Week 16 in Calcium Chloride Treatment and Water

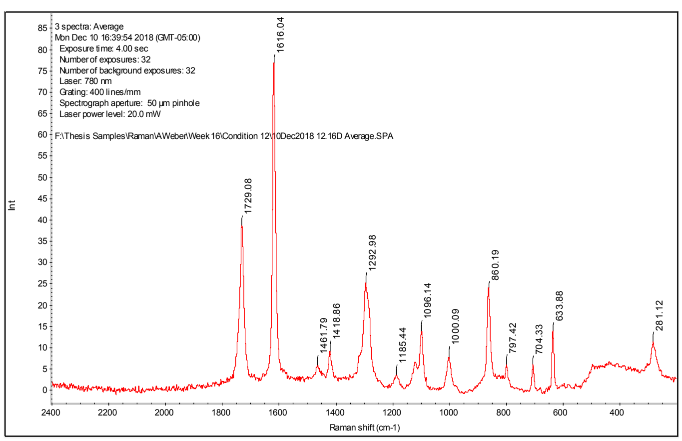

Figure 230: Raman Average Spectrum of Polyester - Week 16 in Calcium Chloride Pretreatment

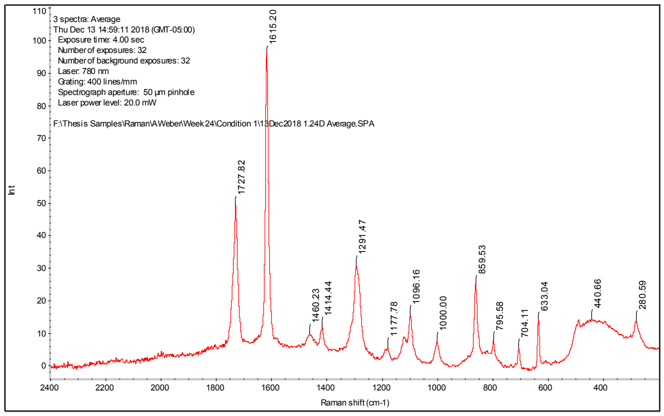

Figure 231: Raman Average Spectrum of Polyester - Week 24 in Sand

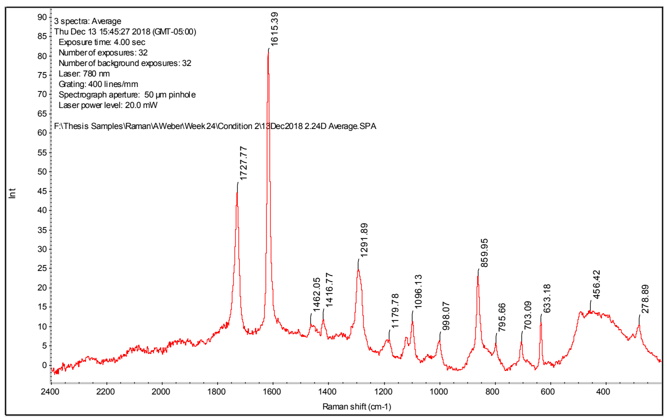

Figure 232: Raman Average Spectrum of Polyester - Week 24 in Soil

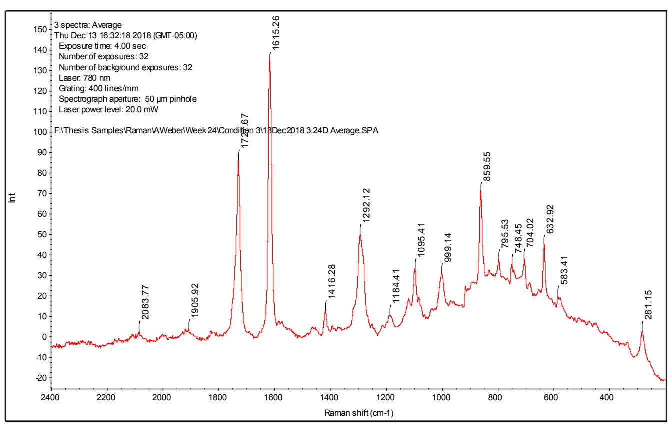

Figure 233: Raman Average Spectrum of Polyester - Week 24 in Soil and Chicken Manure

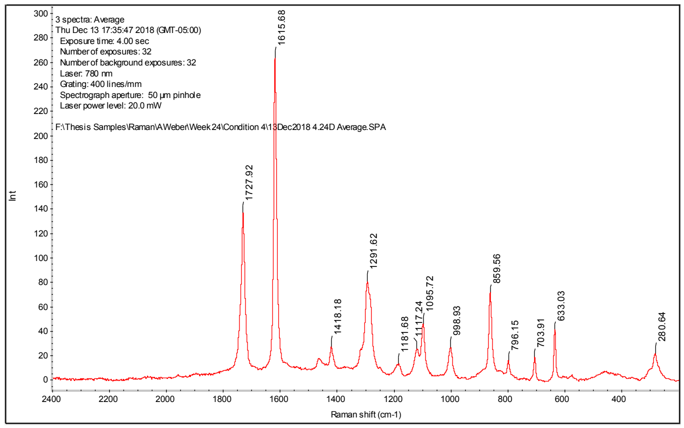

Figure 234: Raman Average Spectrum of Polyester - Week 24 in Chicken Manure

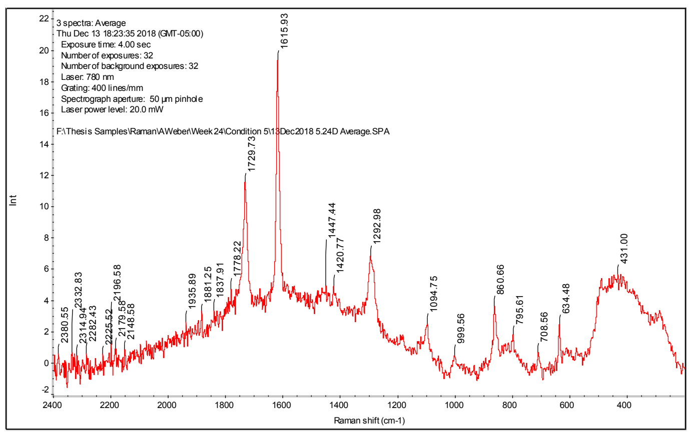

Figure 235: Raman Average Spectrum of Polyester - Week 24 in Soil and Cow Manure

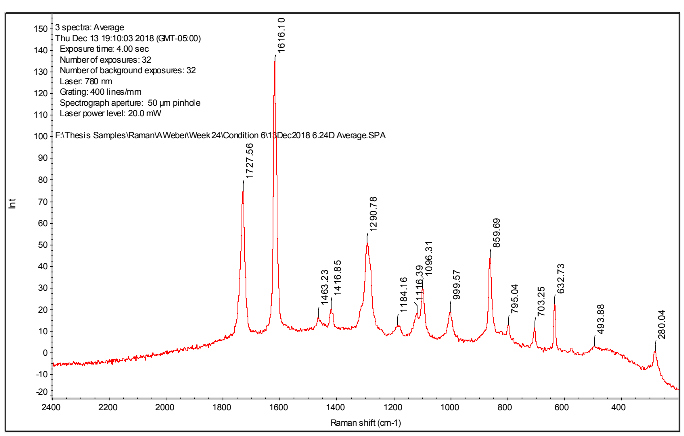

Figure 236: Raman Average Spectrum of Polyester - Week 24 in Cow Manure

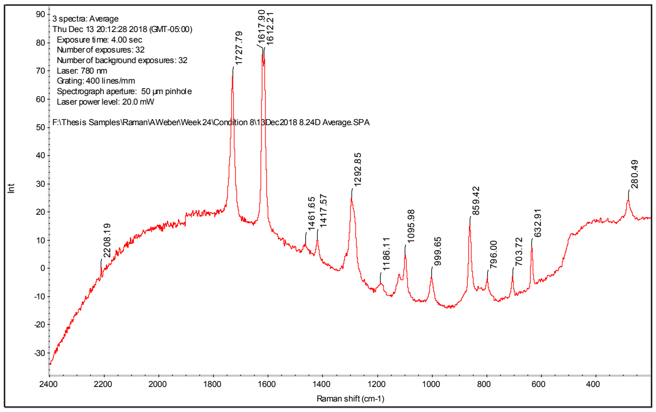

Figure 237: Raman Average Spectrum of Polyester - Week 24 in Oil

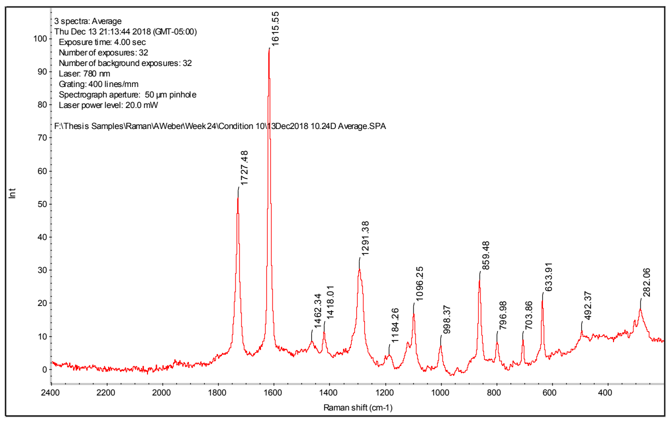

Figure 238: Raman Average Spectrum of Polyester - Week 24 in Salt Pretreatment and Water

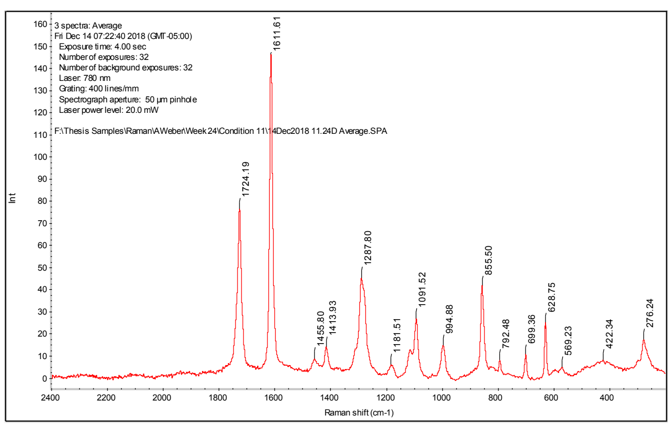

Figure 239: Raman Average Spectrum of Polyester - Week 24 in Calcium Chloride Pretreatment and Water

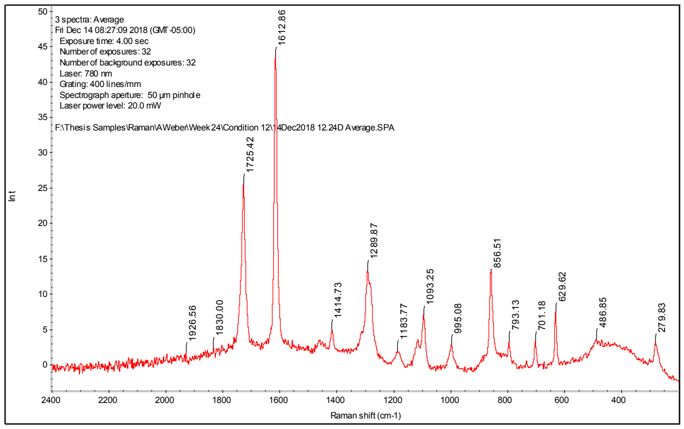

Figure 240: Raman Average Spectrum of Polyester - Week 24 in Calcium Chloride Pretreatment

APPENDIX Q: TABLES OF RAMAN DATA OF POLYESTER

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1726.72	1727.35	1726.59	1726.48	1726.41	1728.49	1727.3	1723.72	1727.71	1728.52	1728.27	1727.64	1727.82
1614.24	1614.86	1614.84	1614.31	1613.69	1615.93	1615.33	1610.79	1614.92	1616.31	1615.99	1615.37	1615.2
1290.36	1291.17	1293.21	1291.17	1290.94	1292.05	1291.81	1286.26	1291.13	1292.59	1291.77	1291	1291.47
1094.23	1094.79	1094.52	1094.67	1094.67	1096.77	1095.37	1091.26	1095.26	1096.52	1096.11	1095.59	1096.16
857.94	858.96	858.28	858.15	858.17	859.96	859.15	854.94	859.25	860.46	860.43	859.54	859.53
702.48	702.8	702.46	702.07	701.3		702.92	699.48	703.12	704.42	704.27	703.76	704.11
630.95	632.52	631.87	632.08	630.97	632.83	632.52	628.19	632.31	634.07	633.99	632.73	633.04

Table 73: Raman Data of Polyester in Sand

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1726.72	1728.67	1726.41	1724.27	1726.79	1727.67	1728.1	1725.38	1727.35	1728.63	1726.15	1728.1	1727.77
1614.24	1616.37	1614.1	1612.07	1614.7	1615.68	1615.69	1613.01	1614.86	1616.47	1615.88	1615.87	1615.39
1290.36	1292.35	1289.59	1288.64	1290.73	1291.45	1292.17	1288.51	1290.01	1291.88	1292.49	1288.12	1291.89
1094.23	1096.38	1094.5	1092.64	1094.84	1094.31	1096.39	1093.02	1094.82	1096.84	1096.2	1096.22	1096.13
857.94	859.92	857.61	855.83	858.65	859.61	859.82	856.79	859.72	860.64	860.24	859.88	859.95
702.48	704.07	701.59	700.03	702.23	703.78	704.6	701.94	703.79	704.72	704.11	**	703.09
630.95	633.79	630.68	629.24	632.16	632.88	633.19	630.23	632.8	634.4	633.63	632.37	633.18

Table 74: Raman Data of Polyester in Soil

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1726.72	1729.86	1727.26	1726.39	1727.14	1727.15	1728.2	1726.29	1727.5	1728.99	1728.17	1727.98	1727.67
1614.24	1617.24	1614.77	1613.97	1615.36	1615.29	1615.58	1614.09	1615.07	1616.78	1615.83	1615.47	1615.26
1290.36	1294.27	1291.35	1290.39	1291.79	1290.17	1293.17	1291.05	1291.16	1292.55	1292.22	1291.55	1292.12
1094.23	1096.27	1094.75	1094.08	1095.75	1096.17	1096.31	1094.19	1094.77	1096.93	1096.17	1095.08	1095.41
857.94	861.39	858.98	857.37	859.39	859.5	859.69	857.88	858.86	861.01	860.16	859.63	859.55
702.48	705.2	705.62	701.83	702.97	703.19	704.72	702.03	702.44	704.73	703.94	703.11	704.02
630.95	634.88	631.84	630.74	632.55	632.63	633.02	630.73	632.04	634.43	633.36	632.94	632.94

Table 75: Raman Data of Polyester in Soil and Chicken Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1726.72	1729.19	1725.36	1727.08	1727.04	1726.91	1724.3	1727.34	1727.57	1728.96	1728.33	1727.94	1727.92
1614.24	1615.89	1613.47	1614.39	1614.46	1614.6	1611.63	1615	1615.17	1616.91	1615.65	1615.64	1615.68
1290.36	1293.35	1289.9	1291.27	1290.57	1290.82	1288.58	1291.7	1292.81	1292.07	1291.8	1290.82	1291.61
1094.23	1096.68	1093.46	1093.85	1094.73	1094.85	1092.01	1096.72	1096.22	1097.92	1096.26	1096.12	1095.72
857.94	860.6	857.1	858.28	858.28	858.86	855.53	859.31	860.3	861.32	859.98	860.04	859.56
702.48	704.64	701.47	702.66	702.06	702.33	699.9	702.33	704.04	704.84	704.14	704.15	703.91
630.95	634.23	630.35	632.06	631.23	632.13	628.71	632.59	633.23	634.49	633.83	633.47	633.03

Table 76: Raman Data of Polyester in Chicken Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1726.72	1729.94	1727.14	1726.91	1726.99	1726.78	1725.12	1727.72	1727.56	1727.72	1728.03	1724.04	1729.73
1614.24	1617.23	1614.54	1614.57	1614.92	1614.74	1613.35	1615.66	1615.58	1616.81	1615.9	1611.57	1615.93
1290.36	1293.09	1289.76	1291.11	1290.35	1289.85	1289.06	1291.36	1291.71	1293.58	1292.61	1286.66	1292.98
1094.23	1099.04	1094.12	1095.11	1095.01	1095.45	1092.42	1096.4	1096.15	1097.56	1096.06	1092.34	1094.75
857.94	861.56	858.23	858.74	859.31	858.84	856.27	858.79	859.92	861.52	860.22	856.19	860.66
702.48	705.37	702.5	702.53	703	702.43		703.17	704.07	705.94	704.7	699.48	708.56
630.95	635.62	631.71	632.37	632.46	631.94	628.91	632.55	632.8	634.65	633.76	629.06	634.48

Table 77: Raman Data of Polyester in Soil and Cow Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1726.72	1730.09	1727.59	1726.87	1727.57	1725.95	1726.63	1728.27	1727.79	1725.75	1724.75	1726.05	1727.56
1614.24	1617.87	1616.9	1614.75	1615.72	1614.81	1614.38	1615.62	1615.41	1612.21	1611.76	1613.67	1616.1
1290.36	1294.47	1291.88	1291.44	1292.98	1291.26	1290.67	1292.45	1291.6	1287.62	1288.67	1289.45	1290.78
1094.23	1098.47	1095.68	1095.62	1096.07	1095.21	1094.67	1096.01	1095.93	1092.85	1092.03	1092.05	1096.31
857.94	862.83	858.63	859.08	859.37	858.76	858.38	859.7	859.43	856.31	855.55	857.18	859.69
702.48	706.69		702.68	702.98	702.9	702.33	704.4	703.77	700.77	699.49	701.71	703.25
630.95	635.93	632.23	632.42	632.73	632.09	631.94	632.94	632.53	629.57	629.05	630.93	632.73

Table 78: Raman Data of Polyester in Cow Manure

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1726.72	1730.25	1727.45	1727.07	1725.67	1727.45	1727.73	1728.06	1725.4	1726.35	1726.12	1727.49	1727.79
1614.24	1618.26	1614.99	1614.95	1613.37	1614.77	1615.91	1615.63	1612.72	1614.03	1613.98	1614.3	1612.21
1290.36	1294.41	1290.84	1289.19	1289.58	1291.07	1291.8	1291.41	1288.9	1290.14	1289.28	1289.18	1292.85
1094.23	1098.59	1094.87	1095.5	1093.08	1095	1095.77	1096.46	1092.84	1094.57	1094.01	1096.11	1095.98
857.94	862.74	858.99	858.97	856.9	858.54	859.71	860.42	856.37	858.46	858.28	858.98	859.42
702.48	706.54	703.11	702.65	700.42	702.78	704.18	703.85	700.97	702.11	702.21	702.04	703.72
630.95	636.24	632.54	632.17	629.88	632.3	632.85	633.52	629.75	631.71	631.31	631.9	632.91

Table 79: Raman Data of Polyester in Oil

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1726.72	1730.51	1722.97	1724.8	1727.92	1726.89	1727.58	1727.96	1726.55	1727.64	1727.02	1726.99	1727.48
1614.24	1618.4	1611.07	1612.62	1615.22	1614.61	1615.73	1615.56	1614.25	1614.89	1614.6	1614.9	1615.55
1290.36	1293.96	1286.38	1288.14	1291.22	1290.56	1291.86	1291.51	1289.32	1291.13	1290.51	1291.13	1291.38
1094.23	1099.2	1089.94	1092.43	1095.49	1094.45	1096.19	1096.25	1095.35	1095.11	1094.51	1094.98	1096.25
857.94	862.92	854.68	856.91	858.88	858.23	859.63	859.59	858.9	859.11	858.66	859.02	859.48
702.48	706.83	699.64	700.74	702.97	702.26	704.8	703.13	703.51	702.21	702.29	703.47	703.86
630.95	636.53	627.95	630.01	632.46	631.59	633.27	632.88	631.98	632	631.88	632.08	633.91

Table 80: Raman Data of Polyester in Salt Pretreatment and Water

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1726.72	1727.08	1726.23	1727.58	1727.5	1726.58	1728.31	1725.07	1727.98	1727.59	1727.11	1727.22	1724.19
1614.24	1614.41	1616.04	1614.43	1615.28	1614.12	1615.51	1612.51	1615.36	1615.13	1614.82	1615.04	1611.61
1290.36	1290.56	1288.24	1290.85	1291.16	1289.78	1292.52	1287.57	1291.69	1290.8	1290.5	1291.05	1287.8
1094.23	1094.6	1094.36	1094.68	1095.14	1094.66	1096.13	1092.34	1095.96	1096.01	1095.59	1095.77	1091.52
857.94	858.69	857.99	858.37	859.27	858.54	859.58	856.93	859.49	859.11	858.96	859.26	855.5
702.48	702.61	702.3	702.93	703.29	702.5	704.2	701.16	703.74	702.9	703.08	703.37	699.56
630.95	632.15	631.66	631.96	632.64	631.88	633.1	629.99	632.93	632.23	632	632.44	628.75

Table 81: Raman Data of Polyester in Calcium Chloride Pretreatment and Water

Control Wave Numbers	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week 18	Week 20	Week 22	Week 24
1726.72	1727.07	1726.38	1726.78	1727.44	1727.34	1727.97	1726.72	1729.08	1728.11	1728.01	1727.85	1725.42
1614.24	1614.64	1613.73	1614.64	1615.23	1614.88	1615.79	1614.1	1616.04	1615.69	1615.41	1615.13	1612.86
1290.36	1290.67	1288.93	1290.55	1291.24	1291.42	1293.28	1290.25	1292.98	1291.49	1289.75	1291.37	1289.87
1094.23	1094.51	1094.5	1094.47	1095.95	1095.99	1096.48	1094.29	1096.14	1095.39	1096.23	1096.3	1093.25
857.94	858.56	857.38	858.17	859.29	859.06	859.66	858.02	860.19	859.48	860.26	859.77	856.51
702.48	702.56	702.23	702.25	702.64	702.94	702.87	702.23	704.33	703.98	703.36	703.59	701.18
630.95	631.91	630.78	631.74	632.45	632.51	632.75	631.27	633.88	633.18	632.91	632.92	629.62

Table 82: Raman Data of Polyester in Calcium Chloride Pretreatment

APPENDIX R: UV-VIS FLUORESCENCE DATA OF RAYON

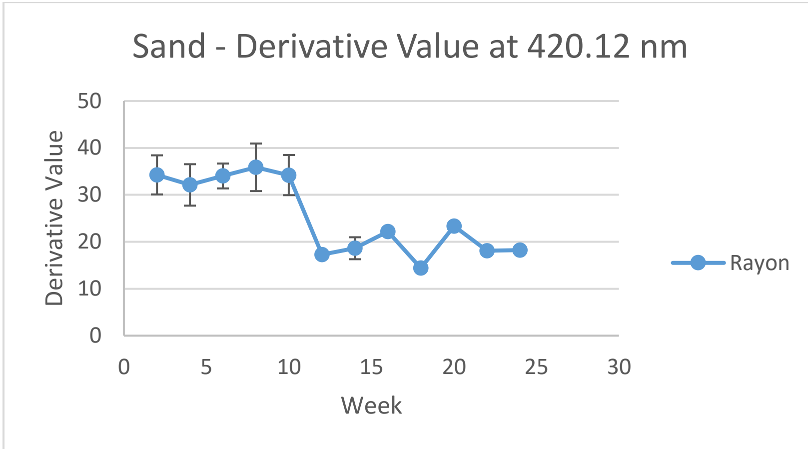

Figure 241: Changes to Fluorescence of Rayon in Sand

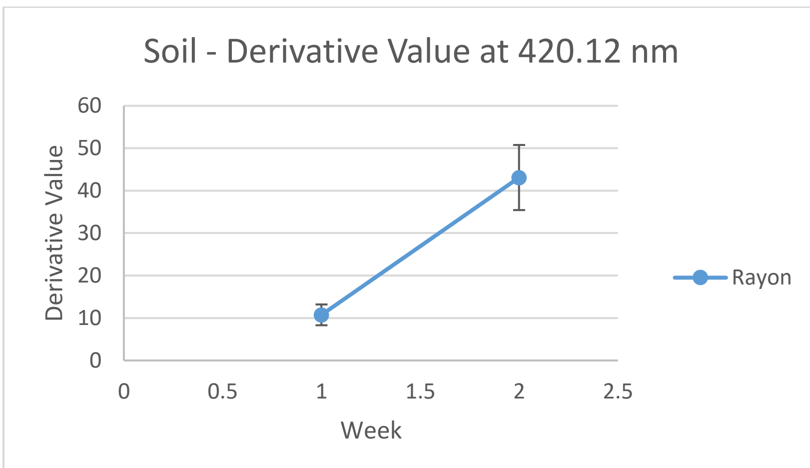

Figure 242: Changes to Fluorescence of Rayon in Soil

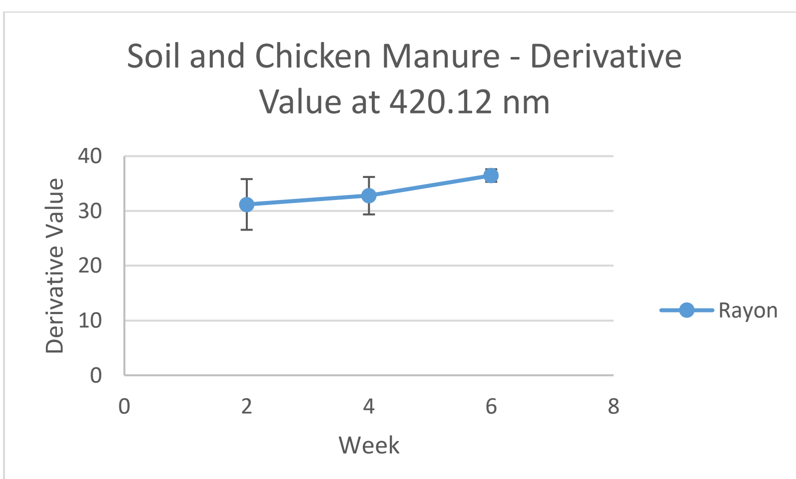

Figure 243: Changes to Fluorescence of Rayon in Soil and Chicken Manure

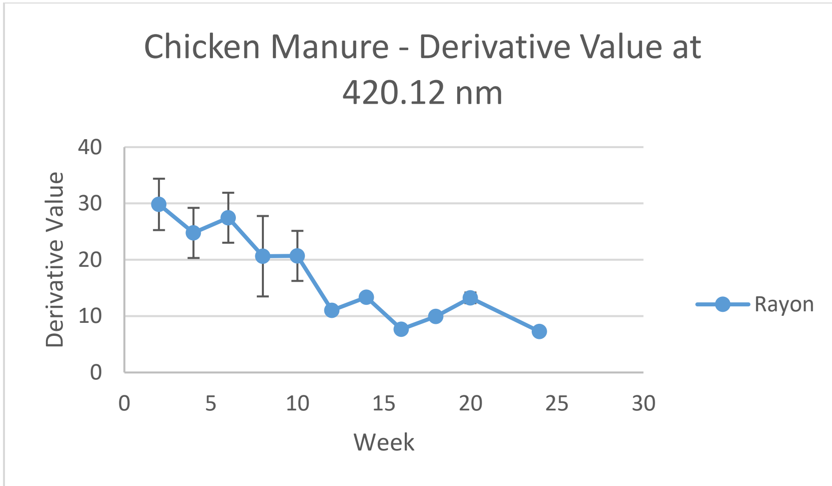

Figure 244: Changes to Fluorescence of Rayon in Chicken Manure

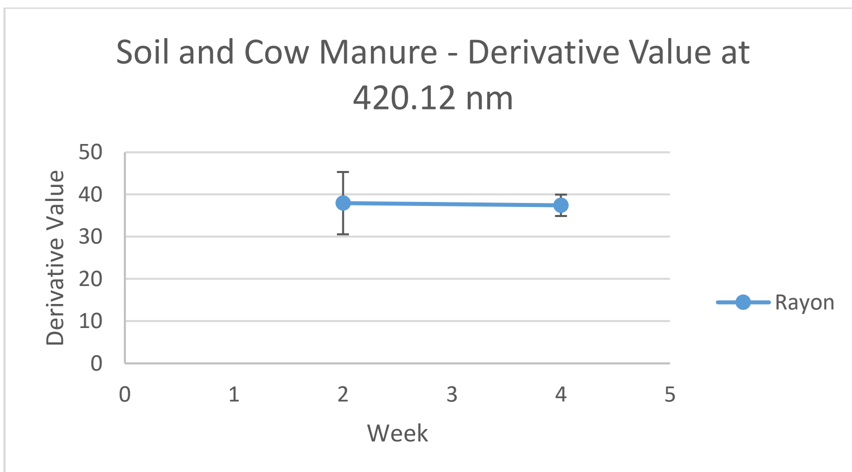

Figure 245: Changes to Fluorescence of Rayon in Soil and Cow Manure

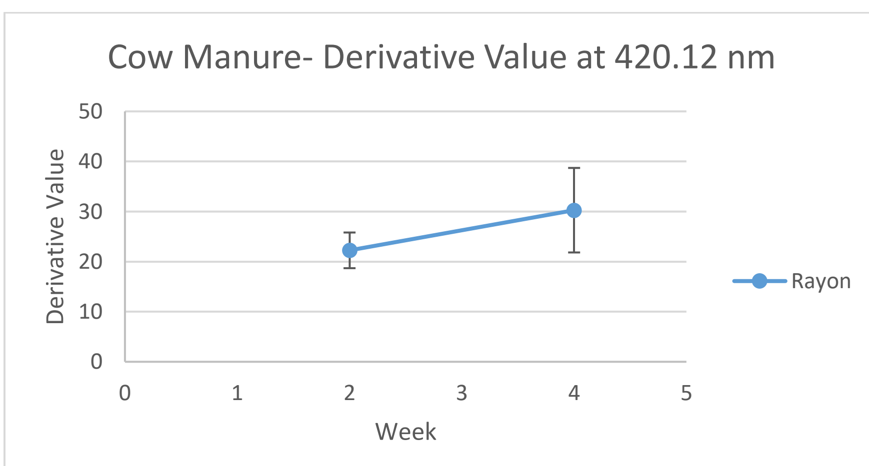

Figure 246: Changes to Fluorescence of Rayon in Cow Manure

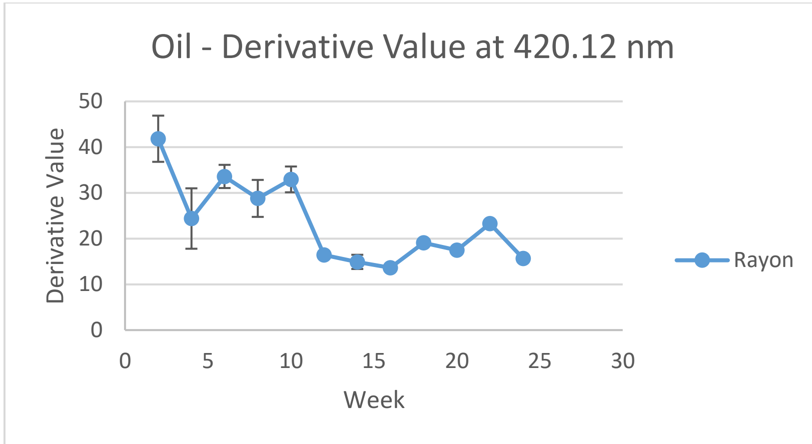

Figure 247: Changes to Fluorescence of Rayon in Oil

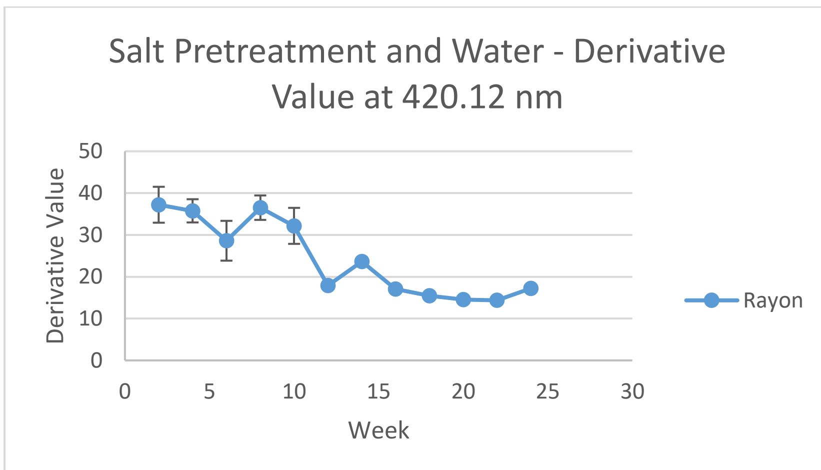

Figure 248: Changes to Fluorescence of Rayon in Salt Pretreatment and Water

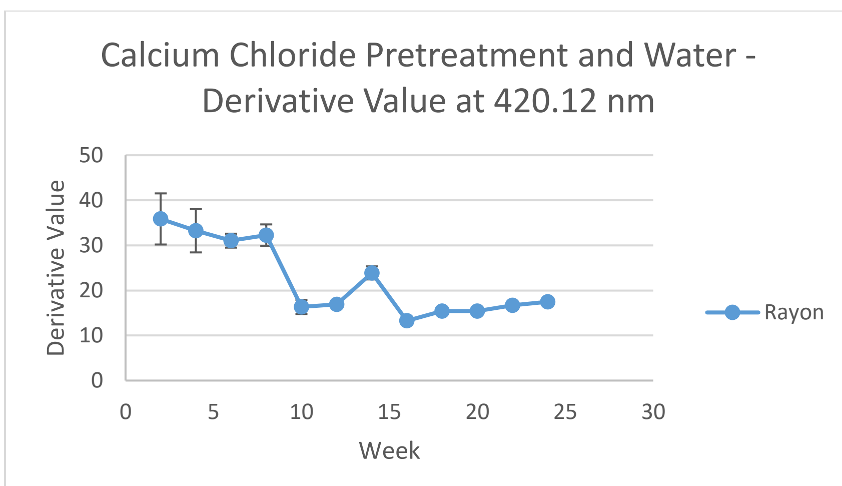

Figure 249: Changes to Fluorescence of Rayon in Calcium Chloride Pretreatment and Water

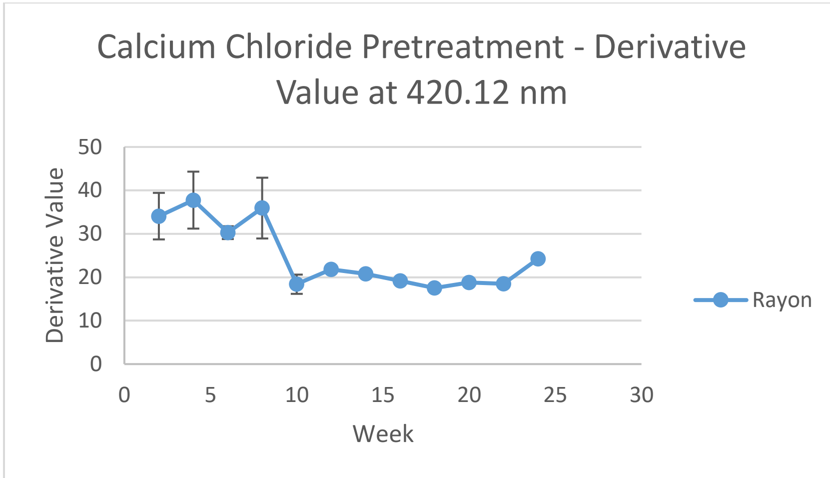

Figure 250: Changes to Fluorescence of Rayon in Calcium Chloride Pretreatment

APPENDIX S: UV-VIS FLUORESCENCE DATA OF POLYESTER

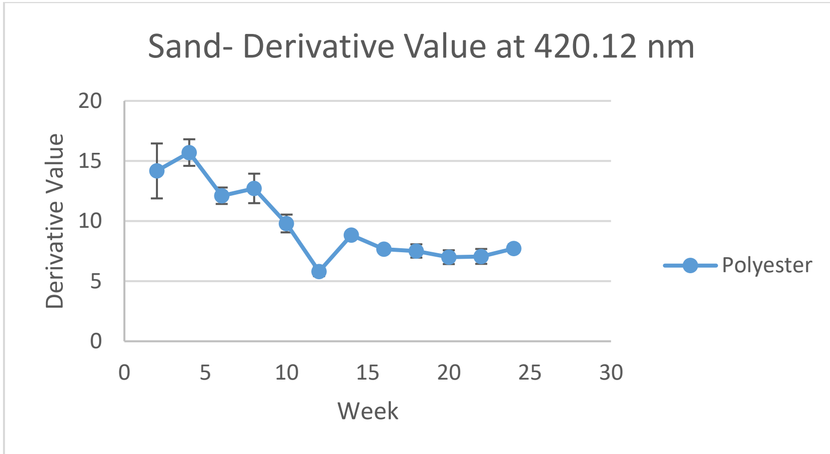

Figure 251: Changes to Fluorescence of Polyester in Sand

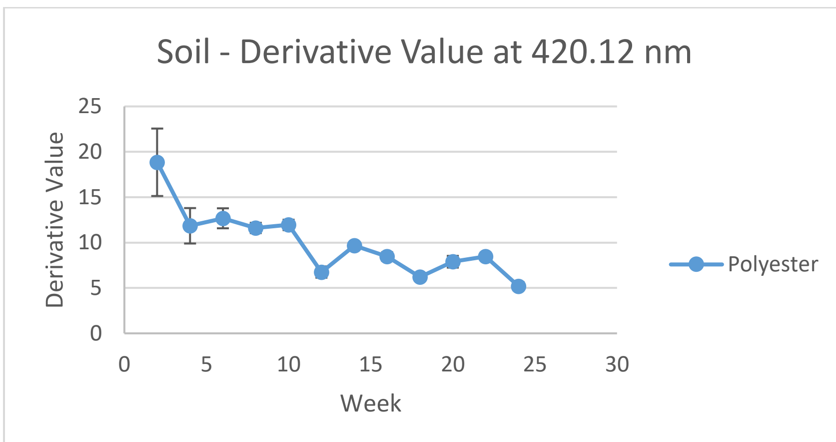

Figure 252: Changes to Fluorescence of Polyester in Soil

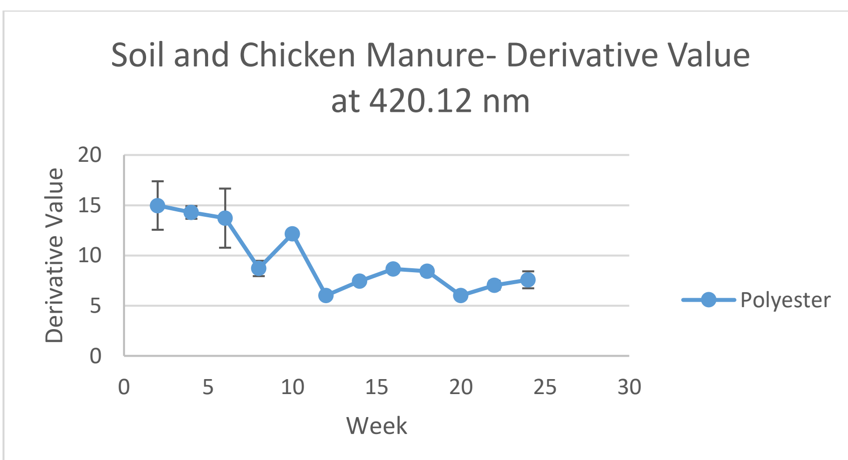

Figure 253: Changes to Fluorescence of Polyester in Soil and Chicken Manure

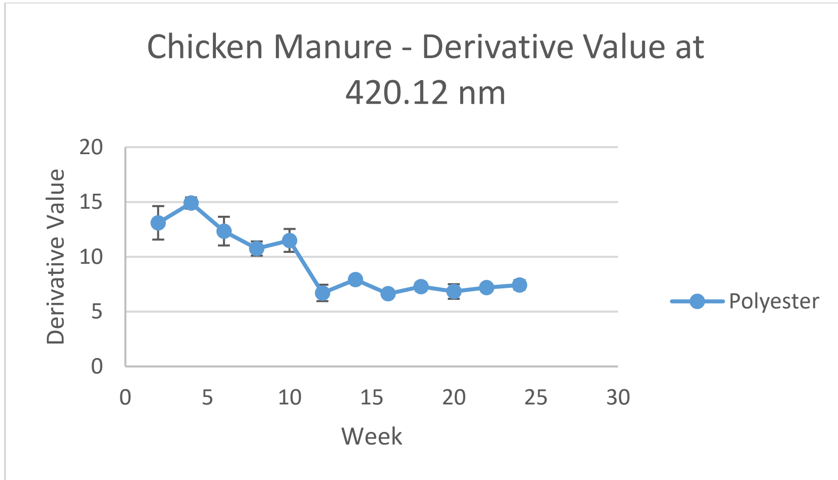

Figure 254: Changes to Fluorescence of Polyester in Chicken Manure

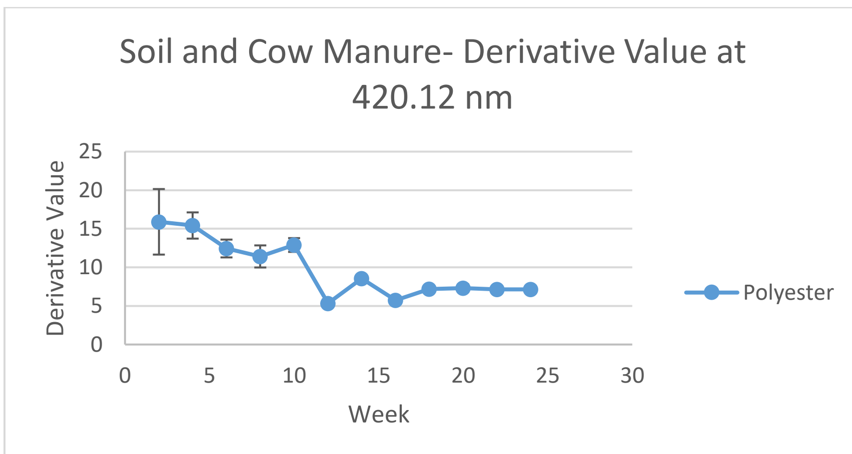

Figure 255: Changes to Fluorescence of Polyester in Soil and Cow Manure

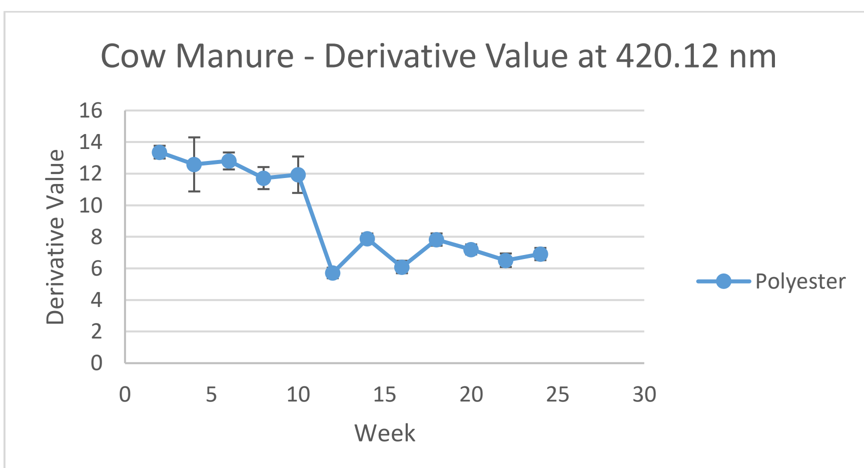

Figure 256: Changes to Fluorescence of Polyester in Cow Manure

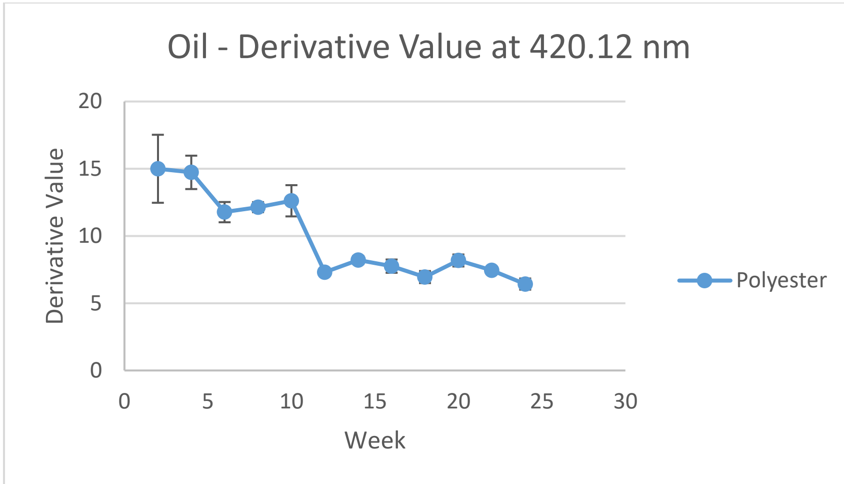

Figure 257: Changes to Fluorescence of Polyester in Oil

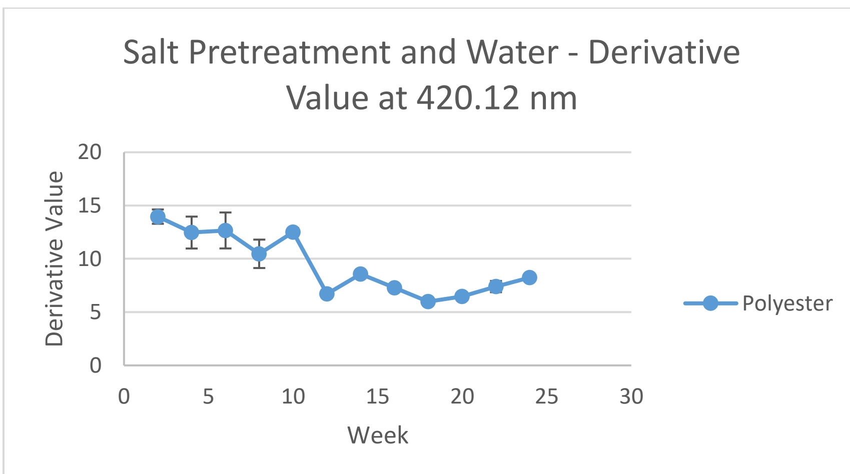

Figure 258: Changes to Fluorescence of Polyester in Salt Pretreatment and Water

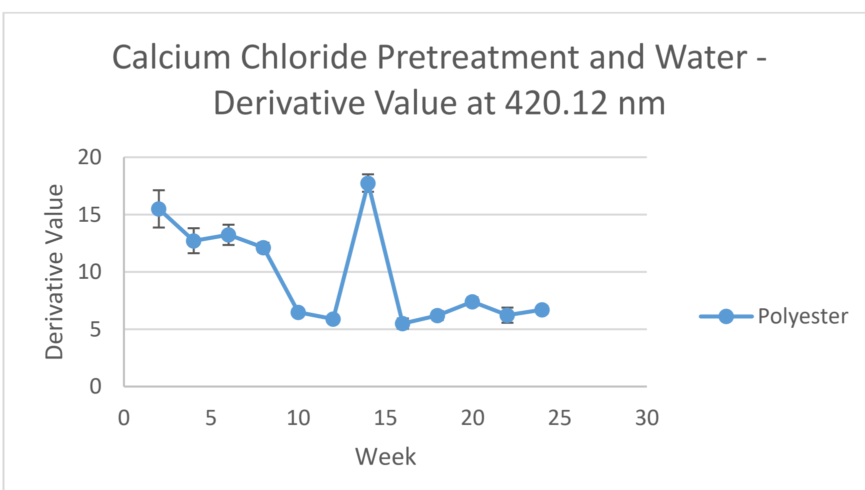

Figure 259: Changes to Fluorescence of Polyester in Calcium Chloride Pretreatment and Water

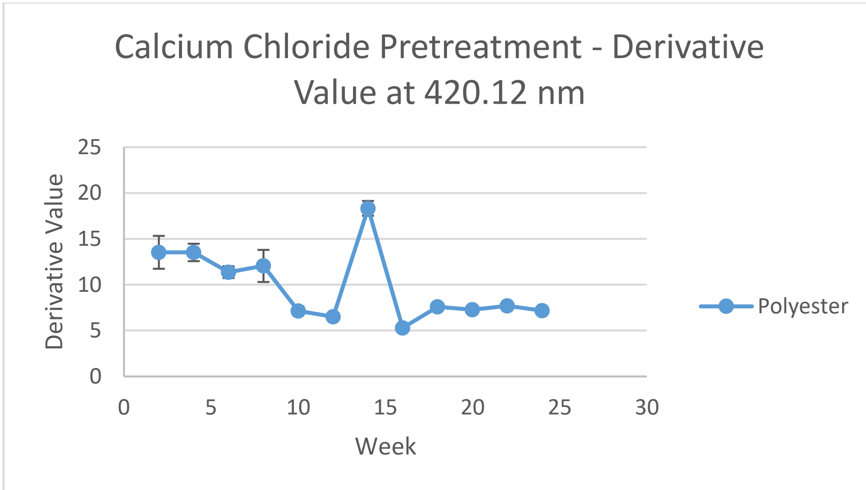

Figure 260: Changes to Fluorescence of Polyester in Calcium Chloride Pretreatment

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